DESIGN METHODOLOGY FOR SUSTAINABLE HIGH RISE BUILDINGS

A DISSERTATION

Submitted in partial fulfillment of the requirements for the award of the degree

of

MASTER OF ARCHITECTURE

By

DATTATREYA O.V.

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JUNE, 2011

CANDIDATE'S DECLARATION

I hereby declare that the work, which is being presented in the dissertation, entitled **'DESIGN METHODOLOGY FOR SUSTAINABLE HIGH RISE BUILDINGS'**, in partial fulfilment for the award of the **MASTER OF ARCHITECTURE** submitted in the Department of Architecture & Planning of the Indian Institute of Technology, Roorkee is an authentic record of my own work carried out during the period from August 2010 to June 2011 under the supervision of **Dr. Pushplata**.

The matter embodied in this dissertation has not been submitted by me for the award of any other degree.

Place: Roorkee
Dated: June 30th, 2011

(DATTATREYA.O.V)

CERTIFICATE

This is to certify that the above statement made by the candidate **DATTATREYA.O.V** is correct to the best of my knowledge.

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ACKNOWLEDGEMENT

I express my sincere thanks and gratitude to the Indian Institute of Technology, Roorkee for having given me an opportunity to pursue the Master Degree of Architecture.

I convey my sincere gratitude to my guide **Dr. Pushplata, Professor and Head, Department of Architecture**, for the valuable guidance and encouragement provided to me at every stage of the project.

I am grateful to **Prof.R.Shankar, Department of Architecture** for his personal interest and support.

My heartfelt thankfulness to **Gurneet Singh, Director, Environmental Design Solutions**, for his timely help and also to **Ar. Karan Grover** and **Ar. Vivek Rathore** for being a source of encouragement.

I also thank all my teachers and staff of our department for their support and for providing me with all the facilities without which this research would have been incomplete.

I thank my parents and family members for the strength and support they have provided throughout the completion of this research.

And last, but not the least, I thank God for his blessings.

Date: June 30th, 2011

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ABSTRACT

The process of architectural design is ever changing and has gone through a lot of changes since the time of architects like F.L.Wright and Le Courbusier. The considerations that one used to keep in mind for designing a high rise building i.e. structural, aesthetic and functionality are no longer enough to make a building that performs well.

High rise buildings are rising day by day and they are the only way to keep up with the ever expanding population. Sadly, these buildings are great energy guzzlers, produce a lot of wastes and use up a large quantity of resources which calls for the need for designing high rise buildings that are energy efficient and sustainable

The conventional method of designing high rise buildings majorly considers only the structural, aesthetic and functional requirements thus not completely tending to the needs of sustainability and efficiency. Many new software like Ecotect, Vasari, IES are being used in the developed countries to simulate the building designs and estimate the energy consumption. Many new methods of designing have come up such as parametricism and bioclimatic design which give a whole new direction to the process of designing. Thus there is a need to develop a design methodology for sustainable high rise buildings that incorporates the features of sustainability and building efficiency through he use of new design methods and software.

For this reason, a few eminent architects were chosen, who are working in the field of sustainability and their works and process of designing was thoroughly studied. In addition, sustainable design itself and high rise building design were studied too. These studies brought into the front the requirements of sustainable design and sustainable design methodology.

On basis of this a new design methodology was formulated which consists of four major phases, Vision, Conceptual design, Preliminary design and Detailed design followed by the construction. Research and analysis are included in every phase of design and phase 2, 3 and 4 feedbacks into the first phase. The research and analysis done at every phase ensure that the process is optimized till there is no more improvement possible with the current level of technology.

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CHAPTER 1: INTRODUCTION

1.1 OVERVIEW

The process of designing in architecture is very complex. Form ages the design process has undergone considerable changes, from the intuitive stage to the one where one simply satisfies the requirements of function and structure and aesthetics. Today the world is asking for more.

Over the past century, high rise buildings have successfully and increasingly responded to the need of the increasing population. But despite being in such a large number, most high rise buildings perform poorly in terms of environmental impact and social benefit. According to Ken Yeang a leading architect in the field of bio climatic architecture, in a 50 year lifecycle, energy costs contribute to 34% of the total cost. Successful high rise designs need to use a minimum of nonrenewable energy. At the same time pollution and minimizing their carbon footprint, without diminishing the comfort, health, functional needs and safety of the people who inhabit them are essential for reducing the impacts of high rise buildings on the environment.

To respond to these environmental, economic and social pressures, the profession of architecture needs to revise traditional high rise design and analysis methods. Recent advancements in computers promise a vastly improved design process, but most designers are ill equipped to take advantage of these new opportunities.

1.2 NEED OF THE STUDY

More and more high rise buildings are coming up each day on the planet. High rise buildings are more energy consuming, produce more wastes in terms of solid waste and water, utilize large quantities of resources and with the impending climate change and rising earth's temperatures, there is a need to design high rise buildings that are sustainable and efficient.

The prevalent practices of design of high rise buildings in the architectural offices of India generally consist of deriving the overall building form, height and dimensions from a collaborative effort between the architectural considerations like site, development controls, functional efficiency; economic considerations and structural considerations like the structural system and aspect ratio. Concepts such as sustainable design practices, eco skyscraper design and parametricism and the new digital tools developed for design analysis and simulation such as BIM, Vasari, Design Builder, Ecotect are not being taken into account thus limiting the benefits of incorporating these in the design process to a select few. Even offices that are into green/sustainable architecture use these tools only for simulation after the design phase is complete resulting in potentially high performance designs being left unconsidered.

Therefore there is a need to develop a new design methodology for high rise buildings incorporating the factors of sustainability and performance efficiency, making use of the new software and technology.

1.3 AIMS AND OBJECTIVES

1.3.1 AIMS

The aim of this dissertation is to study the existing design methodologies adopted for designing high rise buildings and develop a design methodology for the sustainable high rise buildings.

1.3.2 OBJECTIVES

a) To understand the requirements for a high rise building design
b) To identify the additional / special inputs required to design high rise buildings
c) To understand conventional design methodology
d) To study emerging design methodologies and buildings designed using these methodologies.
e) To identify the stages in the design process where the research inputs from sustainable design practice needs to be incorporated
f) To develop a design methodology for sustainable high rise buildings.

1.4 METHODOLOGY

The research methodology primary includes a literature study of the design of high rise buildings and the other inputs required for building design such as the study of building systems, the latest technological advancements in digital design such as BIM, energy simulating software such as Design Builder, IES, Ecotect etc.; a study of sustainability and how it is achieved in buildings and a study into the conventional design methodologies followed and the changing trends in design methodologies. A series of case studies and interviews were be conducted in order to get first-hand information from architects and designers about their approach and process of design and methodologies adopted by them in designing selected sustainable high rise buildings.

This was later compiled to help identify the various data about sustainable design, high rise buildings, contemporary design methods and design methodologies required for designing a sustainable high rise building. Later a scheme was worked out to determine the different stages of the design methodology where this information gathered through these studies is to be incorporated.

This helped in identifying the advantages and lacunas in the current design methodologies followed and formulating the design methodology for sustainable high rise buildings.

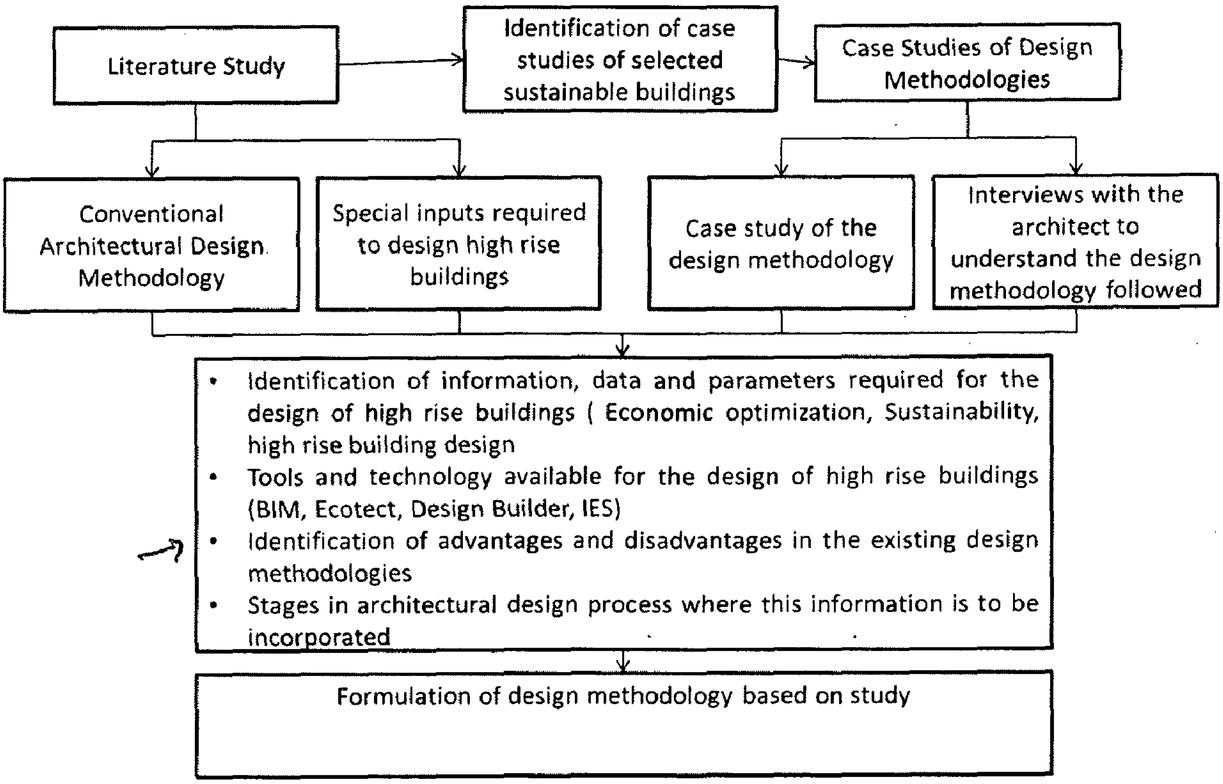

Figure 1.1 Methodology

1.5 SCOPE AND LIMITATIONS

For the purpose of this study, the international examples will be studied only through literature reviews and the Indian examples will be studied through both literature and interviews with the architects/designers, which can be conducted during the course of this study.

CHAPTER 2: LITERATURE STUDY

This chapter consists of the review of the current literature and research done in the fields of high rise buildings, sustainability and design methodologies. The study of high rise buildings gives us an idea about the various aspects that go into the process of design i.e. types of high rise buildings, the building services, various building systems used in the design of high rise buildings. A detailed study into the principles and practices of sustainable design is done to better understand the goals of sustainable design and the basic sustainable design process. Finally, a study into design methodologies in made that includes studying the conventional design methodology, parametric design methodology and the ecological design methodology to understand how the challenges of design have been taken up since the ages and how this process is changing over the years.

2.1 HIGH RISE BUILDINGS

'....two main reasons people go for skyscrapers are either sheer necessity or to depict power and glory, both are justifiable....' – Hafeez Contractor

2.1.1 OVERVIEW

The human desire to defy gravity has resulted in the quest for height in architecture through the ages. Thousands of workers toiled day and night on the Pyramids of Egypt, Cathedrals of Europe and the hundreds of other towers to build something awe inspiring. The Roman Empire had 23 meter towers constructed for human habitat in the 4th century where tenement housing was used.

The real era of high rise buildings/skyscrapers started in the latter half of the 19th century. The first high rise building of modern times was the 11 storied Home Life Insurance Building, Chicago, 1884 followed by many others such as the Empire State Building, World Trade Centre, Sears Tower etc. The latest being the Burj Khalifa which its massive height of 884m.

More and more high rise buildings are being constructed all over the world, not just limited to the metropolitan cities but even in the smaller cities. India too has its fair share of high rise buildings, the DDA building at Delhi, Ubi City Bangalore, Utility Building Bangalore, Royal Ensign Jaipur, The Bombay Stock Exchange etc. are just some of the examples. Many new high rise buildings such the Spire Edge at Manesar, India Tower at Mumbai, India Forum Tower at New Delhi are coming up and many more are likely to be built in the next couple of years. The trend of building high is picking up and is no longer limited to offices and residential spaces but has spread to other areas such as commercial, recreational, hospital buildings etc. The main reason for the construction of these buildings is due to the rapid increase of population and the pressure for development on limited land in cities. Building high on a small footprint has become more of an economic necessity.

2.1.2 DEFINITIONS OF HIGH RISE BUILDINGS

In everyday usage, the term high-rise commonly refers to any tall building. The height at which a building is considered tall is relative and has undergone many changes at different times and places throughout all eras of building history. A building is characterized as high rise when it is considerably higher than the surrounding structures. For example, if buildings in an urban setting have an average height of two or three stories, a five story building would be considered a high rise. However, matters become complicated if a building's neighbors are five to six storied; now a building exceeding their height even by two or three stories would become considerably taller. The town planners' definition of a high rise as a building that rises above the skyline offers a relative but not absolute measure.

Although there is no precise definition that is universally accepted, various bodies have tried to define what 'high-rise' means:

a) High-rise building is defined as a building 35 meters or greater in height, which is divided at regular intervals into occupiable levels.
b) Emporis Standards defines a high-rise as 'A multi-story structure between 35-100 meters tall, or a building of unknown height from 12-39 floors.'
c) According to the National Building Code of India, a high-rise building is one with four floors or more, or one 15 meters or more in height
d) The *New Shorter Oxford English Dictionary* defines a high-rise as "a building having many stories".
e) The *International Conference on Fire Safety in High-Rise Buildings* defined a high-rise as "any structure where the height can have a serious impact on

evacuation Massachusetts, United States General Laws define a high-rise as being higher than 70 feet (21 m).

f) Most building engineers, inspectors, architects and similar professions define a high-rise as a building that is at least 75 feet (23 m) tall.

2.1.3 THE EVOLUTION OF HIGH RISE BUILDINGS

The high-rise as a specific type of structure originated in the thriving city of Chicago, towards the end of the 19th century. Its development was gravely influenced by the inventions of this time. Technology made possible the elevators and the structural steel skeleton – two most important parameters – along with these service systems for high rise buildings were also developed. Their combined effort led to the development of larger and taller buildings.

The first high rise structure was the Home Insurance Building, Chicago, by William Lebaron Jenney in 1884. This building was one with a load bearing structural system and rose to height of 11 stories and had certain heaviness reminiscent of the Italian Renaissance period. This was followed by two most famous sky scrapers in the 1930's, the Art Deco style Chrysler Building and the Empire State Building which was the beginning of the American skyscraper. This building remained the world's tallest building for over 40 years.

Advancements in technology led to much taller buildings such as the fateful World trade Centre of New York and of course todays tallest building, the Burj Khalifa of Dubai soaring to a massive height of 884 m.

2.1.4 BUILDING SYSTEMS

A building design is never considered complete without the building services and systems. It is these that help run the building and make it comfortable for inhabitation. Various building systems that affect building design are:

a) Structural systems
b) Mechanical systems
c) Cladding systems
d) Building services (electrical, plumbing, fire safety, garbage disposal etc.)

CLEANING OUTSIDE

Factors affecting comfort in buildings and building systems play a critical role in efficient design of high rise buildings. Accordingly, structural systems and mechanical systems have been discussed in detail.

2.1.4.1 STRUCTURAL SYSTEMS

Building design is never complete with the aesthetics alone; it is structural integrity that becomes an important aspect in the design of high rise buildings. The interpretation of design and structure played a huge role in the evolution of high-rise construction.

The first structural design in Chicago was done by using timber battens which were easily fabricated and nailed together. Gradually timber structures were replaced with iron structures. Economic pressures increased and cities all over the world expanded rapidly and soon land was in short supply and thus expensive, and this led to increasing the building heights and dense development.

The first architect to master new technology was William le Baron Jenny. He use steel structures instead of cast iron for his structures, thus achieving a rigid tensic and pressure proof total structure.

The structural system of a building must be stable when subjected to external loads. Due to their sizes, high rises are usually characterised by dead loads and net loads. The greater number of floors the greater the influence on the horizontal loads on the structural system: High-rises perform like cantilevered beams fixed into the subsoil. Corner bracing is needed to prevent torsion. At least three plates are required across the entire height of the building for bracing, to direct the wind loads and transfer them to the ground. Their longitudinal axes must not intersect or the building would be able to rotate around this point.

Load transfer systems are classified as direct and indirect systems. Direct load transfer systems gather the various loads from top to bottom and transfer them directly into the subsoil without diversion. This includes the skeleton systems, frameless systems, tubular systems and megastructure systems. Combinations of these systems may also be possible. Indirect load transfer systems are divided into three sub groups: support systems, suspended systems and cantilever systems. The loads are transferred to the subsoil from various floors in different ways, usually not along the direct or shortest path. For example, the façade could be used to transfer the load down to the ground, thus making the structure dependent on the design of the whole building.

Direct load transfer systems

Skeleton systems

Skeletons are load bearing systems composed of hinged columns and cross members, which are only capable of transferring vertical loads. The horizontal loads are transferred through panels. The cores are often utilized for bracing, because they are needed for vertical access and for the supply and disposal shafts. Panels can be installed on the exterior or interior walls and thus influence the ground plan or the facade.

Some buildings using this system are the Seagram Building designed by Ar. Philip Johnson, reaching a height of 157 meters with 39 stories; the Chase Manhattan Bank by SOM soaring to an impressive 250 m with 60 stories.

The only spatial constraints are imposed on the ground floor as a result of the columns and panels. Large spaces requiring column free spaces cannot be achieved with this method, but they sure did bring in some interesting concepts like the famous curtain wall.

Panel and shear wall systems

Panels are massive load bearing systems that absorb the external loads parallel to their plane. They differ from the bracing panels as they transfer not only the horizontal loads but all the loads. Panel systems are made usually with concrete, thus they can be coupled with the floors to achieve greater rigidity. Transverse panels are inflexible and are therefore used in the construction of residential towers, hostels, and hotels where the panels double as sound insulators. Spatiality is limited when panels are used, for this reason, combinations of transverse panels and load bearing core are employed for office buildings.

Longitudinal panels allow tremendous flexibility on the ground floor but restrict the number of openings and façade design as they can only permit small openings or a perforated façade. For example, the Metropolitan Convention Center and the city jail of Chicago use this to their advantage.

Tube systems

This high performing system is based on a box girder principle. The facades are constructed as detached panels coupled at the corners. The tube thus created is additionally braced through floor panels. A circular plan is ideal for this type of construction. In tube systems, all horizontal loads are transferred to the façade and then to the ground, this reduces the use of steel and thus reduces the building weight relatively low permitting enormous building heights.to maintain flexibility between the façade and core, large span widths are tolerated – World Trade Center: approx. 18m. Theoretically this allows complete freedom for ground floor plan layout. However the façade is strongly determined by the structural dynamics because of the shear element of force. The options here are:

a) Truss grids
b) Frames
c) Column-Diagonal frames

2.1.4.2 MECHANICAL SYSTEMS

It was the invention of the rope and pulley thousands of years ago that gave birth to the elevator. In 1854, in Crystal Palace, New York Elisha Graves Otis presented his elevator safety device in a free fall experiment. This made the use of elevator cars safer and opened up new possibilities in architecture for high rise buildings.

One must differentiate between elevators in residential high-rises, offices, small office buildings and tall office buildings. Elevators in high-rises must ensure a building specific handling capacity. The elevator planner's job is to determine the required capacity and calculate the number of elevators necessary. Certain building parameters are often taken into consideration while designing elevators

a) Usable floor space

   The basic parameters for elevator traffic calculation are as follows: for office buildings the office space, for hotels the number of hotel rooms, residential buildings the number and size of the apartments. These spa must be determined for each floor and the number and height of each ' must also be determined.

b) Number of passengers

The population of each storey is determined by the usable floor space. This varies from one building type to another

i. Office building with one user: 8-10 m^2 net area/person
ii. Office building with multiple users: 10-12 m^2 net area/person
iii. Residential building and hotels: 1.5-1-9 m^2 net area/person

c) The recommended values are

i. Residential : 13 m2 / person
ii. Hotel: 1.5-1.7 m2 / person, I person per single room
iii. Residential building depending on apartment size 1,2 or 3 people per apartment

d) Required handling capacity

The total mean occupancy of each floor is used to determine the necessary carrying capacity of each elevator group in rush periods. An elevator installation is regarded as sufficient for all normal types if the five minute handling capacity during the building filling corresponds at a minimum to 11-25% depending on the building use. Co

e) Average waiting time

The average waiting time is used to determine elevator efficiency. This is half of the average interval time i.e. the average time period between two elevator runs in the peak time.

i.	Office building	20 - 25 s
ii.	Other buildings	25 – 39 s
iii.	Residential buildings	40 – 100 s

f) Cab capacity

The necessary floor area of cabs is calculated using the number of passengers to be transported each run to achieve the handling capacity with good average waiting times. A net floor space of at least 0.22 m2 per person is desirable. Cabs with greater height are a positive contributory factor as more passengers can squeeze together.

g) Speed

Elevator speed in high rises is dependent on hoisting weight and on the basis of traffic calculations. The following table shows the effect of speed on travel times for an average acceleration of 1 m/s^2

Table 2.1 Effect of speed on travel times (Source: Eisele,J, 1999, High Rise Manual)

Speed m/s	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
Shortest distance m	4	9	16	25	36	49	64	91	100
Travel time for 100 m	52.0	36.3	29.0	25	22.7	21.3	20.5	20.1	20
Time saving against 4 m/s			0	4	6.3	7.7	8.5	8.9	9
Time saving against 7 m/s						0	0.8	1.2	1.3

The fastest elevators are used in the Burj Khalifa, moving at a speed of 18 m/s. the limits for the speed are not set by technology but by the passengers. High accelerations and decelerations are disagreeable by many people. Speeds above 7 m/s, particularly while travelling down lead to some unpleasant pressure in the ears caused due to change in air pressure. Fast elevators require complex equipment for the drive mechanism, cares and counterweight design; they need costly measures to ensure structural and airborne noise insulation.

h) Elevator configurations

Buildings up to 25 m high are usually served on all floors by just one elevator group. All floors can be reached with a single trip with no necessity to change elevators. This is difficult if there are more than 6 elevators. Then they are divided into groups.

i. Elevator groups from main lobby

Division into long and short distance groups reduces number of stops for each elevator, increasing handling capacity and shortens waiting times. Short and long distance groups are for buildings of between 20-35 stories. For taller buildings three groups are preferred. One drawback of this is the large elevator shaft volume required and the high floor space necessary in the entry level. With increasing building height these requirements

ii. Stacked elevator groups and sky lobby

For heights above 200m it is possible reduce total shaft volume and required floor space In the main lobby by stacking elevators on top of each other. Express groups are the only economically viable and structurally acceptable solutions for buildings of this height. The skylobbies divide the building into three or four equal zones, each zone being served by a short and long distance group. The shafts housing the stacked elevators run the entire length of the building and help provide reinforcement.

iii. Double deck elevator groups

Double deck elevators have one car frame containing two vertically stacked decks. These elevators require a two story main lobby. One deck stops only at the odd floors and the other at all the even. These are usually express elevators.

2.1.5 FACTORS AFFECTING THE DESIGN OF HIGH RISE BUILDINGS

The design of buildings is influenced by a wide variety of factors. Laws, standards and regulations have significant influence on the design on high rise buildings. The demands of the client also play an important role, as can function, the envelope, energy and material concerns, building services, structure, and the finishing details.

Certain factors see to it that the rooms are comfortable for human usage i.e. suitable for high levels of intellectual productivity and performance. The principle factors to be taken care of are.

a) Temperature
b) Humidity
c) Noise
d) Light
e) Smell

TEMPERATURE AND HUMIDITY

Optimum conditions for performance are illustrated in the following figure. The image clearly shows that performance levels for demanding intellectual tasks are linked to a narrow temperature range. In addition to temperature, relative humidity plays an important role. Occupants need to cool down. Performance is hindered when relative humidity levels rise above the prescribed level. (Figure 2.1)

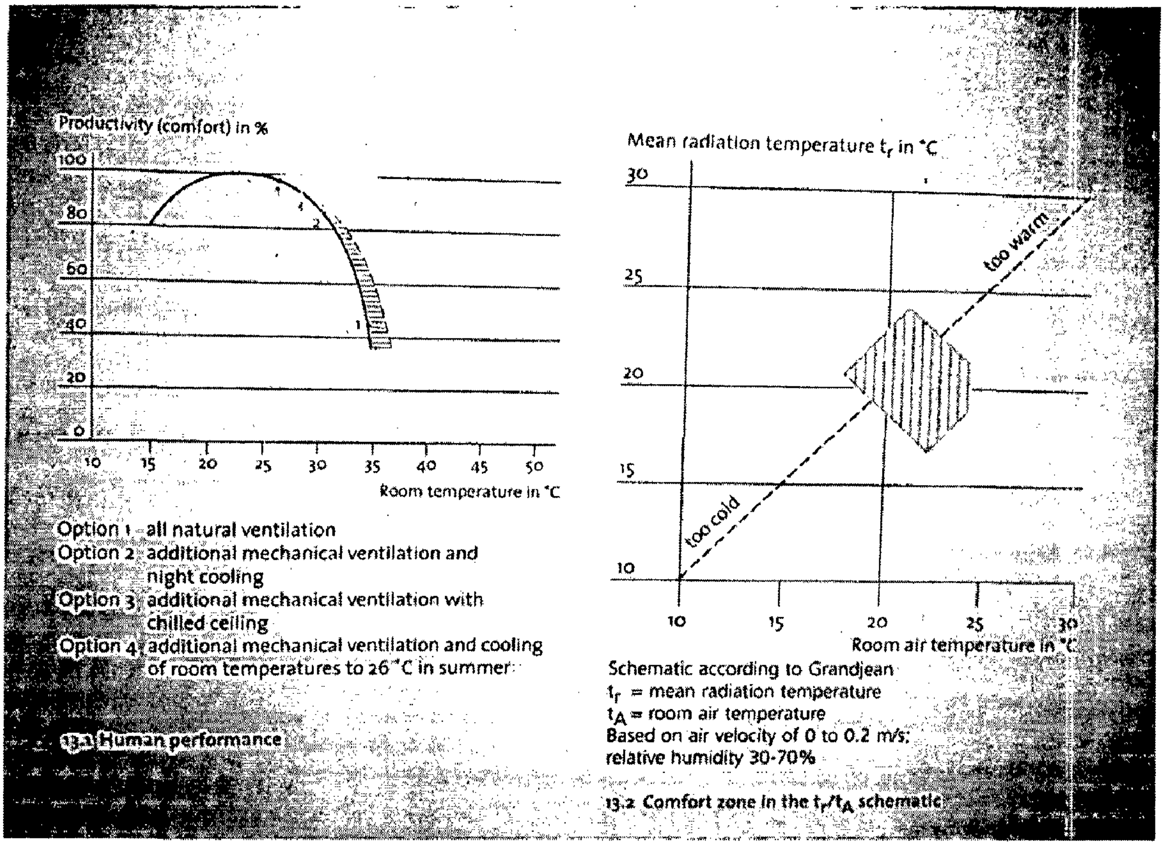

Figure 2.1: The change in efficiency in human performance with temperature and humidity (Source: Hindrichs,D et al, 2007, Sustainable building design in tropical and subtropical regions)

NOISE

In addition to temperature and humidity, acoustic isolation is also very important for comfort. There were 313,000 complaints in England and Wales to Environmental Health Officers about domestic noise disturbance in 2004, up from 155,000 in 1999 and from only 31,000 in 1980 . As a result of the growing number of complaints and the potential litigation arising from these, building regulations have considerably improved acoustic insulation requirements since 2002. Testing is now mandatory if robust details are not used. However there are still a number of problem areas, and many building systems which have been designed for good thermal performance will not necessarily be good from an acoustic point of view. This applies particularly to lightweight structures. Certain types of thermal insulation can actually be bad for acoustic insulation, by increasing noise reverberation and flanking sound .

The point to note with regard to acoustics is that this is all about getting the shell of the building right in the first instance. It is extremely difficult, if not impossible to retrofit proper acoustic performance.

LIGHT

Lighting can have either a positive or negative effect on health and wellbeing. The effects may be felt immediately or only in the long term. There are four types of effects: light as radiation, light acting through the visual system, light acting through the circadian system and light as a purifier.

Generally natural daylight is understood to be beneficial both to health and wellbeing. Maximising good daylight in buildings is therefore an important consideration. Good daylight means levels of daylight which are sufficient to see properly without glare or excessive contrast. Too much direct sun can actually cause discomfort and ill health, particularly with highly reflective surfaces.

On the other hand darkness is also an important source of wellbeing. Our bodies require a regular cycle of light and darkness for both physical and mental health. Bedrooms need to be dark and quiet for most people to receive proper rest. Psychologically it is also important that the outside is also dark, wherever possible. Light pollution is now a commonly accepted problem in many built up areas.

Building better means taking the quality of lighting, particularly natural daylighting, seriously. A strategy to maximise the benefits of daylight, along with well-designed low energy lighting will provide the best solution for health and comfort and the lowest impact on the environment.

SMELL

Substances that enter the nasal cavity may be sensed either by the olfactory senses or by the limbic system. The first is responsible for odour detection, the second is sensitive to irritants. On the whole people adapt to odours relatively quickly, whereas irritants can get worse the longer exposure continues. Furthermore many of the irritants are at levels where they are not detectable as odours.

On the whole when building well, the objective should be to eliminate odours and air borne irritants of all kinds. There are some "natural" paints and other decorating materials which utilise natural essences such as citrus oil. The pleasant smell is often seen as a selling point, but it should be noted that many people have extreme allergic reactions to citrus essence, and furthermore that it will react as a VOC with other chemicals to produce low level ozone, which is a danger to asthmatics and those with respiratory problems.

The main ways of dealing with odours are outlined in the TM40 document in order of importance as follows:

a) Eliminate contaminants at source
b) Substitute with sources that produce non-toxic or less malodorous contaminants
c) Reduce emission rates of contaminants
d) Segregate occupants from potential sources of toxic or malodorous substances
e) Improve ventilation
f) Provide personal protection

Another important factor in high rise building design would be avoiding the sick building syndrome. Buildings should not cause sickness but should meet thermal and hygienic requirements to provide an agreeable environment for the users. In the past many buildings were found to be lacking in this department. The goal should be to not only use ecologically sound materials, but to avoid the basic deficiencies in ventilation and lighting. The sick building syndrome was coined by DR.P.Kroling.

The factors causing SBS are:

a) Excessive air velocity or turbulent air flow in a room > 0.12 m/s
b) Symptoms arising from microbial allergens
c) Malfunction of thermal regulation
d) Low frequency sound <100Hz
e) Odours from badly maintained humidifiers.

2.2 PRINCIPLES AND PRACTICES OF SUSTAINABLE DESIGN

2.2.1 OVERVIEW

Sustainable design is an immense topic. According to The World Watch Institute worldwide building constructions and operations account for 40 % of the world's energy consumption. Developers, building owners, architects and engineers can help reduce or eliminate some of the unintended environmental and societal problems if they can begin to shift their approach to sustainable design. So-called sustainable design involves several changes in how a planning team thinks about design. The term sustainable design is chosen over sustainable architecture because design can be both a verb (connoting a process) and a noun (connoting a result) and because design better conveys the interdisciplinary involvement needed to meet sustainable goals.

2.2.2 GOALS OF SUSTAINABLE DESIGN

In a standard design, each team member typically focuses on a narrow area of responsibility and works toward goals that only encompass actions within his or her discipline. While all the disciplines in conventional practice are coordinated with each other and respond to the requirements of the other disciplines, there is little emphasis on integrated problem-solving for larger integrated goals. For example, envelope materials, lighting design and HVAC equipment must each meet certain minimum requirements. But there are no requirements for total building energy consumption in most countries, and seldom are these pieces designed as a whole to optimize energy use.

An integrated, holistic approach is achieved by intelligent and creative designs that respond to the following requirements:

a) Achieving the highest quality building at the lowest lifecycle cost.
b) Creating a simple form.
c) Designing for adaptability and flexibility - current and future uses.
d) Using resource efficient systems and components that are easy to maintain.
e) Inspiring the communities through buildings that teach sustainability.
f) Creating a healthy building to serve healthier people.
g) Creating a show-case for cost-saving and efficiency-enhancing.

2.2.3 SUSTAINABLE DESIGN PROCESS

In any design process it is most efficient, to implement sustainable goals from the beginning of the planning procedure. Sustainable decisions can be made at early stages of the planning process such as program definition. In order to achieve optimal results for sustainable development questions relating to functionality, urban development, architecture, planning laws and building laws must be investigated and answered during predesign phases and in advance of architectural competitions. In other words, sustainable planning processes require more emphasis on planning at the earliest stages of a building project. (Figure 2.2)

Sustainable design processes possess the following characteristics:

a) Integration of sustainable design experts into the building process.
b) Well documented goals for the building process subsequent to the competition.
c) Application of simulation models as a means to support decision making in the design process.
d) Close cooperation of the various stakeholders.

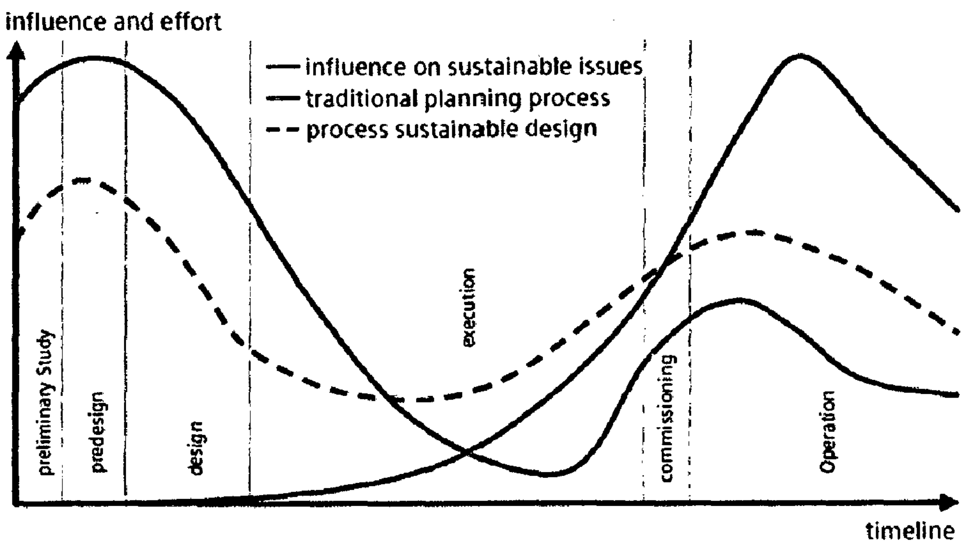

Figure 2.2: Efforts made to achieve sustainable design in early planning phases yield the greatest return. (Source: Sigg.R, et al, 2006, Sustainable Building Design)

2.2.4 SUSTAINABLE DESIGN FACTORS AFFECTING THE SITE

Design of the site is one of the most important steps towards sustainable design. The major aim of this stage is to avoid the development of inappropriate sites and reduce the environmental impact from the location of a building on a site.

2.2.4.1 MINIMIZING SITE IMPACTS

One must always decide how to use a site and determine whether if indeed it should be built on at all, this establishes the basis for all later decisions. The site provides the context for the building, but the buildings in turn modifies the site. The local ecosystem is altered; habitats changed and flows of energy, water, nutrients and pollutants modified. Neighbouring buildings are affected. Site review serves to consider possible improvements to the overall site design to achieve the most effective integration within the natural environment. The goal is to minimize impacts to natural areas.

The site must be analysed for microclimate, land use, density, expandability, green space, water, energy, waste and soil contamination considering the following factors:

a) Using passive solar strategies, including daylight.
b) Providing sufficient aeration for site and surrounding.
c) Minimizimg impermeable surface areas and soil interferences (e.g. reduce parking areas underground, minimize hard surfaces and maximize green space).
d) Using renewable energy systems (e.g. active solar systems).
e) Designing sub natural green spaces.
f) Designing the building with building technology and components appropriate to the region.
g) Designing high-rise parking areas instead of underground garages.

2.2.4.2 PROVIDING EASE OF ACCESS

Land use, density and urban transportation systems are closely interdependent. Cheap road and rail transport and specialized land-use zoning have encouraged dispersed development patterns. This pattern causes increased commuting while making public transportation systems uneconomical. Automobiles are the most wasteful use of energy and the greatest source of air pollution emissions today.

Sustainable design must seek to achieve measures to reduce and restrict automobile use by ensuring the following in the design:

a) Creating cyclist and pedestrians routs that are continuous, reasonably direct and free from heavy traffic, noise or pollution.
b) Building on sites served by existing public transit, sidewalks and bikeways.
c) Considering the availability of shuttle-bus systems.
d) Integrating parking areas into the overall landscape.
e) Planning footpaths by taking advantage of landmarks, views and existing vegetation.
f) Ensuring security on the footpaths (surface coating, illumination).
g) Providing secure and sufficient bicycle storage close to building entrances.
h) Providing changing and/or shower facilities in the building close to entrances.
i) Providing access for people of all ages and abilities (e.g. facilities for disabled persons).
j) Considering the introduction of car-sharing and car-pooling.
k) Considering option to telecommute.
l) Designing attractive entrances
m) Providing appropriate design for underground parking areas:
    i. Separating the entrance from exit
    ii. Providing efficient illumination

2.2.5 SUSTAINABLE FEAURES IN THE BUILDING ENVELOPE

2.2.5.1 CREATING A SIMPLE BUILDING FORM

Building plan and form emerge as a result of complex process. Functional, technical and aesthetic considerations all contribute to this synthesis. Wind, solar availability and orientation, shelter and exposure, air and noise conditions, all contribute to inform the relationship between a building and its environment. Each affects the form and the design of the envelope. Simply making the building the right shape and placing it in the correct orientation can reduce energy consumption by 30 – 40% without extra cost.

Strategies for form development:

For northern latitudes where heating is the dominant requirement, the following strategies must be used:

a) Optimizing the ratio of surface to volume to reduce heat losses by transmission.
b) Maximizing solar heat gains.
c) Designing an intelligent building orientation to minimize impacts of prevailing wind.
d) Providing simple multi-story design:
   i. To optimize building structure systems.
   ii. To reduce impacts on site and conserve site.
   iii. To offer flexibility for site placement.
e) Designing an efficient building structure:
   i. By zoning and stacking of space uses with similar building technology requirements (HVAC, plumbing, etc.).
   ii. By grouping of space uses according to performance needs (e. g. daylight, indoor air climate, etc.).

For southern latitudes where cooling is the dominant requirement, the following strategies must be used:

a) Orienting building in a north- south orientation to avoid unwanted heat gains.
b) Providing simple multi-story design:
   i. To optimize building structure systems.
   ii. To reduce impacts on site and converse site.
   iii. To offer flexibility for site placement.
c) Designing an efficient building structure:
   i. By zoning and stacking of space uses with similar cooling requirements.
   ii. By grouping of space uses according to performance needs (e. g. daylight, indoor air climate, etc.).

2.2.5.2 OPTIMIZING HEAT PROTECTION

The performance of the building envelope is based on the relationship between the building and its external environment; determining factors are wind, solar availability, direction, shelter of excessive exposure, air quality, and noise conditions.

Sustainable design strives to optimize energy performance and guarantee a high level of comfort. Summer heat gains and winter heat losses must be avoided by an effective means of protection.

Strategies for optimizing heat protection in buildings:

For northern latitudes where winter heat protection is the dominant requirement, the following strategies must be used:

a) Designing an airtight building envelope.
b) Maximizing the insulation of the opaque envelope elements.
c) Minimizing glass in the facade and minimize u-value of windows and glass elements.
d) Optimizing the distribution of thermal mass within the building's envelope in order to modulate heat gains.
e) Selecting an appropriate envelope colour.
f) Providing appropriate landscape plantings in order to shade during summer and slower wind velocity during winter (deciduous trees).

For southern latitudes where summer heat protection is the dominant requirement the following strategies must be used:

a) Designing an airtight building envelope.
b) Reducing heat gains by installing external sunscreens.
c) Reducing glass in the facade.
d) Designing landscaped roofs.

2.2.5.3 CHOOSING AN APPROPRIATE FAÇADE

The facade has a decisive impact on the building quality. The selection of façade materials poses a challenge when reconciling economic considerations in combination with aesthetics and comfort.

Strategies for choosing an appropriate facade:

a) Space efficiency and flexibility:
    i. Designing room depth and room adjacencies to allow for flexible use and furnishing.
b) Simple structure:
    i. Providing a simple structural concept with span lengths appropriate for the material involved.
    ii. Avoiding vertical structural supports within room areas (results in space loss, limits flexibility in furnishing and cleaning).
c) User comfort:
    i. Providing high thermal comfort.
    ii. Providing simple controls for windows, shading devices and lighting appliances.
d) Energy:
    i. Using sunlight.
    ii. Verifying installation of efficient thermal -insulation of the building envelope.
    iii. Observing and not exceeding the energy standards.
e) Ecology:
    i. Striving to minimize energy uses and emissions of toxic.
    ii. Designing for durability and recyclability.
f) Building services:
    i. Attaching heating surfaces to window areas and external walls.
    ii. Designing for effective interaction of sunscreens, artificial lighting and daylight.
g) Security:
    i. Using appropriate systems for security and fire prevention.
    ii. Using appropriate guardrails.
h) Facility Management:
    i. Providing accessibility to cladding and glass facades for cleaning, as well as access to shading devices for repair and maintenance work.

ii. Providing window elements adjustable from inside or fixed.

2.2.6 MANAGING ENERGY IN SUSTAINABLE DESIGN

2.2.6.1 MINIMIZING ENERGY USAGE

Sustainable design seeks to reduce both embodied and operating energy. The amount of energy a building consumes is an indicator of efficient design. In most building design processes the optimization of the energy performance saves money by reducing the size of equipment and by minimizing operating costs. Factors such as sitting, orientation, window selection, material selection and the efficiency and control of the mechanical and technical equipment all contribute to reducing the amount of energy used to heat, cool, ventilate and light a building.

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Strategies for minimizing energy consumption:

a) Reducing energy use:
   i. By optimizing construction technique:
      1. Designing a climate responsive facade.
      2. Optimizing daylighting.
      3. Using natural ventilation.
      4. Providing appropriate glazing and shading devices.
      5. Using thermal mass.
   ii. By using efficient mechanical and electrical equipment:
      1. Incorporating energy responsive systems, including motion and occupancy sensing systems or daylight sensing systems.
      2. Selecting energy-efficient appliances (e.g. lamps, HVAC-systems, office equipment, elevators).
      3. Designing shorter and straighter duct runs.
      4. Locating equipment centrally, such as printers.
      5. By integrating energy-efficient technical concepts.

b) Using heat recovery systems.

c) Using sources of renewable energy.

d) Using task lighting.

e) Reducing secondary energy output by selecting energy-efficient primary energy sources/ factors:
   i. Electrical power.
   ii. Fossil fuels.
   iii. Biomass energy.

2.2.6.2 MINIMIZING EMBODIED ENERGY

Construction and operation of buildings consumes 40% of the world energy supply. Designing building to be energy-efficient is an imperative of sustainable design and must consider both embodied and operating energy consumption.

Strategies for minimizing embodied energy:

a) Designing a compact building form.
b) Minimizing the amount of materials required for construction to reduce total embodied energy.
c) Optimizing the amount of glazed areas as glass has an extremely high amount of embodied energy (compare the chart below).
d) Choosing windows with minimal embodied energy (e.g. windows with wooden frames instead of windows with metallic frames).
e) Selecting materials requiring minimal embodied energy (incl. transportation):
   a. Materials from local/regional sources.
   b. Materials requiring less energy for their manufacture and use.
f) Selecting materials made using renewable energy.
g) Selecting durable, maintenance-free materials.
h) Designing weather protection for external facades.
i) Detailing building assemblies with minimal energy requirements.
j) Designing to allow use of energy-efficient electrical and mechanical systems.
k) Selecting materials with high levels of recycled content.

2.2.6.3 USING RENEWABLE ENERGY

Conventional sources of energy have well-documented, adverse environmental, economic and social consequences including production of greenhouse gasses and the depletion of non-renewable resources. Sustainable design seeks to lower total energy consumption while also striving to use renewable sources of energy.

Strategies for using renewable energy:

a) Using sources of waste heat:
   i. Heat recovery systems in ventilation and air-conditioning systems.
   ii. Recapturing waste heat, e.g. from exhaust air and wastewater.
b) Using geothermal systems using thermal sources or groundwater in combination with heat pumps for heating and/or cooling:
   i. Vertical ground loop.
   ii. Energy piling.
   iii. Horizontal ground loop.
   iv. Ground-air heat exchanger.
c) Considering using wood-fired systems:
   i. Low emission wood-chip furnaces for local district heating.
d) Considering using biomass:
   i. Biomass heating.
e) Considering using solar systems (dependent on the availability of solar radiation):
   i. Hydraulic solar systems for basic hot water requirements:
f) Locating solar collectors with optimal positioning for hot water production. South-oriented (vice versa southern hemisphere) with an inclination between 30° and 45°.
g) Photovoltaic modules and cells located on roofs and south facing facades (vice versa southern hemisphere) for electricity production, as well as for cooling.

2.7 PROVIDING ROOM COMFORT IN SUSTAINABLE DESIGN

2.2.7.1 PROVIDING HIGH THERMAL COMFORT

The thermal comfort of occupants is dependent on air temperature, wall temperature, air velocity and relative humidity. Each of these factors contributes significantly to determining the overall level of comfort attained. In addition, the activities and clothes of the occupants must be considered. Since thermal comfort affects the productivity of people a level of climate control acceptable to building users must be achieved.

Strategies for providing thermal comfort:

The goal is to guarantee the temperature limit of 26°C for 90 %. This must be proved for the different versions with simulations.

a) Simulating air flows and room temperatures to support development of the design concept.
b) Providing appropriate heat protection for the building envelope:
   i. Using glazing and facades with low U-values.
   ii. Reducing the amount of glazed areas.
c) Using effective sunscreens (see/ compare visual comfort):
   i. Installing exterior sunscreens.
   ii. Automating sunscreens to retract wind speeds of 45 km/h.
   iii. Installing sensors to control solar gain.
   iv. Ensuring systems operate in coordination with day lighting zones.
d) Using Efficient HVAC systems:
   i. Designing responsive systems for effective distribution of heat.
   ii. Providing for zone control of temperatures including user control.
   iii. Considering separated heating systems that respond to varying levels of solar input.
   iv. Providing perimeter heating at exterior walls for glazed areas and to accommodate flexibility in adjusting temperatures in critical areas.
e) Avoiding suspended ceilings to facilitate use of thermal mass.
f) Installing energy-efficient appliances and lighting to reduce internal heat loads.
g) Providing thermal mass to reduce temperature swings: thermal mass stabilizes the modulation of indoor temperatures.
h) Avoiding exceedingly dry or humid indoor air.

2.2.7.2 PROVIDING VISUAL AND ACOUSTIC COMFORT

The availability of daylight is a significant contributing factor to determining the quality of a workplace. Daylight is beneficial to human health and improves productivity. Sustainable Design strives to provide enough daylight to all occupied areas to eliminate the need for artificial lighting during the day. The amount of daylight available in the building is affected by the building's site orientation, the amount of shading from the building itself or adjacent buildings, and the external landscaping and finishes. The amount of daylight that reaches the interior of a room lit from windows on one side is a function of the distance from the window, the height of the window, and the reflectivity of the interior surfaces. While making it possible for daylight to reach "every corner" of a room is desirable for better health, problems such as glare and direct solar gains can cause discomfort. An informed approach to handling daylight and artificial light is required in order to provide visual comfort for every occupant.

Strategies for providing visual and acoustic comfort are:

a) Performing daylight simulations to guide design decisions.
b) Daylight:
    i. Providing daylight to all occupied.
    ii. Providing exterior views.
    iii. Specifying window designs to provide daylight to achieve required lighting levels while controlling for heat gain and loss.
    iv. Considering use of an atria or light courts to bring daylight to interior areas.
    v. Considering use of skylights in corridors.
    vi. Selecting an appropriate colour for internal surfaces:
    vii. Decreasing surface reflectance from the ceiling to the ground.
    viii. Providing daylight reflecting surfaces to increase penetration of daylight into interior spaces furthest from windows.
c) Glare:
    i. Avoiding glare by eliminating:
    ii. Avoiding reflection of light from polished surfaces.
    iii. Avoiding intense sources of light entering directly into the field of view.
    iv. Using appropriate shading devices.
    v. Installing user-friendly shading devices room by room.

d) Providing separate sunscreens from glare shields (normally optimal protection cannot be achieved using a single system).
e) Artificial light:
    i. Providing even lighting levels to all occupied areas.
    ii. Providing appropriate artificial light: in offices use cold colour fluorescent lamps.
f) Acoustical comfort:
    i. Providing a high acoustical insulation (outdoor noise, noise generated by mechanical installations).
    ii. Avoiding long reverberation times (necessary for speech comprehensibility).

2.2.7.3 PROVIDING HIGH INDOOR AIR QUALITY

Conservation of energy often means highly insulated, and well-sealed interior environments. The choice of materials in energy-efficient buildings affects indoor air quality to an even higher degree than in conventional buildings. Materials specified that include toxic ingredients can result in off gassing. Reduced air movement and ventilation can magnify the adverse health effects from off gassing resulting in a wide range of impurities in the indoor environment.

Strategies for providing high indoor air quality are:

a) Considering air quality influencing aspects such as external air, building materials, technical equipment and user behaviour.
b) Providing high rates of indoor air exchange.
c) Avoiding materials releasing toxic substances.
d) Avoiding airborne particulate matter that could be inhaled.
e) Preventing microbiological contamination from bacteria and molds.
f) Integrating air quality considerations into the planning process:
    i. Determining indoor air quality objectives at early stages of the planning process.
    ii. Integrating indoor air quality considerations into the selection process for architectural competitions.

iii. Evaluating material-, service- and building concept based on indoor air quality criteria.
iv. Optimizing building concept and materials concerning indoor air quality.
v. Specifying commissioning with indoor air quality criteria.
vi. Evaluating compliance with criteria during construction works.
vii. Considering indoor air quality criteria during final inspection.

2.2.8 SUSTAINABLE HVAC SYSTEMS

2.2.8.1 EFFICIENT HEATING AND HOT WATER SYSTEMS

Energy required for heating and cooling buildings comprises 6.7% of total world energy consumption. Sustainably designed buildings could reduce this energy use by an average of 2.35 % of total world energy consumption. Sustainable design emphasizes first the optimization of the building systems to protect against heat loss before installing complex heating systems. In most regions active heating systems have to be installed to guarantee comfortable room temperatures during heating season. Significant energy-savings can be achieved by combining conventional systems (such as condensing boilers) with innovative systems that allow for dynamic system operation.

Strategies for designing efficient water heating systems are:

Heating generation:

a) Considering the use of renewable energies:
b) Considering the use of geothermal heat (heat pumps, horizontal ground loop, vertical ground loops, energy piping, ground-air heat exchanger).
    i. Groundwater (see thermal heat).
    ii. Wood (wood-chip-heating).
    iii. Solar energy (solar collectors).
c) Incorporating the use of combined systems for heat and power generation :
    i. Power plants.

Heat distribution:

a) Incorporating the use of central heating systems:
b) Using a central system with renewable energies for hot water heating

c) Local heating:

   i. For warm water heating in office buildings:
   Using decentralized boilers that heat water on demand.

d) *District heating:*

   i. Combined heat and power plants:
   Advantages: high efficient, low global emission-load, combinable with geothermal power.
   Disadvantages: not combinable with solar collectors.

Heating surfaces:

a) Considering systems with low temperature zones
b) Radiators (panel/ sectional/ duct radiators): conventional systems.
   Convector heater: more economic due to faster preheating, but maintenance-intense and can adversely affect air quality.
   Panel heater (overhead/ floor/ wall heating): undesirable due to limited accessibility in regard to maintenance; mainly used in entrance halls.

2.2.8.2 DESIGNING EFFICIENT VENTILATION SYSTEMS

The use of natural ventilation via operable windows should be considered before installing mechanical ventilation systems. Mechanical ventilation systems can be particularly necessary in cases where the air quality is low due to the site surroundings, or in cases of high ambient noise levels or elevated thermal losses resulting from use of natural ventilation.

Strategies for designing efficient ventilation systems:

All heating systems that use heat pumps can be used in combination with ventilation systems for heating and cooling air.

Energy efficient ventilation systems:

a) Natural ventilation: depending on air pollution and noise.
   i. Cross ventilation: depending on wind speeds, window position and size.
   ii. Stack ventilation (e. g. chimney ventilation): dependent on room height.

b) Additional systems: wind catchers.
c) Considering mechanical ventilation as a means to dependably introduce high rates of outdoor air into buildings at relatively low rates of energy consumption as opposed to use of conventional air conditioning.
d) Considering location of air inlet at the roof level, air may be cooler and cleaner.
e) Considering filtering the incoming air; saver, because fans allow smaller inlets.
f) Careful positioning of air inlet:
   i. Favouring shaded areas.
   ii. Locating at least three meters above grade.
   iii. Avoiding locations near air exhaust vents or other contaminated areas.
g) Space ventilation using a whole house fan: fans that move cooler outdoor air to the inside, removing heat from rooms.

2.2.8.3 DESIGNING EFFICIENT COOLING SYSTEMS

In many climate zones of the world acceptable room temperatures cannot be maintained year-round using natural or passive systems alone. Supplemental means of maintaining the required comfort level is then required. Still, passive systems should be evaluated first when considering how best to meet the required comfort parameters. Such passive cooling has economic benefits resulting from lower energy demands, and unusually results in high indoor comfort without adversely affecting the air quality. In some countries, such as Switzerland, mechanical cooling must be kept to a minimum in order to comply with regulations related to energy consumption.
Strategies for designing efficient cooling systems:

Cooling generation:

a) Considering the use of renewable energies: All heating systems that use heat pumps can also be used for cooling.
   Advisable cooling methods:
b) Passive cooling:
   i. Night cooling (Natural/ mechanical ventilation).
   ii. Radiant cooling: Work with cooling storage.
   iii. Evaporative/ desiccant cooling /cooling towers.

c) Ground cooling: earth-air heat exchanger.
d) Aquifer cooling.
e) Avoiding active cooling requiring electrical energy, such as chillers using compression refrigeration.

Cooling distribution:

f) Using central cooling systems, if it is possible to work with renewable energies.
g) Working with local cooling systems, when needed for only a few rooms.
h) Using district cooling systems

Cooling operating conditions

i) Avoiding passing below the dew point.
j) Optimizing flow temperatures to avoid thermal losses.
k) Providing effective controls.
l) Considering the required cooling capacity.
m) Considering the noise generated by different systems.

2.2.9 DESIGNING EFFICIENT ELECTRICAL SYSTEMS

The selection of an appropriate system for power generation should consider electrical demand, investment and operating costs, safety environmental impacts.

2.2.9.1 DESIGNING EFFICIENT LIGHTING SYSTEMS

Day lighting controls and control of artificial lighting must be optimized to achieve energy-efficiency requirements. An effective layout of lighting fixtures and a user friendly plan to zone lighting controls must be achieved. The type and colour selection for interior wall and ceiling finishes dictates the level of reflectance attained. Choosing the right reflectivity for surfaces is the key to meeting required lighting levels while ensuring occupant comfort. The types of lighting fixtures used also play a decisive role.

Strategies for efficient lighting design:

a) Providing even lighting to avoid rapid fatigue.
b) Installing task lighting: use free-standing lighting fixtures with user controls.
c) Installing automated lighting control systems:
    i. Motion, Occupancy or sound sensing detectors.

ii. Daylight sensors (photosensitive cells).
iii. Timing devices.
iv. Dimmers controls.
v. *Lumen maintenance strategies that can save 30 – 50% of energy* consumption due to electric lighting office buildings.

d) Designing electrical lighting so that lights can be turned on in areas that need additional light and left off in areas that do not:
   i. Placing lighting systems parallel to window walls.
   ii. Installing zoned switching mechanisms.
e) Using energy-efficient lamps:
   i. Installing long-lasting lamps.
   ii. Avoiding multiple-filament fixtures with low efficiency levels.
   iii. Making use of energy-saving ballasts when installing fluorescent lamps.

2.2.10 EFFICIENT WATER MANAGEMENT

2.2.10.1 MINIMIZING WATER USAGE

Conservation of water is critical to maintaining life. Nearly two billion people worldwide must deal daily with lack of water. Architects and engineers can make significant reductions in water use by specifying materials that minimize water use in their manufacture, by selecting water efficient fixtures and appliances and by specifying vegetation that requires minimum amount of irrigation.

Strategies for minimizing water usage:

a) Incorporate water-efficient technologies:
   a. Water-saving fixtures for toilets, faucets, showers, etc.
   b. Motion sensors on faucets.
   c. Self-closing faucets.
b) Facilitate measurement and control of water use by installing water meters to monitor water consumption (e.g. to detect leaks).
c) Select building materials that do not require excessive water use in their manufacture.

d) Demonstrate to users that water saving appliances do not affect the level of comfort.

e) Consider to substituting the use of groundwater with rainwater and waste water, e.g. use alternate sources of water to flush toilets, cool office appliances or operate cooling-plants.

f) Specify drought-tolerant, native planting in landscape design to ensure minimum irrigation.

2.2.10.2 EFFECTIVE RAINWATER MANAGEMENT

Rainwater use is another efficient means of reducing groundwater use. Rainwater catchments systems collect the rainwater for use as a substitute for fresh water. Rainwater can be used for landscaping, flushing toilets and, where appropriate, for cleaning. Rainwater may also be suitable for cooling equipment.

Strategies for effective rainwater management:

Rainwater use:

a) Incorporating rainwater collection and storage systems:
   i. Integrating a rainwater cistern.
   ii. Providing for straining debris from and/ or filtering the collected rainwater.
   iii. Accommodating drainage for excess rainwater.

b) Installing rainwater-filtering systems (e.g. landscaped roofs) to avoid accumulation of dirt particles inside the toilet tank and the toilet bowl.

c) Ensuring separation of grey water and black water.

Rainwater disposal:

a) Providing adequate surface infiltration to avoid periodic flooding:
   i. By providing sufficient space for infiltration.
   ii. By avoiding impermeable surfaces wherever possible (specify gravel lawn, turf stone, water-permeable paving stone, etc.).
   iii. By designing subsurface infiltration ditches.
   iv. By designing landscaped roofs.

b) Avoiding infiltration of contaminant-loaded rainwater into soil:

i. By avoiding wider roofed areas covered with uncoated zinc, copper or lead - in Germany per prohibition regulated.

c) By providing appropriate means to remove contaminants from surface runoff.

Wastewater management:

a) Ensuring efficient wastewater disposal:
   i. By designing drainage systems with the objective to avoid effluent leaking into surrounding ground.
   ii. By facilitating access to plumbing for ease of maintenance.
   iii. By selecting plumbing materials for strength, durability, and the ability to resist to corrosive action of wastes.

2.2.11 MAINTAINING A HEALTHY ENVIRONMENT IN BUILDINGS

2.2.11.1 USING APPROPRIATE BUILDING MATERIALS – SHELL AND STRUCTURE

A number of factors influence the selection of building material and components including cost, aesthetics, performance and availability. Sustainable design seeks to minimize environmental and health impacts caused by building materials. Material selection must focus on sourcing materials with the least impact to the environment and human health.

Strategies for selecting the right construction materials:

Construction Strategies:

a) Avoiding composite materials that cannot be separated at the end of their life cycle.
b) Avoiding using adhesives or sealants that limit disassembly of components.
c) Designing buildings to facilitate deconstruction and recovery of materials.
d) Selecting materials considering global and regional environmental impacts from extraction to disposal.
e) Avoiding using materials harmful to the environment.
f) Avoiding the use of materials that result in waste and cause pollution (incl. noise, vibration, dust).
g) Using materials and products that can be easily disassembled to ensure reuse or recycling.

Strategies for the selection of materials:

a) Avoiding the use of tropical woods.
b) Avoiding the use of materials that result in harmful emissions into soil, air and water such as CFCs, heavy metals, zinc leachate.
c) Avoiding the use of materials that release or contain toxic substances. Select materials that are:
    i. Hygienic and harmless including adhesives and paints.
    ii. Biocide-free.
    iii. Formaldehyde free.
    iv. Low in VOC (volatile organic compounds) emissions.
d) Providing protection for workers and occupants when using materials containing toxic compounds that cannot be avoided.
e) Using environmentally-friendly certified materials such as eco labels or green seals.

2.2.11.2 USING APPROPRIATE BUILDING MATERIALS – FINISHES

Indoor air quality can be affected by the types of materials used for interior finishes. A healthy workplace supports occupant health and well-being. To reduce indoor air contaminants select materials with the least negative impact on indoor air quality. Poor indoor air quality can result in mental and physical health impairments. Improving indoor air quality has been shown to increase worker productivity and lower absenteeism. Using healthy materials also protects the health of workers during construction.

Strategies for choosing the right finishes:

a) Defining goals and criteria for material selection and inventory materials to be used, the functional units and the amount of material to be used.

b) Avoiding materials and products releasing health harming substances during and after installation:
    i. Emissions containing eye-irritants.

ii. Emissions containing skin irritants.
iii. Emissions containing mucous membrane/respiratory tracts irritants.
iv. Cancer-causing emissions.
v. Toxic emissions.

c) Defining goals for the material:
   i. Using low-VOC emission products, materials and chemicals.
   ii. Checking the manufacturer product lines for Green Products and use Green Seal Products.

2.2.11.3 USING APPROPRIATE BUILDING MATERIAL IN LANDSCAPING

Sustainably designed green spaces protect air, water and soil quality while preserving biodiversity and protecting human health. Public spaces and landscaping can affect the microclimate of buildings and their environment.

Strategies for choosing the right material for landscaping:

a) Site:
   i. Reducing impacts on ground from the very start of construction.
   ii. Minimizing soil disturbances, especially in regard to foundation depth.
   iii. Integrating the floor sweep into design to avoid unnecessary ground excavation and grading.
   iv. Making use of the excavated earth on the site.
   v. Reserving and reusing topsoil.
   vi. Separating waste materials from storing materials.
   vii. Protecting existing vegetation, especially native plants.

b) Avoid using impermeable, "hard surface" materials:
   i. Designing pervious surfaces such as gravel lawns, permeable paving, grass pavers-blocks/ turf pavers to ensure infiltration.
   ii. Considering landscaping roof areas, green roofs.

c) Designing landscape to support biodiversity:
   i. Providing semi-natural habitats for flora and fauna by:

1. Selecting native vegetation adapted to the site.
2. Protecting existing trees and vegetation/ plants.
3. Designing hedges to provide habitat for several (animal) species, as well as to provide protection from noise and view.
4. Integrating new plantings with existing trees and vegetation.

ii. Considering planting of exterior wall surfaces and facades.

iii. Designing spaces using plants; e.g. trees as natural composition element of the design.

iv. Avoiding the use of de-icing salts during winter.

v. Beginning design of green spaces at early stages of the planning process.

vi. Specifying low-maintenance green spaces to save on costs, as well as on resources (water) by:
1. Using robust plant species.
2. Using xeriscaping (plants requiring only little water).

2.2.12 ENSURING PROPER COMMISSIONING AND OPERATION

2.2.12.1 EFFICIENT ENERGY MANAGEMENT

Building operation costs can be reduced by continuous control of building performance and clear communication to operators and users in regard to goals of sustainability. Periodic analysis of building operations must be made. Sustainable design considers energy flows over the whole lifecycle of a building. The energy demands for construction of a building (including the energy required for each building material) and for the building operation must be analysed.

While the design and construction of a building determine its future energy requirements, it is the buildings users that must practice energy-efficient behaviour during operation.

Strategies for efficient energy management:

a) Energy Management systems (EMS) and internal processes to manage energy demands combine together to form an energy measuring concept. Potable water is as significant a resource as energy.

b) Specifying a measuring concept:
    a. Measuring and index values without creating 'data graveyards'.
    b. Dividing energy demand into various zones.
    c. Providing clear performance measures.
    d. Designing technical installations so that measuring equipment can be used effectively and at various times.
c) Analysing measured values:
    a. Evaluating the values received.
    b. Defining specific characteristics.
    c. Determining annual energy demand and energy costs.
    d. Comparing energy characteristics from year to year.
d) Using results of analysis to optimize building performance:
    a. Analysing demand for heat, electricity and water.
    b. Reviewing instantaneous values to optimize several processes, such as selective cylinder operation, operating time of burners, etc.
    c. Using simulation models for optimization.
e) Ensuring coordination of various technical components.
f) Ensuring systems durability by providing regular maintenance and cleaning of the various technical components.
g) Tracking performance in regard to energy use targets set during the planning process.
h) Providing appropriate technical instruments to measure and control energy.
i) Comparing energy target values defined during the planning process with actual consumption values.
j) Inspecting and correcting differences, so target values are achieved.

2.2.12.2 WASTE MANAGEMENT AND BUILDING CLEANING

Waste generated from homes and businesses, street litter, construction debris, industrial processes and sewage sludge create monumental environment problems. While the waste handling systems existing in many countries minimize local impacts, the eventual disposal of waste contaminates land, air and water sources at a regional and global scale. In the Netherlands, processing sites recover an estimated 60% of the waste material. In 1993, Denmark, achieved an 80% recycling rate for construction and demolition waste through landfill and materials tax incentives

Strategies for effective waste management:

a) Reducing waste at its source:
    i. Designing buildings to minimize waste during operation.
b) Separating wastes:
    i. Defining specific targets in regard to treatment and handling of wastes during commissioning.
    ii. Designing safe, sufficient and expandable storage for different categories of wastes.
    iii. Surveying waste treatment and waste separation.
c) Reusing or recycling:
    i. Separating wastes considering various waste categories.
    ii. Storing wastes so that future recycling is possible.
d) Ensuring safely dispose of waste to reduce impacts on ecosystems.
e) Documenting and analysing waste accumulation periodically (at least once a year).
f) Using of self-cleaning materials for facades to reduce the cleaning intervals.
g) Establishing an ecological cleaning strategy:
    i. Using microfiber textiles to prevent cleaning agents.
    ii. Avoiding overdose of cleaning agents.
    iii. Controlling the consumption of cleaning agents.
    iv. Adapting the cleaning to the pollution degree.

2.3 DESIGN METHODOLOGY

2.3.1 OVERVIEW

Design Methodology refers to the development of a system or method for a unique situation. The key to Design Methodology is finding the best solution for each design situation, whether it be in industrial design, architecture or technology. Design Methodology stresses the use of brainstorming to encourage innovative ideas and collaborative thinking to work through each idea and arrive at the best solution.

Meeting the needs and wants of the end user is the most critical concern. Design Methodology also employs basic research methods, such as analysis and testing.

2.3.2 NEED TO STUDY DESIGN METHODOLOGY

Design has traditionally been considered as largely an intuitive activity of an architect. Many designers believe that a study of the design process will hinder their ability to design. They believe that the study will lead to creation of numerous procedures that will destroy their intuitive creativity and perception. During the process of design, it is not uncommon for the designer to hit a 'block' or a 'dead end', by understanding the structure of the design knowledge; he will be well prepared to handle unforeseen problems. Thus instead of giving up or settling for something mediocre, the designer will be capable of developing alternate strategies that look at the problem in a whole new way.

Also, there is now a change creeping into the profession of architecture. A sense of '*corporateness*' is slowly becoming the norm for many of today's practicing architects. This however results in eliminating the designer as the final decision maker.

While making decisions about a project, clients expect the architect to use crisp and understandable language. The line '....my intuition tells me it will be better....' or '......I think this will really make the design interesting....'doesn't really justify the extra 2.5 lakhs the clients are being asked to spend, justifications are just not good enough. Instead the designer must be able to exactly explain how or why the added design factor will benefit the project, thus justifying its additional expense.

Thus architects need to learn this else, the removal of the designers from the decision making process significantly degrades design quality.

Looking at today's trends where everything is green, sustainable or ecofriendly one realizes that there should exist a methodology for the design of such buildings which have minimum impact on the world around us.

2.3.3 ARCHITECTURAL DESIGN METHODOLOGY

Architectural design methodology in the formative years was a blend of design methods and scientific study of design. Both areas are now more distinct, and it is appropriate to talk about design research on the one hand and design methodology on the other. Design methodology is relevant when:

- Trying to find a design solution will take a long time
- When the cost of not succeeding is very high
- When the process has to be accounted for
- When the design task is very complex
- When a high number of parties are involved in the design project

2.3.4 CONVENTIONAL DESIGN METHODOLOGY

In the conventional practice of tall building design process, generally, schematic design starts with designer's conceptual sketches. With the conceptual sketch, many architects start to plan core, floors, and elevations, in the format of 2D and 3D drawings. However, the conventional process of tall building design requires much time and labour to develop a single alternative because of the following:

- Large number of design considerations and their complex interrelationships
- Difficult of manipulations by changing of each design consideration
- Limitations of designer's ideal concept

When the building form is not a basic geometric form, it is much harder to plan and draw the scheme with conventional design process.

Development of tall building can be determined by design factors; these factors have several parameters of architectural and structural considerations. Items related to architectural considerations are building functions, lease span, floor-to floor height, core planning, and vertical transportation. Structural systems, mechanical systems, cladding systems and building serviceability are considered as building systems in tall building design. These considerations are interdependent and they affect many other factors that must be considered when developing a project. Architecturally and structurally, it is a very complex task to develop an optimal tall building due to these interrelations of large number of design considerations (Figure 2.3).

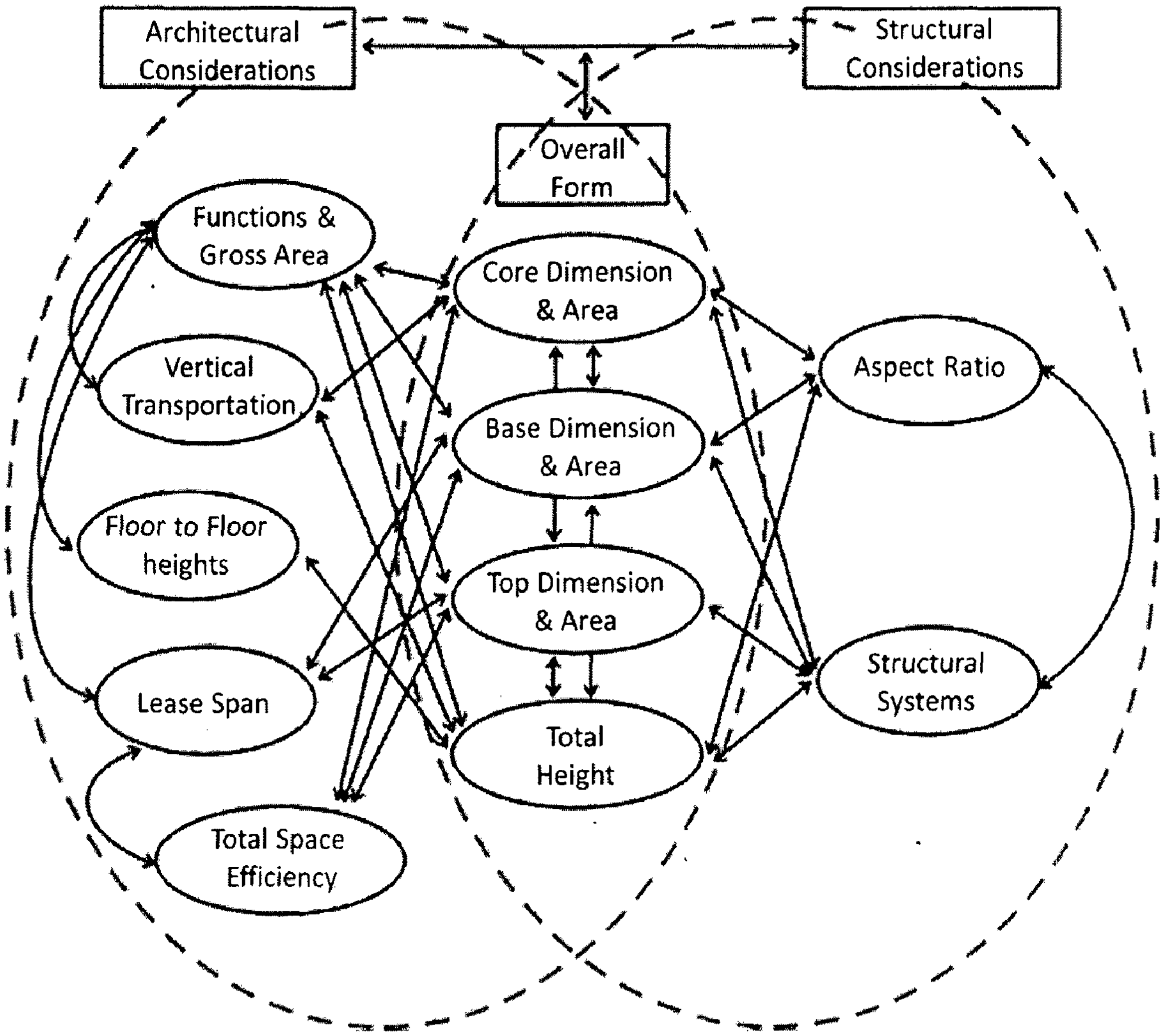


Figure 2.3: The interrelationship of a large number of design considerations (Source: Park, S.M, 2004, Innovative Tall Building Form Generation)

The conventional architectural design process involved the architect working out all the factors in his mind. Formulating the area requirements, Zoning of the site, conceptualizing the design keeping in mind the functional, climatic, aesthetic and economic considerations, estimating/costing was all done by the human mind and then drawings were prepared manually.

2.3.5 CHANGING PRACTICES IN DESIGNING HIGH RISE BUILDINGS

The practices in designing high rise buildings have been changing over the years and broadly they can be classified under two categories, the ecological design methods that involve an approach that is guided by nature i.e. climate, wind direction, sun path etc.; and the parametric design methods that involve major use of software and other digital tools for design and form generation.

2.3.5.1 ECOLOGICAL DESIGN METHODS

Throughout history buildings have been interrelated with certain indigenous characteristics such as regional climate, culture and religions. Shelters that are built of regional materials and resting comfortably in the landscape can be found all over the world within their different regional environments. Furthermore, when mankind was confronted with more hostile climates in the past, the people tried to protect their bodies' deficiencies by creating man-made environments and clothing. This was a logical starting point to create more spacious enclosures and the shelter became his most elaborate defence against hostile climates. Therefore, the primary means of providing human comfort in the different natural conditions was creating their own protection using clothing and shelters.

Different regional climates have provided different types of living environments to adapt survive and provide comfort from the extreme cold and heat. The design of traditional buildings is greatly different from region to region according to the natural resources available and the prevailing regional climate. Although the nature system is very complex, it is obvious that climate is a dominant constituent of nature. Therefore, the design considering climate in architecture might be regarded as a part of the ecological approach. A regional climate physically provides that the architects legitimately begin the architectural expression in relation to building site, since climate is one of the major factors that determine the regional lifestyle as well as the landscape's ecology.

In particular, the control of regional climate has been primarily a concern for compatibility with nature. In our modern age, technologies to control climate have been successfully developed in architecture but the loss of large quantities of natural resources can also produce environmental problems.

Design strategies for high rise buildings have been developed by analysing various combinations of building design configurations based on regional climates. The objective of this strategy is to determine the optimum architecture of high rise buildings during the initial design process that will reduce energy consumption for regional climatic conditions. The exterior design parameters include building forms, window areas and building orientations. Software like E-Quest and IES are used to analyse the data. The results are statistically analysed and presented in functional architectural design decision-making tables and charts. As a result of the comparison of architectural design considerations in relation to regional climates, buildings need less energy consumption when the architecture is concerned with the regional climate and it produces a more reasonable design methodology. In reality, imbalanced planning which is architectural design's lack of regional characteristics requires additional natural resources to maintain desired comfortable indoor conditions. Therefore, the application of integrated architectural design with regional nature should be the first architectural design stage.

2.3.5.1 PARAMETRIC DESIGN METHODS

There has been an extraordinary development of computer-aided tools intended to present or communicate the results of architectural projects during the past few years. Recently, a few architects have presented building forms that exhibit a more complex geometry. With the introduction of digital tools, generative design possibilities can be more fully explored with these geometries.

In the development of tall buildings, the overall building form should be one of the major elements that impacts building aesthetics and behaviour. However, architecturally, structurally and aesthetically, it is a complex task to develop an optimal form for tall buildings due to the interrelations of large numbers of components (Figure 2.3).

The use of digital tools in the schematic design phase of tall building design is still quite limited. The computer-aided design includes using a computer not only for visualization, analysis, and evaluation, but also for the generation of designs or, more accurately, for the rapid generation of computable designs describing conceptual design alternatives. Potential design alternatives are generated and evaluated in order to obtain the most promising solution. The advantage of parametric design is to plan and synthesize the overall requirements and relationships of many design elements into one form as shown in Figure 2.4. This process allows the designer to investigate variety of possible solutions quickly.

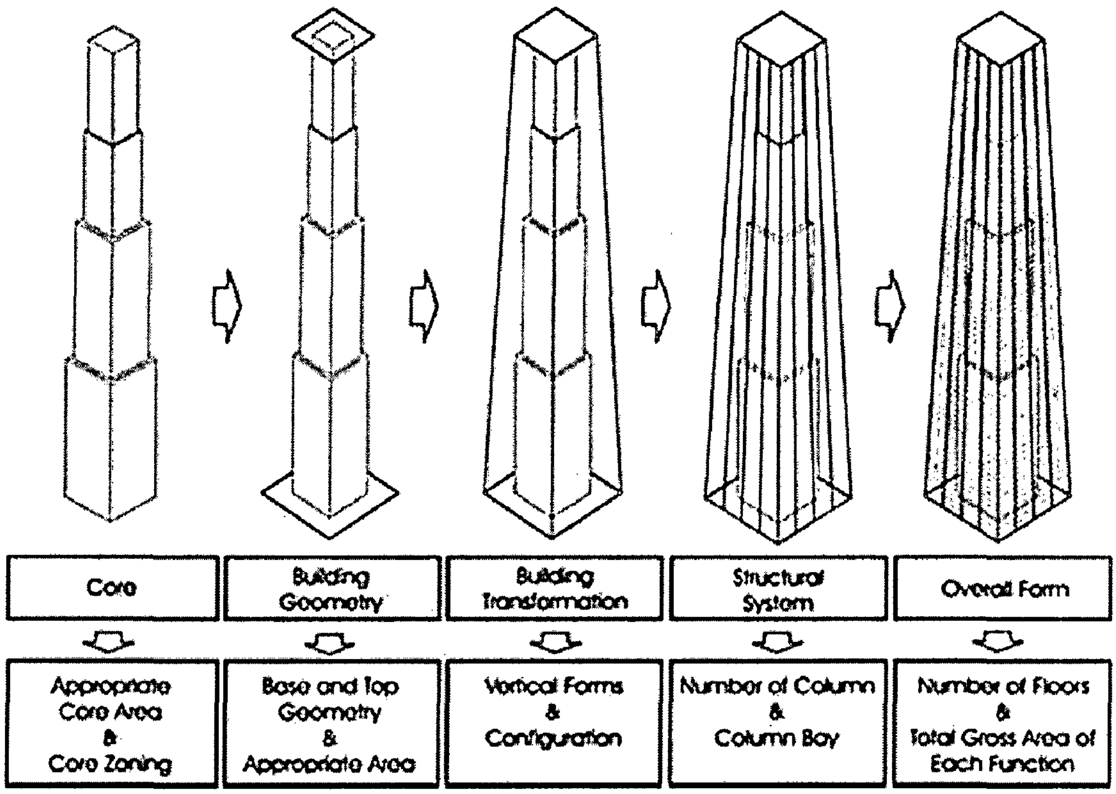


Figure 2.4: Design elements of high rise building form (Park, S.M, 2004, Tall Building Form Generation by Parametric Design Process)

Parametric design primary takes care of the following objectives:

a) Defining the relationships between design criteria and overall tall building form
b) Exploring the various geometries and transformations for tall building form
c) Suggesting an innovative digitally based design process for tall building design
d) Suggest generative forms and concepts of tall building that meet the design criteria
e) Developing an architectural design methodology using digital tools.

Thus, technology can be used as an architectural tool to produce not only the better performance design but also generative and innovative concepts. The improvement of design quality and design process using advanced technology is a more practical and challenging task for the profession. By integrating digital tools based on design criteria and design requirements with new conceptual building forms enables designers to uniquely apply their design concepts easily and evaluate a variety of alternatives.

2.4 INFERENCES FROM THE LITERATURE STUDY

High rise buildings are complex and a number of factors like building systems, structural design, core design, building services, aesthetics, climatic considerations come into play during their design process, and, all these factors are inter linked and thus affect each other.

Designing buildings is not just about making structures on the face of the earth but, it is about doing it in such a way that one does not disturb the harmony of the ecosystem by taking care of certain simple factors like site considerations, effective water and energy consumption, providing a good internal environment etc.

The process of design has long evolved since the time man used to hunt animals and live in caves. Now technology plays a huge part in the process of design. The development of concepts like Eco design, parametricism etc. has revolutionized the way architects work and has brought into focus parameters that were never thought of before.

A detailed explanation of the methodologies and relevant examples are discussed in the next chapter.

CHAPTER 3: CASE STUDIES OF DESIGN METHODOLOGIES

3.1 INTRODUCTION

This chapter deals with the detailed study of the design process followed by renowned international and Indian architects followed by its application in certain exemplary projects. The architects whose design methodologies have been that have been studied in this chapter are Ar. Ken Yeang for his work in the field of Eco Design, Ar. Karan Grover for designing the first platinum rated building in India, Ar. Vivek Rathore of Salient Design Studio for his Holistic Design Approach. In addition, the Parametric Design Process used by various architects like Zaha Hadid, Patrick Schumacher etc. has also been discussed. A detailed study of the process has be made and which turn to evolving a design methodology.

3.2 PARAMETRIC DESIGN METHODOLOGY

The design of a high rise building involves professionals from several disciplines, starting from the conceptual design to final design documents. The entire process is rather complex and in that it requires experts from different disciplines. In the schematic design phase, architects and engineers create a set of alternative possible high rise building forms. The output of conceptual design can lead to design concepts that can be used as a basis for design and detailing. Although schematic design phase only occupies 15% of the total design fee, this stage is more important than the other stages because about 80% of the resources required to build a structure are committed by decisions made during the conceptual design stage. This early phase of design is the most crucial part of the entire process. Potential design alternatives are generated and evaluated in order to obtain the most promising solution. Ordinarily, several alternative solutions are proposed to the client for consideration or approval.

In parametric design, it is the elements of a particular design that are declared, not its shape. By assigning different values to the parameters, different configurations can be created. Parametric design process is based on parametric input (Figure 3.1). Parametric design consists of a set of variables and a series of relations to define a form. The overall form can be manipulated by altering specific parameters that are able to automatically adjust building data such as total gross area, total building height, total number of floors, and aspect ratio.

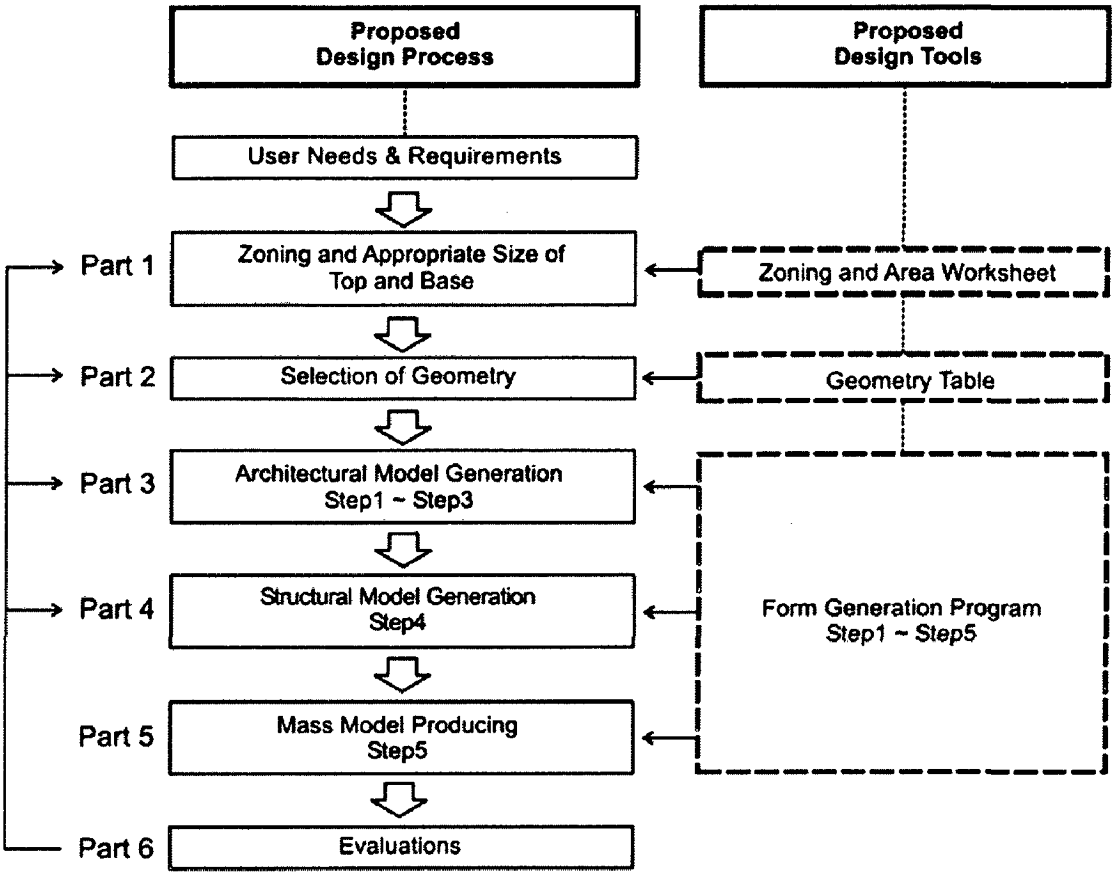


Figure 3.1: Proposed design process and tools (Park, S.M, 2004, Tall Building Form Generation by Parametric Design Process)

There are six major parts in porposed design process. Every part plays a crucial role and is executed in a sequential order to achieve a tall building form.

a) Part 1 consists of zoning and working out the areas
   i. Zoning and Area Calculation (Using Area and Zoning Worksheet)
   ii. Preparing vertical transportation systems and appropriate core size
   iii. Preparing appropriate base and top size

b) Part 2 is the stage where the building geometry is selected
   i. Explorations of Geometry (Using Explored Geometry Table)
   ii. Selecting base and top geometry and their combination type
   iii. Deciding number of points connecting base geometry to top geometry

c) Part 3 consists of generating the building form
   i. Architectural Model Generation (Using Form Generation Program)
   ii. Generating architectural 3D model

iii. Creating building data spreadsheet

iv. Run Form Generation Program

- Step 1: Each Function's Necessary Number of Floor Calculation
- Step 2: All Floor Plates and Building Data Generation
- Step 3: Architectural 3D Model Generation

d) Part 4 includes designing the structural system for the form

i. Structural Model Generation

ii. Generating Structural 3D Model

iii. Creating Structural Input File for Structural Analysis Program

iv. Run Form Generation Program

- Step 4: Structural 3D Model Generation and Creating Structural Input Files

e) Part 5 involves generating individual floor plans

i. Mass Model Producing

ii. Preparing Mass Model Making Layout

iii. Run Form Generation Program

- Step 5: Mass Model Layout for Laser Cutting

f) Part 6 involves evaluating the building

i. Evaluations (Using all output 3D models, data, and mass model)

ii. Evaluating Generated Alternatives

Geometry plays a critical role in the generation of building form and structure. Geometry in the schematic design helps to explore design ideas. Potential geometries and new concepts of vertical transformation help create an overall spatial form using non-conventional concepts. Each geometric shape has its own architectural and structural characteristics. Tall building forms can be designed based on a variety of geometric shapes. The geometries for tall buildings discussed here are focused on symmetry = simple polygons and generated polygons. This process presents the development of a series of starting and ending floor plate shapes for a set of floors using simple polygons and generated polygons.

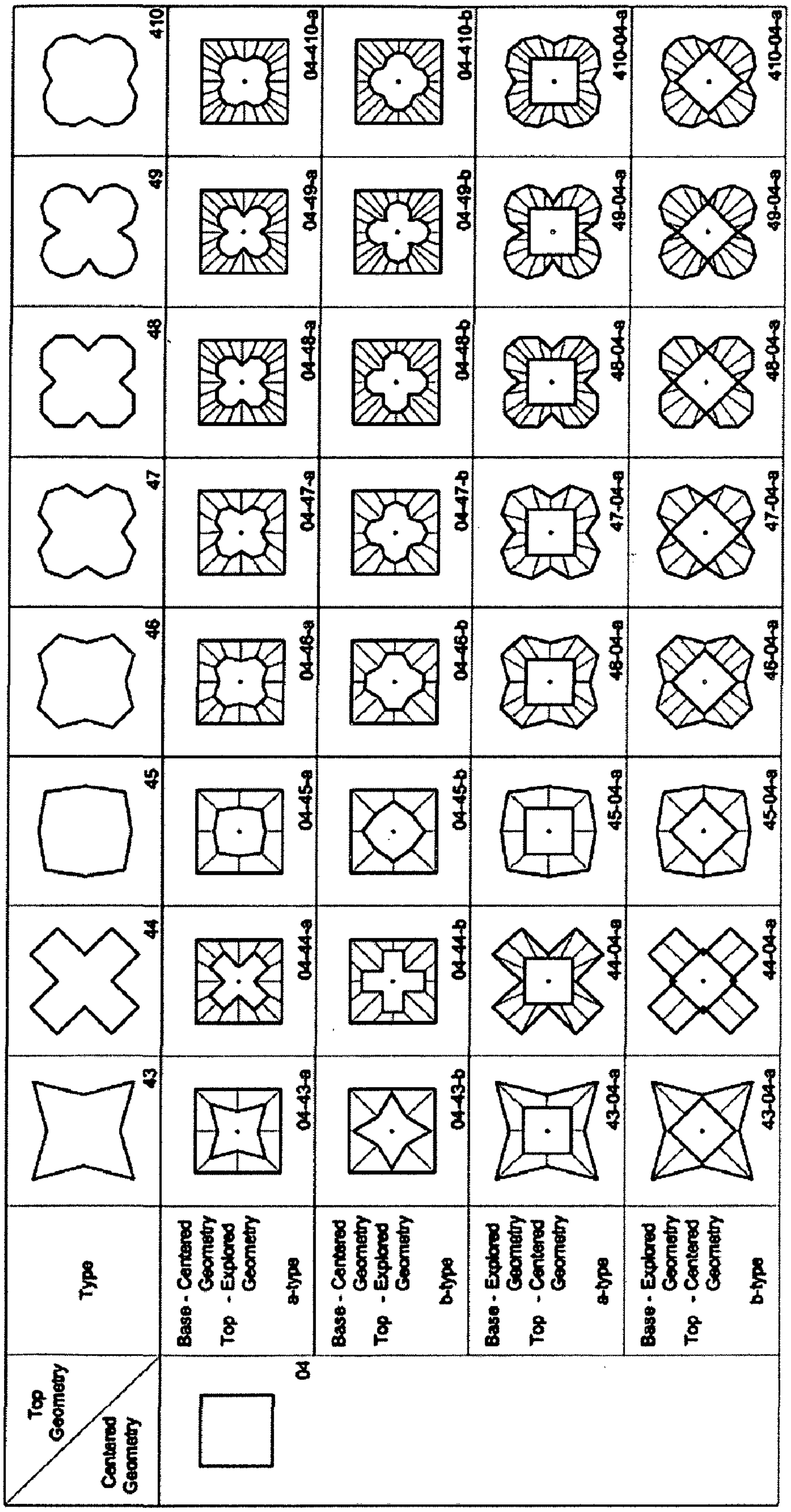


Figure 3.2: Square Centered Simple Polygons and Generated Polygon's Combinations (Park, S.M, 2004, Tall Building Form Generation by Parametric Design Process)

With the same architectural parameters, different combinations of base and top geometries and transformation, such as, morph, setback, twist, and curvilinear forms are generated through Step 1 to Step 3 of form generation process. The outcomes of this process are 3D surface models and summarized building data.

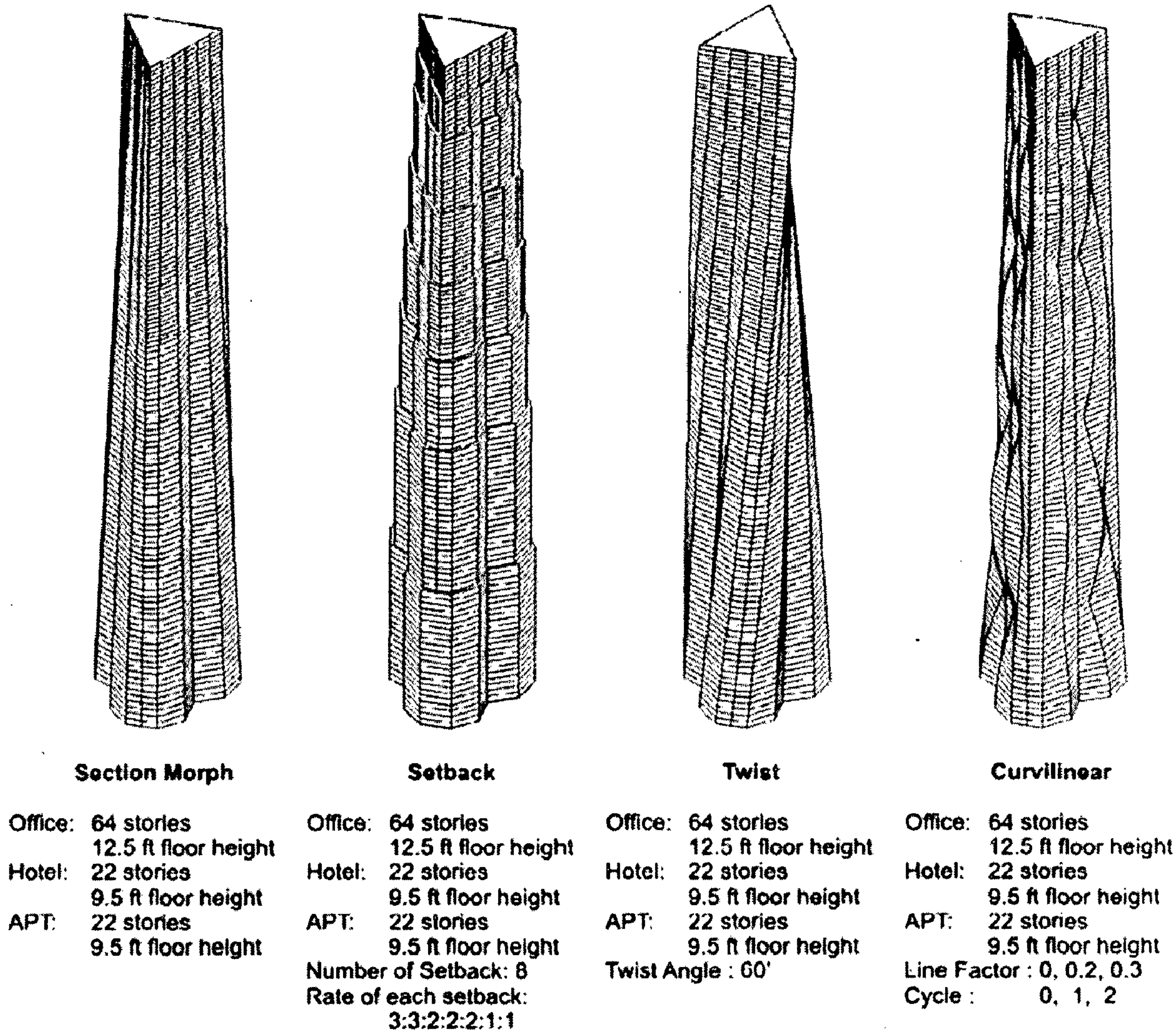


Figure 3.3: Examples of generated forms (source: Park, S.M, 2004, Tall Building Form Generation by Parametric Design Process)

In the conceptual design phase, creativity and exploration are very important. With appropriate input parameters, the form generation program is executed. In this process, forms can be generated with any combinations of the explored geometry and the defined vertical transformation (Figure 3.2). The form generation program consists of four groups, which are section morph, setback, twist, and curvilinear group. Each group has different architectural and structural characteristics and different parameters to create a form. Figure 3.3 shows four example forms with different vertical transformations of same combinations of base and top geometries. After the combination of base and top geometries from the geometry table is selected, each geometry's area and dimension are set based on the area calculation of the floor plate and core area. Examples were generated with 2,000,000 sq ft office, 400 units hotel, and 400 units apartments.

Creative building form has become one of the most important design requirements in high rise building development due to its symbolic value. The approach to designing evolutionary high rise buildings is an open subject of professional debate, and the role of the architect in designing them is very important, particularly from the point of view of form generation. In the future, in architectural design practice, advanced computer aided design technology can be used as an architectural tool to produce, not only the better performance design, but also creative and innovative concepts in tall building development.

In the conceptual design process, architects not only can sketch their design concept, but also establish the real space problem and objective using digital tools. By integrating digital tools based on design criteria and requirements with new concepts of high rise building form, rational potential forms can be generated. Development of such a method enables the designer to uniquely apply his design concepts easily and evaluate a variety of alternatives. The improvement of design quality and design process, using advance technology, is more practical and challenging for professional development.

3.3 ECOLOGICAL DESIGN METHODOLOGY

3.3.1 DESIGN PROCESS FOLLOWED BY KEN YEANG

Regarded by his peers as a man ahead of his time, Ken Yeang recognized 40 years ago that global warming and increased contamination of the environment would adversely affect the natural balance of biodiversity and ecosystems. Applying the ecology based approach to master planning of one of his mentors, Ian McHarg, Yeang has successfully applied those principles to architecture.

Yeang uses his concepts of ecodesign in all of his architectural projects. Through constant experimentation over many decades Yeang developed a solid reputation as a pioneer, advocate, and innovator of authentic bioclimatic ecological design. By the mid 1990's private and public clients around the world have selected him for their ecomasterplans and architectural ecodesigned projects.

Based on the principles of ecomimicry (a term he invented), all of Yeang's architectural ecodesigns and masterplans achieve a connectivity and benign biointegration between the human built environment and the surrounding ecosystems.

Ken Yeang looks at the world as a collection of ecosystems namely:

a) Grey: Engineering infrastructure - Renewable energy systems, eco technology, clean tech, Carbon neutral systems etc.
b) Blue: Water infrastructure - Sustainable drainage, closing the loop, Rainwater harvesting, etc.
c) Red: Human infrastructure - Enclosures, hardscapes, Use of materials, products and lifestyle & regulatory systems
d) Green: Green infrastructure - Natures utilities, Biodiversity balancing, Ecological connectivity, etc.

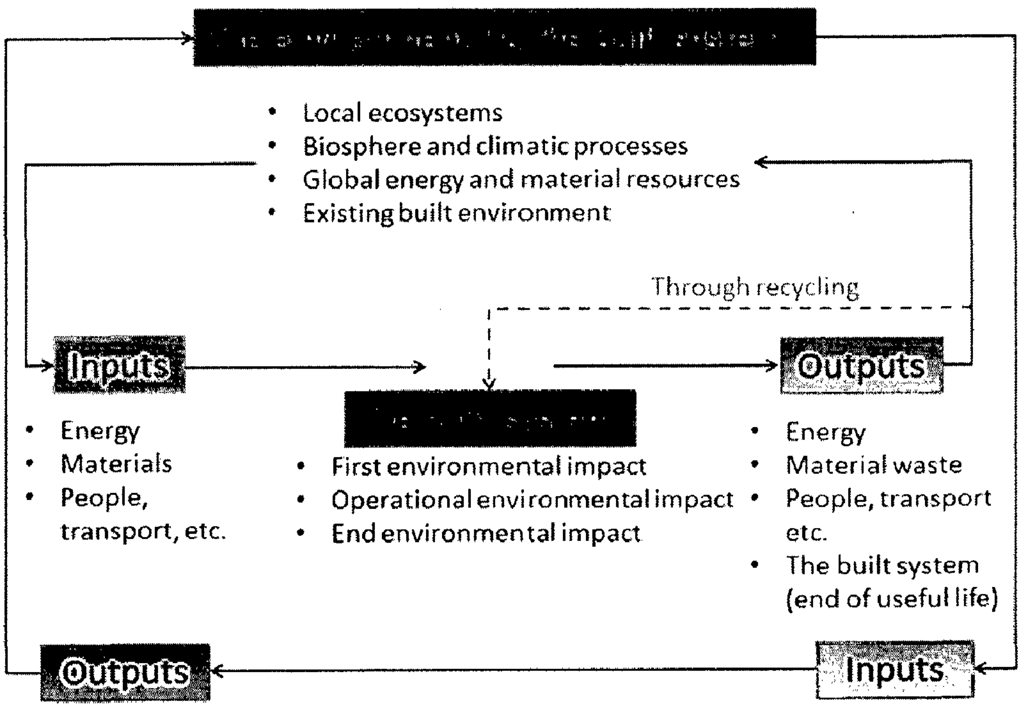


Figure 3.4: Reuse , Recycle, Reintegrate Cycle (Source: http://www.trhamzahyeang.com/)

Ken Yeang believes that ecodesign is not just about making new environments that are ecofriendly, but to undertake green design as a step towards repairing ecosystems and making devastated ecosystems whole.

A simple step towards this process would be to integrate the process or reuse, recycle and reintegrate into every process of designing. The figure shows all the inputs that go into the process of building design and how they were all part of the environment at some part of time, and also, how these components could be integrated back into the ecosystem through the process of recycling and reintegration.

Ecodesign according to Ken Yeang, should be a process of biointegration. For instance, one could take the example of prosthetics, these are mechanical parts manufactured with such finesse that they are naturally accepted by the human body. Thus building design too must be done with the same thought in mind, the buildings being the prosthetics and the earth/ecosystem being the body where the prosthetics must fit in. Biointegration occurs in three stages:

a) **Physical**: Existent features and ecology of the environment
b) **Systemic**: Ecosystemic and biospheric processes
c) **Temporal**: Conservation of resources

3.3.2 DESIGN PROCESS

The design of any building must always begin with a study of the site. Architect Ken Yeang begins all of his designs with a detailed study of the site and all the ecosystems thriving in it, and then classifying it based on the maturity of the ecosystem as follows:

Table 3.1 Taxonomy of Sites (Source: http://www.trhamzahyeang.com/)

Taxonomy of Sites	
Ecologically mature	Pristine ecosystem
Ecologically immature	Partially affected
Mixed artificial	Landscape park
Mono culture	Agricultural land
Zero culture	Urban locality
Contaminated	Brownfield site

Later, based on the type of ecosystem, the approach towards design is decided. After working in this field for a long time, Ken Yeang has developed different strategies for different kinds of sites depending on the hierarchy of the ecosystem maturity.

Table 3.2: Design Strategies based on the Hierarchy of the Ecosystem (Source http://www.trhamzahyeang.com/)

Ecosystem Hierarchy	**Site data Requirements**	**Design Strategy**
Ecologically-Mature	Complete Ecosystem Analysis and Mapping	Preserve Conserve Develop only on no-impact areas
Ecologically-Immature	Complete Ecosystem Analysis and Mapping	Preserve Conserve Develop only on least-impact areas
Ecologically-Simplified	Complete Ecosystem Analysis and Mapping	Preserve Conserve Increase biodiversity Develop only on low-impact areas
Mixed-Artificial	Partial Ecosystem Analysis and Mapping	Increase biodiversity Develop on low-impact areas
Monoculture	Partial Ecosystem Analysis and Mapping	Increase biodiversity Develop in areas of non-productive potential Rehabilitate ecosystem
Zeroculture	Mapping of remaining ecosystem components (e.g. hydrology, remaining trees, etc.)	Increase biodiversity and organic mass Rehabilitate ecosystem

After this comes the design stage. Here too, there are different modes of design that could be followed such as the active mode, passive mode or a mixed mode. Modes of design usually refer to the amount of mechanical and electrical systems that one is going to use in the design process of a given building.

Table 3.3: Different Modes of Design (Source http://www.trhamzahyeang.com/)

Modes	Internal systems	Examples
Passive mode	No M&E systems	Native dwellings
Mixed mode	Partial M&E systems	Double skin facades
Full mode	Full M&E systems	Conventional buildings
Productive mode	Productive M&E systems	Photovoltaics
Composite mode	Composite M&E systems	Composite of the above

Any building design must first optimize all the passive modes of bioclimatic design options before adopting other modes. This ensures that the building remains comfortable and inhabitable even if the other systems fail.

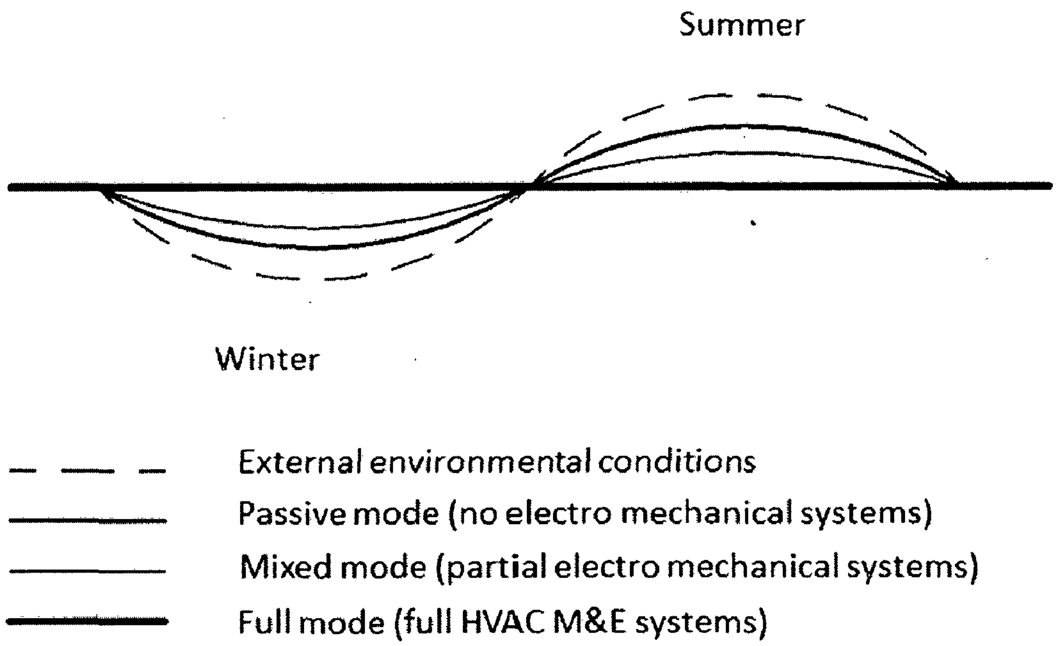


Figure 3.5: Seasonal Change in temperature variation in buildings depending on the weather (Source http://www.trhamzahyeang.com/)

building comfortable at all times whereas the temperature varies inside a building in summers and winters considerably in case of the other modes. So, the talks about sustainability, saving the environment; having a green future all make no sense if one keeps following the present trends of designing building to maintain the same internal temperature throughout the year.

Sustainability is rather a way of life, an attitude that must blossom in everyone in order to save the planet. One must not feel bad about feeling a little hot in summers and wearing more layers of clothes in winter thus making a difference. Passive modes of design too keep the building comfortable and in extremes of temperature a mixed mode could be adapted.

3.3.2 EXAMPLE OF ECOLOGOCAL DESIGN, EDITT TOWER

3.3.2.1 INTRODUCTION

Currently pending construction in Singapore, the EDITT Tower will be a paragon of "Ecological Design In The Tropics". Designed by TR Hamzah & Yeang and sponsored by the National University of Singapore, the 26-story high-rise contains photovoltaic panels, natural ventilation, and a biogas generation plant all wrapped within an insulating living wall that covers half of its surface area. The skyscraper was designed to increase its location's bio-diversity and rehabilitate the local ecosystem in Singapore's 'zeroculture' metropolis.

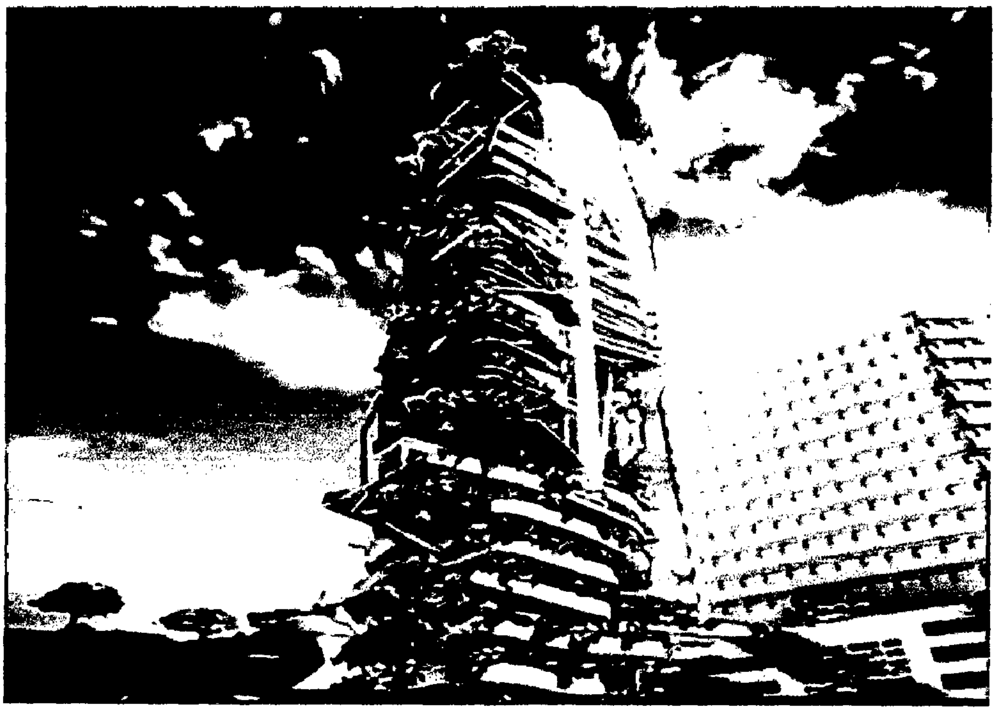


Figure 3.6: Editt Tower (Source: http://www.trhamzahyeang.com/)

The project design integrates green space to human-use area in the ratio of 1:2. A particularly important point in the design of the organic components is the survey of plant life in the neighborhood of the building to ensure that the plants incorporated in the building project do not compete with indigenous species. The organic spaces are intended also to ramp up from the street level to the top of the building, effectively integrating the sky-scraper's 26 stories into the surface landscape. This extension of the horizontal plane into the vertical space is further promoted by drawing the street-level shops and pedestrian activities up to the sixth floor along the system of landscaped ramps.

3.3.2.2 DESIGN PROCESS

The design sets out to demonstrate an ecological approach to tower design. Besides meeting the Client's program requirements for an exposition tower (i.e. for retail, exhibition spaces, auditorium uses, etc.), the design concept brings together a range of issues that demonstrates the expanding domain of the architect for the new century – urban context, vertical placemaking, high level linkages, ecological response to site, orientation, sun control, vertical landscaping, wind effects, deconstruction and recyclability, waste recycling, water collection and re-use, on-site energy production, embodied energy, energy in use, hybrid mixed mode services, and more.

3.3.2.2.1 Response to the site's Ecology

Ecological design starts with looking at the site's ecosystem and its properties. Any design that does not take these aspects of the site into consideration is essentially not an ecological approach.

According to the architects design process, after a broad analysis of the site context, views, microclimate and non-existent flora and fauna the site was described as a 'zeroculture', which was at the bottom of Yeang's hierarchy of ecosystems. A worthy evaluation of the vegetation patterns within a 1.5 km radius of the site was used to create a program of planting on the project that was integrated with the site and structure in a vertical landscaping scheme of planted terraces and facades, using species selected to be compatible with indigenous species of the locality.

3.3.2.2.2 Place Making

A crucial urban design issue in skyscraper design is poor spatial continuity between street-level activities with those spaces at the upper-floors of the city's high-rise towers. This is due to the physical compartmentation of floors.The design creates 'vertical places', using a ramp system that allows pedestrian movement vertically through the tower along a vertical 'street' lined with exhibition and performance spaces, cafés, shops and offices with occasional sitting and gathering areas. There are bridge links to adjoining buildings that reinforce the lower levels as public territory and planted terraces and sky-gardens continue up the full height of the building.

3.3.2.2.3 Wind studies

A wind study of the proposed tower elaborates early Yeang studies of the impact of 'wind wing walls' in domestic buildings using a radical (and far-fetched) concept of inflatable air bags as wind fins strategically positioned on the outside of the tower to create vortices that improve the natural ventilation and that modify wind loads on the building, resulting perhaps in a lightening of the vertical structure. At a more mundane level, these studies also demonstrate the natural ventilation of toilet pods hung on the side of the structure.

3.3.2.2.4 Vertical Landscaping

Vegetation from the street-level spirals upwards as a continuous ecosystem facilitating species migration; engendering a more diverse ecosystem, greater ecosystem stability and facilitating ambient cooling of the facades. As mentioned earlier, species are selected not to compete with others within surroundings. "Vegetation percentages" represent of area's landscape character.

Factors influencing planting selection are:

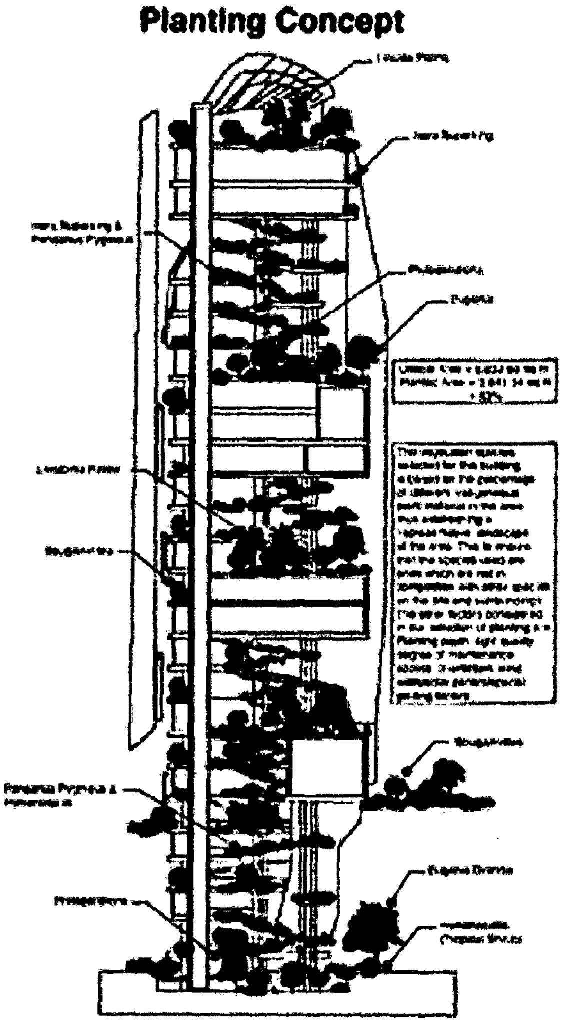
a) Planting depths
b) Light quality
c) Maintenance level
d) Access
e) Orientation
f) Wind-walls / solar panels / special glazing

Vegetation placements within the tower at different heights respond to the microclimates of each individual subzone of the tower.

3.3.2.2.5 Water purification

Rainwater-collection system comprises of 'roof-catchment-pan' and layers of 'scallops' located at the building's facade to catch rain-water running off its sides. Water flows through gravity-fed water-purification system, using soil-bed filters.

The filtered-water accumulates in a basement storage-tank, and is pumped to the upper-level storage-tank for reuse (e.g. for plant-irrigation and toilet-flushing): Mains water is only meant for potable needs.



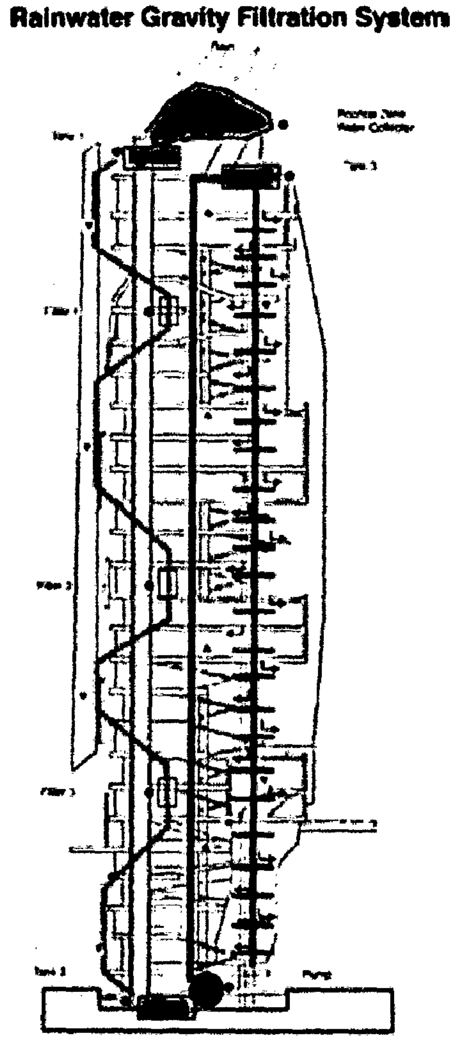


Figure 3.7: The reintroduction of organic mass to an urban site rainwater purification system

3.3.2.2.6 Water recycling

Water self-sufficiency (by rainwater-collection and grey-water reuse) in the tower is at 55.1%:

Table 3.4: Water Recycling Calculations (Source: http://www.trhamzahyeang.com/)

	Total gross area	= 6,032 sq.m.
	Water requirements	= 20 gallons/day/10 sq.m. gross area + 10% wastage
	Total requirements	= (6,032 ÷ 10 x 110%) x 20 gallons = 13,270 per gallon/day = 60.3 m3 per day x 365 days = **22,019 m3 annum**
	Total rain-fall catchment area	= 518 sq.m.
	Singapore average rainfall / annum	= 23.439m
	Total rain-water collection	= 12,141 m3 per annum
	Water self sufficiency	= 12,141 ÷ 22,019 x 100 = 55.1%

3.3.2.2.7 Sewage recycling

The design optimises recovery and recycling of sewage waste:

Table 3.5: Sewage Recycling Calculations (Source http://www.trhamzahyeang.com/)

	Estimated sludge	= 230/P.E. / day @ 3. P.E. per 100 m2 GFA
	Building GFA	= 6,032 sq.m.
	Sewage sludge collected/day	= 230 litres x 6,032 ÷ 100 x 3 = 41,620.8 litres or 41.62 m3/day = **15,190 m3/ annum**

3.3.2.2.8 Solar energy use

Photovoltaics are used for greater energy self-sufficiency.

Table 3.6: Solar Energy Calculations (Source : http://www.trhamzahyeang.com/)

	Average photovoltaic-cell energy output	= c. 0.17 kWh sq.m.
	Total sunlight hours per day	= 12 hours
	Daily energy output	= 0.17 x 12 = 2.04 kWh sq.m.
	Area of photovoltaic	= 855.25 sq.m.
	Total daily energy output	= **1,744 kWh**
	Estimated energy consumption @ 0.097 kWh /sq.m. enclosed	& 0.038 kWh/sq.m. unenclosed = (0.097 x 3,567 sq.m.) + (0.038 x 2,465 sq.m.) = 439.7 kWh
	Estimated daily energy consumption	= 10 hrs x 439.7 = 4,397 kWh
	% self sufficiency is 1,744 ÷ 4,397	= 39.7%

3.3.2.2.9 Building material recycling and reuse

Design has an in-built waste-management system. Recyclable materials are separated at source by hoppers at every floor. These drop-down to the basement waste-separators, then taken elsewhere by recycling garbage collection for recycling.

The expected recyclable waste collected/annum:

a) Paper / cardboard : 41.5 metric tonnes
b) Glass / ceramic : 7.0 metric tonnes
c) Metal : 10.4 metric tonnes

The building is designed to have mechanically-joined connections of materials and its structural connections to facilitate future reuse and recycling at the end of building's useful-life.

3.3.2.3 SUMMARY OF THE CASE STUDY OF EDITT TOWER

The main tenet of 'green' architecture is that it must deliver energy and resource efficiency and environmental comfort – it is not a style. The EDITT Tower is a concept project that one hopes will see realisation as a paradigm for integrated 'bioclimatic' building design. The formal and stylistic qualities of the design are seductive, but the technical detail appears to need more careful consideration and refinement. The building has a very high embodied energy (and is probably very expensive) but it does not yet appear to demonstrate commensurate utilisation energy savings and associated thermal comfort.

3.3.3 EXAMPLE OF ECOLOGOCAL DESIGN, MENARA MESINIAGA

3.3.3.1 INTRODUCTION

The Menara Mesiniaga is the headquarters for IBM in Subang Jaya near Kuala Lumpur. It was first conceived of in 1989 and finally completed in 1992. IBM asked the office of T.R. Hamzah & Yeang for a building which was a high-tech corporate showcase for their highly visible site and high-technology industry. Also, Ken Yeang designed this building as an example of his bioclimatic skyscraper practices and principles.

a) Control of fresh air and air movement
b) Access to operable windows
c) Potential for natural ventilation
d) A good view
e) Access to green space
f) Access to transitorial spaces
g) Receiving natural sunlight
h) Control of lighting levels
i) Greater comfort in furnishings
j) Ability to move furniture
k) Provision of exterior and interior areas for relaxing
l) Spaciousness
m) Adjustable temperatures
n) Less noise and distraction
o) Bio climatic functioning of the building
p) Interaction with nature, sunlight and shadow

3.3.3.4 SITE AND CLIMATE

Climatically Malaysia is a hot and humid country; Kaula Lampur is about 3 degrees North of the equator. The country has no distinct summer or winter, temperatures are more or less consistently between 20°C and 40°C and humidity is between 60 and 70%. The site for Menara Mesiniaga is located on a major highway from the airport to Kuala Lumpur. It is in a highly visible location with few buildings within the surrounding context. (Figure 14)

Figure 15 and 16 describe the process by which the sun shading devices on the façade of the building were designed.

Figure 3.8: Menara Mesiniaga (Source http://www.trhamzahyeang.com/)

The building is an environmental filter, an analogy for synthesis and analysis. The Menara Mesiniaga is a built work that utilizes a basis of traditional Malaysian building models and their transition or evolution into modern principles. It is Yeang's vision of the tropical garden city and it uncovers "the relationship of buildings, landscape and climate . . ." transforming the impact of high-rise development in the ecosystem of a city.

3.3.3.2 FUNCTION AND USE

The building is equipped with 6- classrooms, a demo centre, a 130-seat auditorium, lounge, cafeteria, and prayer rooms. The building boasts an excellent audiovisual system, complete lighting equipment, administrative and catering services and a large entry foyer for product display and demonstration. It is wired for communications within itself and with its technology partners.

The company wanted to own the building; because renting would have been expensive in the city centre. They were expanding and needed a company identity. They decided to construct a building not only to express the quality of IBM products, but as a symbol of their corporate offices.

3.3.3.3 GENERAL OBJECTIVES

The client needed more space for their headquarters. But more importantly, the client wanted a showcase building to contribute to their marketing efforts and to represent projected success.

The architect's objectives, in the design of this project were:

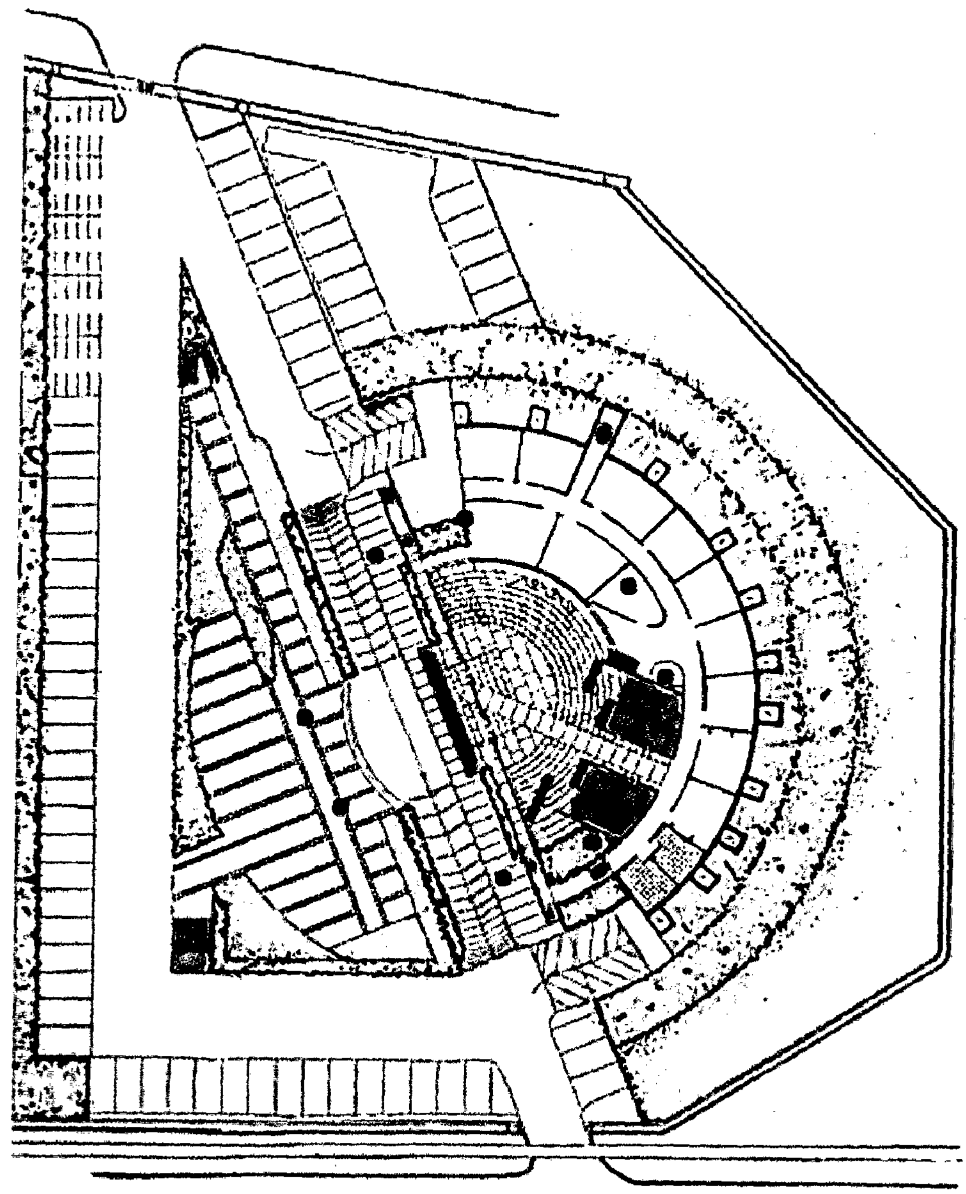
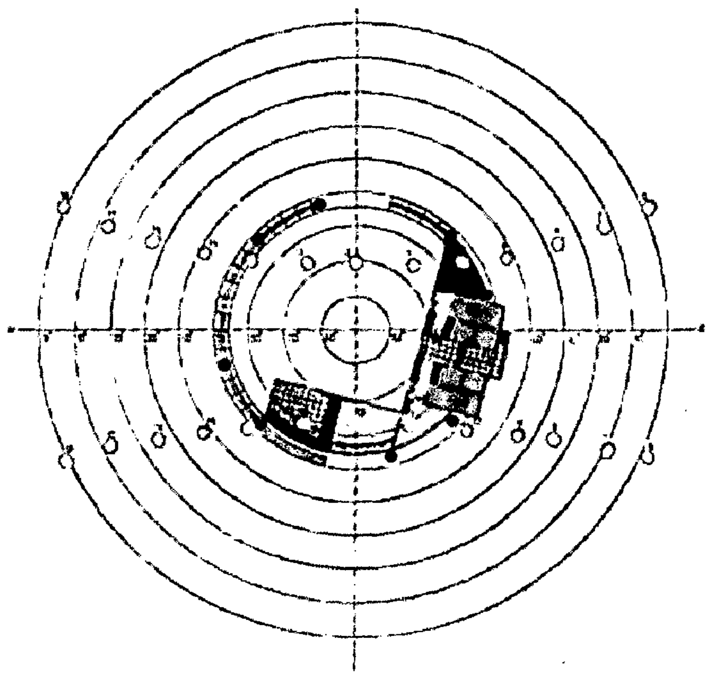


Figure 3.9: Site Plan (Source: Walkzack, E.L, 2004, Architecture 489)



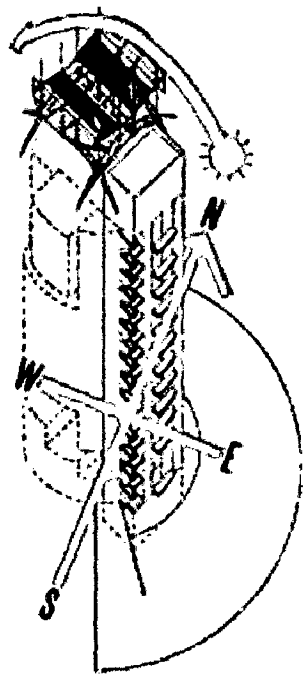


Figure 3.10: Sun shading(Source: Walkzack, E.L, 2004, Architecture 489)

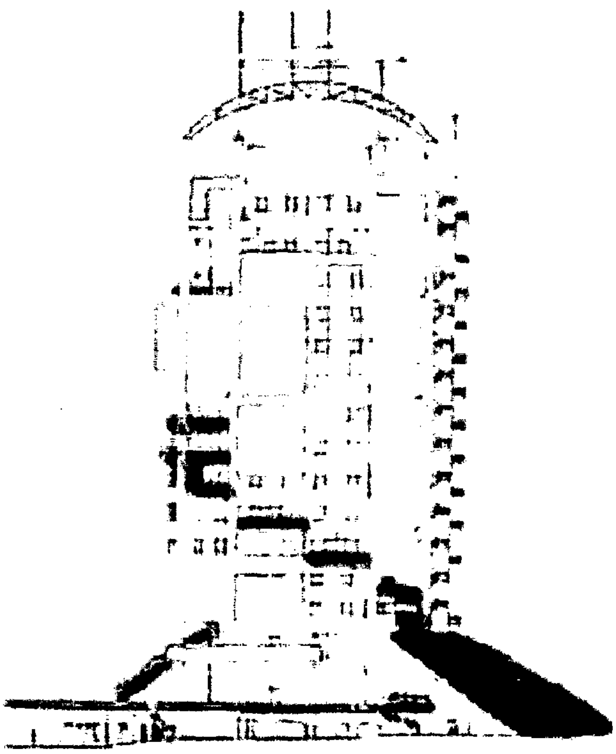


Figure 3.11 Sunshading (Yellow) / Green Areas (Green)
(Source: Walkzack, E.L, 2004, Architecture 489)

3.3.3.5 DESIGN PROCESS

The noticeable building features of the IBM tower not only visually define the high-tech style of the company and its conceptual organic disposition, but also define it as a bioclimatic high-rise.

a) First, the building's general form, structural strategy, component cores, glazed surfaces, is oriented for maximum environmental efficiency shading against direct overheating but allowing for natural daylight.
b) Second, where the main components of the building and its orientation cannot shade the building, ingeniously calculated shading devices are installed on the building face for passive cooling.
c) Finally, the extension of the land that begins at the sloped berm spirals up the height of the building with planted terraces that culminates at the inhabited rooftop. These terraces not only provide for vertical gardens and transitional spaces, but also shades and ventilates the building.

These major innovations in form, envelope and regional adaptations to the typical skyscraper indicated that Yeang's work was at the leading edge of the then contemporary architecture at the time ecological design was at its organizational infancy.

The main ideas and concepts for the Menara Mesiniaga were;

a) Sky gardens that serve as villages
b) Spiralling vertical landscape
c) Recessed and shaded windows on the East and West
d) Curtain wall glazing on the North and South
e) Single core service on hot side - East
f) Naturally ventilated and sunlit toilets, stair ways and lift lobbies
g) Spiral balconies on the exterior walls with full height sliding doors to interior offices

The building is 15 stories tall and circular in plan. Yeang designed this building to include three items: 1- a sloping landscape base to connect the land with the verticality of the building; 2- a circular spiralling body with landscaped sky courts that allow visual relief for office workers as well as providing continuity of spaces connecting the land through the building; and 3- the upper floor provides a swimming pool and gym.

The facade is a "sieve-like" filter (instead of a "sealed skin"). The louvers and shades relate to the orientation of the building. They allow or reduce solar gain. The deep garden insets allow full height curtain walls on the north and south sides- as a response to the tropical overhead sun path. The core functions are located on the "hot" side, the east.

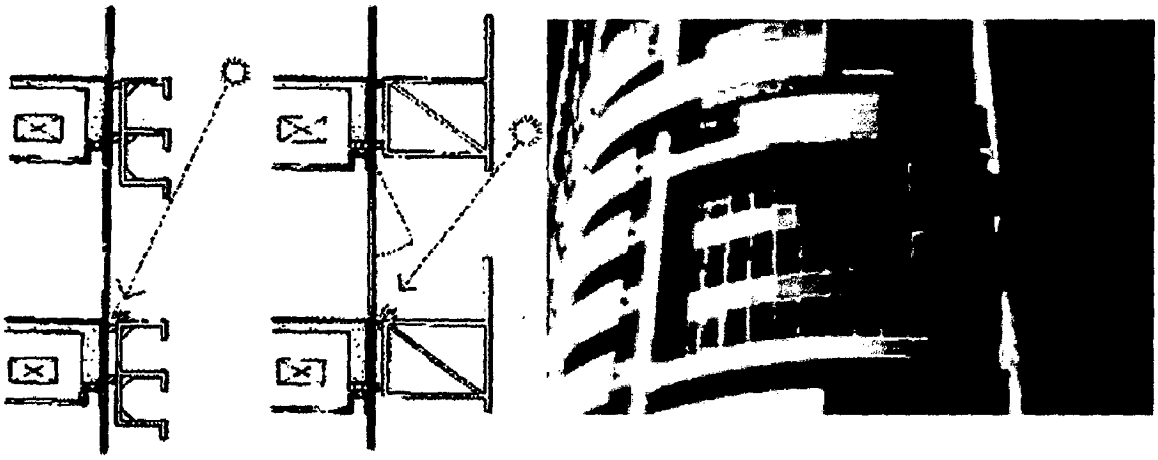


Figure 3.11: Sunshaders and garden spaces (Source: Walkzack, E.L, 2004, Architecture 489)

The main idea behind the design was to create:

a) An urban environment integrated with and by its landscape
b) An aesthetic model - the image of luxuriant tropical urban garden
c) An open way of life - community – all made possible by the tropical climate

Yeang wanted to overcome the typical high-rise heat-island effect by creating positive design responses to wind and shade as well as introducing vertical landscaping, the use of heat-sink cladding and the reduction of air conditioning use. Yeang considers passive low-energy efficiency, an improved social environment, and the use of abundant ambient energy essential to design. Yeang's design principles involve "holistic considersation, of the sustainable use of energy and materials over the lifecycle of a building "system", from source of materials to their inevitable disposal and/ or subsequent recycling." (*Rethinking* 72)

Additionally, Yeang incorporates transitional spaces from exteriors to interiors, the principles of identity and regionalism (building in context of its place-reflecting the cultural and climatic influences) and extensions of the land and garden.

3.3.4 DESIGN PROCESS FOLLOWED BY AR. KARAN GROVER

3.3.4.1 INTRODUCTION

Ar. Karan Grover is one of the most well-known and appreciated Architects in the Green Building Community. Karan Grover and Associates has emerged into a multi-disciplinary organization with an in-house engineering team which an integral part of the architectural design activity. His design the CII Godrej building was one of the first buildings to receive a LEED Platinum rating.

3.3.4.2 PHILOSOPHY

Based on the talks, open ended interviews and discussions it has been found that some of the values that KGA believes are to create 'Contemporary' Indian architectural ideologies drawing essences from Tradition and Culture. 'Traditionalism' is explored as an attempt to reinstate and reinterpret some of the fundamental forms that have shaped our architecture over centuries – and opposing the idea of cosmetic duplication of historic forms and elements. The work focuses only on using the ideas behind these traditions in today's times.

Grover's architecture reflects his concerns with the heritage and built landscape of India. He believes that India needs something more than merely adopting the western norms of architecture. The long architectural history of this country and development of its style to cater to climatic needs provided the framework for this ideology.

Grover became the first architect in the world to win the Platinum Award for Leadership in Energy and Environmental Design (LEED) from the US Building Council in 2002. The award was for the CII-Sohrabji Godrej Green Business Centre at Hyderabad, a collaborative project between US AID, Government of Andhra Pradesh and CII.

Karan Grover, the architect, is today working towards the need for practicing 'Green' architecture inspiring students and fellow architects. A need based on ecological and environmental concerns; a need which involves us all as inhabitants of this planet.

3.3.5 EXAMPLE OF ECOLOGICAL DESIGN, CII GODREJ BUILDING

3.3.5.1 INTRODUCTION

One of the greenest buildings in the world. CII - Sohrabji Godrej Green Business Centre (CII Godrej GBC), cosily nestled close to Shilparamam in Hyderabad, the city of architecture & pearls, is the first LEED Platinum rated green building in India. The building is a perfect blend of India's rich architectural splendour and technological innovations, incorporating traditional concepts into modern and contemporary architecture.

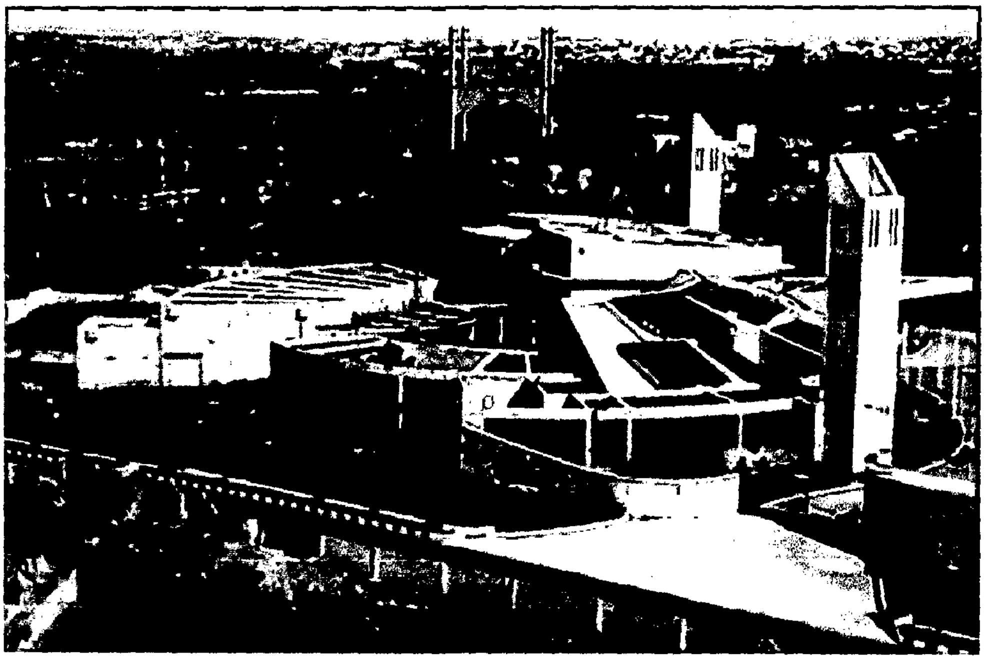


Figure 3.13: CII Godrej Building, Karan Grover (Source: Asia Business Council, 2006)

Extensive energy simulation exercises were undertaken to orient the building in such a way that minimizes the heat ingress while allowing natural daylight to penetrate abundantly. The building incorporates several world-class energy and environment friendly features, including solar PV systems, indoor air quality monitoring, a high efficiency HVAC system, a passive cooling system using wind towers, high performance glass, aesthetic roof gardens, rain water harvesting, root zone treatment system, etc. The extensive landscape is also home to varieties of trees, most of which are native and adaptive to local climatic conditions.

The green building boasts a 50% saving in overall energy consumption, 35 % reduction in potable water consumption and usage of 80% of recycled / recyclable material. Most importantly, the building has enabled the widespread green building movement in India.

3.3.5.2 ENERGY EFFICIENCY

Figure 3.14: Use of Natural Ventilation and Lighting(Source: Asia Business Council, 2006)

State-of-the- art Building Management Systems (BMS) were installed for real time monitoring of energy consumption. The use of aerated concrete blocks for facades reduces the load on air-conditioning by 15-20%. Double-glazed units with argon gas filling between the glass panes enhance the thermal properties.

3.3.5.3 ZERO WATER DISCHARGE BUILDING

All of the wastewater, including grey and black water, generated in the building is treated biologically through a process called the Root Zone Treatment System. The outlet-treated water meets the Central Pollution Control Board (CPCB) norms. The treated water is used for landscaping.

3.3.5.4 MINIMUM DISTURBANCE TO THE SITE

The building design was conceived to have minimum disturbance to the surrounding ecological environment. The disturbance to the site was limited within 40 feet from the building footprint during the construction phase. This has preserved the majority of the existing flora and fauna and natural microbiological organism around the building. Extensive erosion and sedimentation control measures to prevent topsoil erosion have also been taken at the site during construction.

3.3.5.5 MATERIALS AND RESOURCES

80% of the materials used in the building are sourced within 500 km from the project site. Most of the construction material also uses post-consumer and industrial waste as a raw material during the manufacturing process. Fly-ash based bricks, glass, aluminium, and ceramic tiles, which contain consumer and industrial waste, are used in constructing the building to encourage the usage of recycled content.

Office furniture is made of bagasse based composite wood. More than 50% of the construction waste is recycled within the building or sent to other sites and diverted from landfills.

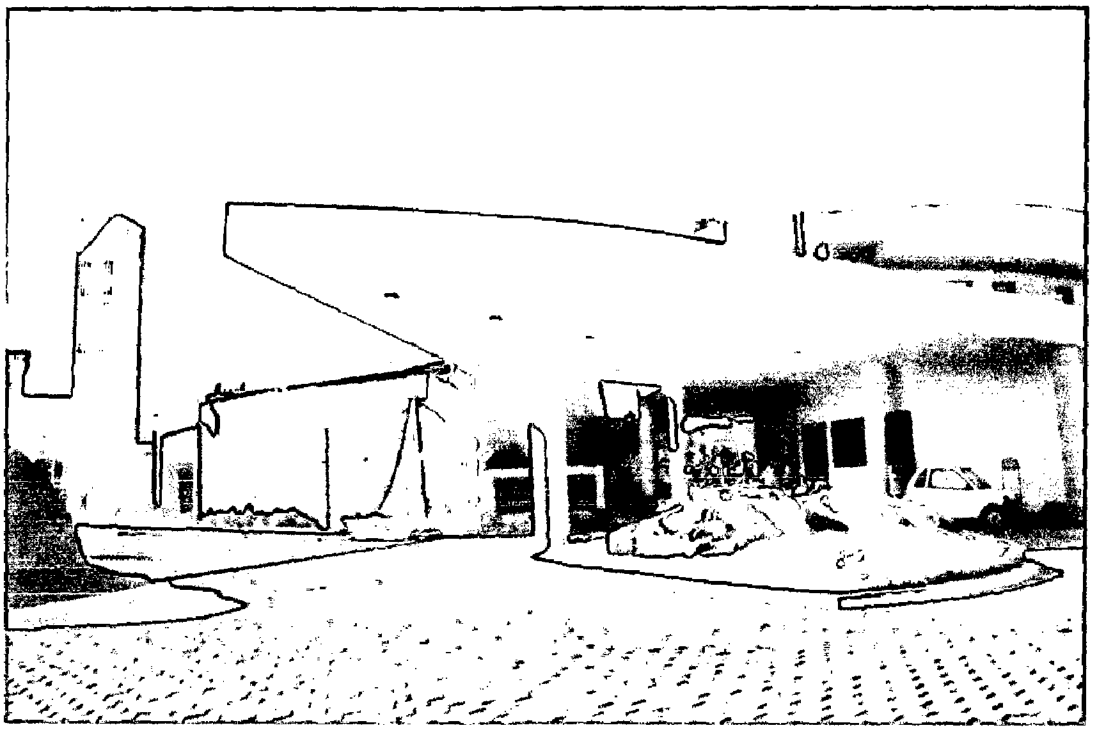


Figure 3.15: Use of porous paving in the parking(Source: Asia Business Council, 2006)

3.3.5.6 RENEWABLE ENERGY

20% of the building energy requirements are catered to by solar photovoltaics. The solar PV has an installed capacity of 23.5 kW.

3.3.5.7 INDOOR AIR QUALITY

Figure 3.16: Making nature a part of the building(Source: Asia Business Council, 2006)

Indoor air quality is continuously monitored and a minimum fresh air is pumped into the conditioned spaces at all times. Fresh air is also drawn into the building through wind towers. The use of low volatile organic compound (VOC) paints and coatings, adhesives, sealants, and carpets also helps to improve indoor air quality.

3.3.6 DESIGN PROCESS FOLLOWED BY SALIENT PVT. LTD.

Ar. Vivek Rathore is the principle architect at Salient Pvt. Ltd., an architectural firm of Kolkata, which has a few sustainable high rise buildings to its name. He has played a major role in the Ambuja Realty Group since its inception. He has been responsible for the Company's design, development and planning, contributed towards urban and physical development design elements of multi-disciplinary projects, is experienced in project development and management of various commercial and residential projects and has been involved in the design and development of infrastructure development projects.

His approach towards design is more of a holistic one. Holistic design is an approach to design which considers the system being designed as an interconnected whole which is also part of something larger. Holistic concepts can be applied to architecture as well as the design of mechanical devices, the layout of spaces, and so forth. This approach to design often incorporates concerns about the environment, with holistic designers considering how their design will impact the environment and attempting to reduce environmental impact in their designs.

Aesthetics is also an important consideration in holistic design. According to the architect designers may consider how the design will look as a whole, thinking about different ways in which people will view the design. For example, when designing a structure, the designer reflects on the environment the structure will be built in, thinking about how it will integrate into the existing environment, and also about how views of the structure may change depending on angle, time of day, and other factors. In addition, the designer considers how the space will feel from the inside, and what kind of messages should be sent with the space. The relationship between nature, culture and design can be depicted as shown below.

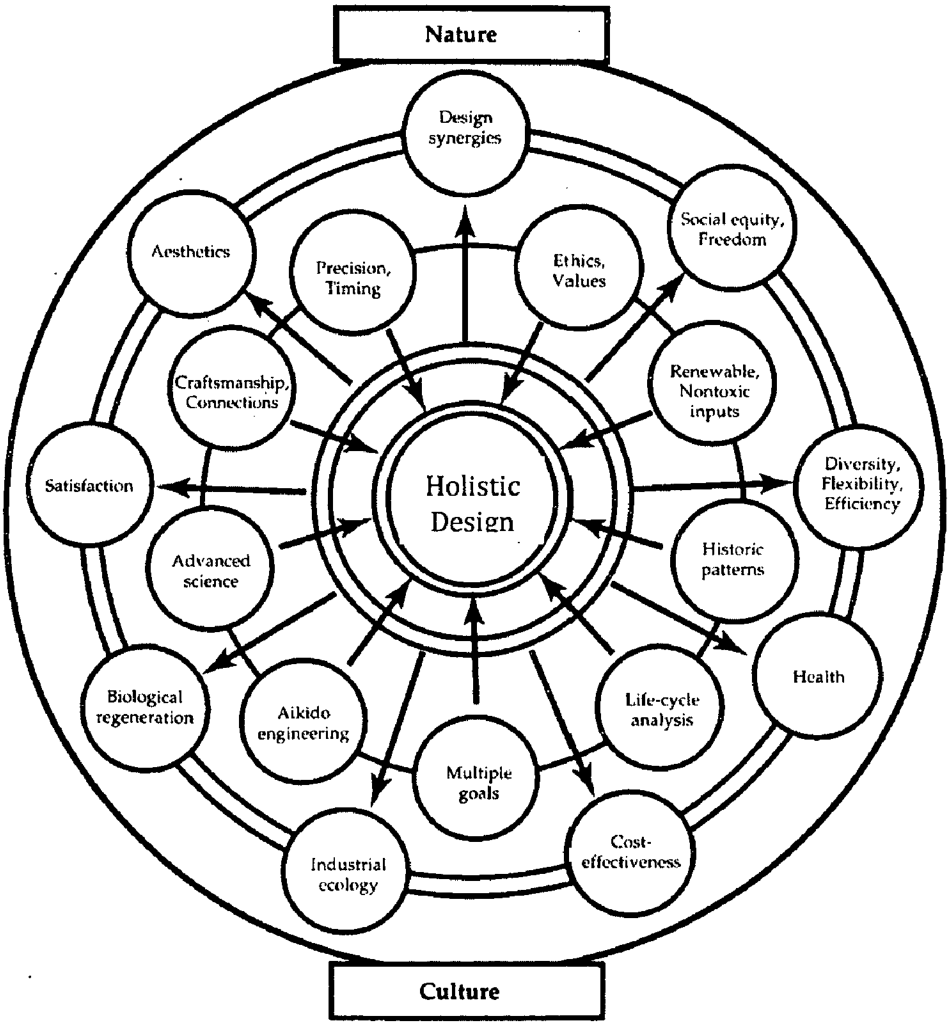


Figure 3.17: Interrelationship between Nature, Culture and Design (Source Wann, D, Deep Design)

Ar. Vivek Rathore believes in a layered approach towards the design where the entire project is looked at different layers, namely:

a) Site

   This phase includes the basic site, climate studies, and wind / sun path analysis. This gives the architect total information about the site and the project at hand.

b) Human

   The human layer is about providing comfort to human beings. Any building made must be of the liking of the users and they must be happy with it because it is something they are going inhabit for a long period of time

c) Modelling

   The next phase would be the conceptual modelling phase which involves the creation of 2D and 3D drawings of the proposed design for further work in other stages

d) Engineering

   The engineering stage involves the incorporation of building services into the design. This is a crucial phase and is the one that actually makes the building functional.

e) Energy

   Finally comes the energy stage where the building is analysed for its performance regarding energy usage and carbon returns etc. this is what integrated the building into the nature.

These five layers do not work independently of each other, as per the holistic approach followed; they must work in harmony in order to achieve the balance between nature, culture and design.

3.4 INFERENCES FROM CASE STUDIES

After studying the processes followed by eminent architects it is realized that design processes are basically of two categories, parametric design methods and ecological design methods.

Parametric design methods help us to create a large number of options without working too hard to achieve them, and then individual forms can be analysed to decide which one satisfies the requirements of the project better. These methods make the use of the latest technology and software, thus showing that technology and software have a large role to play in the process of high rise building design.

Ecological methods are being followed by many architects such as Ken Yeang, Karan Grover etc. After studying their design approach and process it is understood that even though all the architects practice in different parts of the world, their processes still are very similar to each other. Ecological design methods are the need of today as these methods aim at causing minimum damage to the environment and with the rate at which humans are depleting the resources and destroying the environment, these could be the only chance at saving the world.

CHAPTER 4: ANALYSIS OF CASE STUDIES

4.1 INTRODUCTION

In view of drastic changes in the approach towards designing buildings, particularly the complex and large scale ones, and keeping pace with the new innovations in software, building technology and contemporary practices, the design processes that were studied in the previous chapter have been analysed and the gist is explained in this chapter.

Architectural design process have evolved a long way from the conventional methods of just satisfying the requirements, aesthetics and structural elements of a design. Now design is more about building energy efficiency, carbon credits, waste management, ecological balance, environmental sustainability etc. It is these new processes that will take us to new heights of architectural design

4.2 PARAMETRIC DESIGN METHODOLOGY

The parametric process as discussed in the previous chapter is concerned with high rise building forms generated by digital tools based on the architectural and structural criteria. It explores potential generative forms, and also suggests an innovative design process using digital methods. This process helps one create a large number of alternatives in a short span of time, this is one process that reduce the time taken to design any project by a large percentage. The only drawback one sees here is that it is more of a form development process than actually a design process. It takes into consideration many design characteristics but in the end everything just revolves around the form itself.

Objectives of this process are:

a) Defining the relationships between design criteria and overall tall building form
b) Exploring the various geometries and transformations for tall building form
c) Suggesting an innovative digitally based design process for tall building design

d) Suggesting generative forms and concepts of tall building that meet the design criteria
e) Developing an architectural design methodology using digital tools

The methodology for parametric design has been explained in detail in the previous chapter. In accordance with that, there are six parts to the parametric design process. After the study, a few more factors can be identified in this process that are explained in the figure below. This shows the relation between the parameters, design tools and the process and how each of these could bring about changes in the building form if they were to be modified.

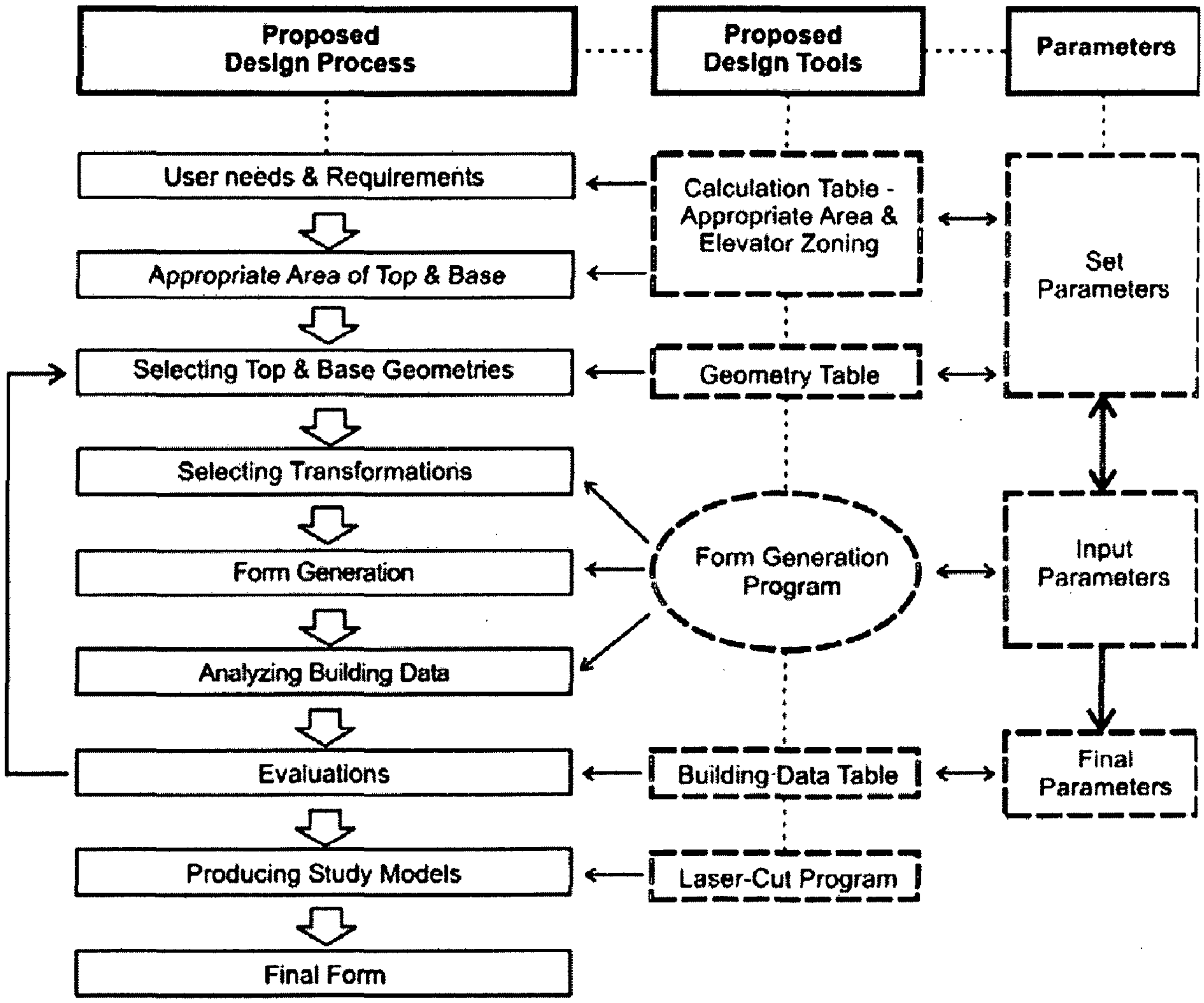


Figure 4.1: Parametric Design Methodology (Source Park, S.M, 2004, Innovative tall building form generation)

The parametric process explained above is an entire approach towards designing buildings. The following are the advantages of the parametric design methodology:

a) Easy generation of a large number of design options at the conceptual level.
b) Creation of interesting new forms of architecture
c) Simplification of the process of designing. Most of the work is done by computer algorithms after the architect works out the initial requirements.
d) Easy generation of floor plans through laser cutting of the generated model
e) Provision of geometrical flexibility
f) Supporting an iterative design refinement process

The parametric design process being completely dependent on computers and software has a few drawbacks as well:

a) Maximum emphasis is given to the form itself even after considering so many design characteristics
b) With the generation of so many design alternatives comes the need to analyse each of these and that makes it very tedious
c) Since many considerations are taken and only a few are used, the choice of rules used to construct the model will limit its usability
d) Certain design variations will be unfeasible
e) In certain cases the technology required to construct the forms generated may be difficult to construct
f) With the type of forms that evolve out of parametric design adding ecological solutions may be very difficult at a later stage

Parametric tools can enable architects to shift from creators of single designs to designers of systems of inputs and outputs that generate design spaces. Such tools provide a foundation to formalize design spaces in terms of explicit theme dependent rules and manage information in a unified environment. However, designers need to understand and reformulate the design process in these terms, which implies new ways of thinking and communicating about design.

4.3 ECOLOGICAL DESIGN METHODOLOGY

Ecological design methods followed by architects like Ken Yeang, Karan Grover and Vivek Rathore; help one understand the effects of architecture on the environment and how to reduce these. This process needs a lot of mind to be put into them and many aspects need to be keenly observed, studied, modified etc. Using this process of design increases the project cost by a large factor, around 40-60% but it is paid back in terms of energy savings and carbon credits in a few years.

4.3.1 KEN YEANG'S DESIGN METHODOLOGY

Yeang's interest in experimenting with ecologically and environmentally sound tall towers – the bioclimatic skyscraper – is to reduce the building costs by lowering its energy consumption and to develop benefits for the users by emphasizing ecological values, i.e., designing with the climate in mind. Yeang believes that a climatically responsive building is a successful building, and both client and users of his projects attest to the success of his approach. The design features of his towers are bold and are not intended to blend with the immediate physical environment, even though its climatic adaptability is a priority.

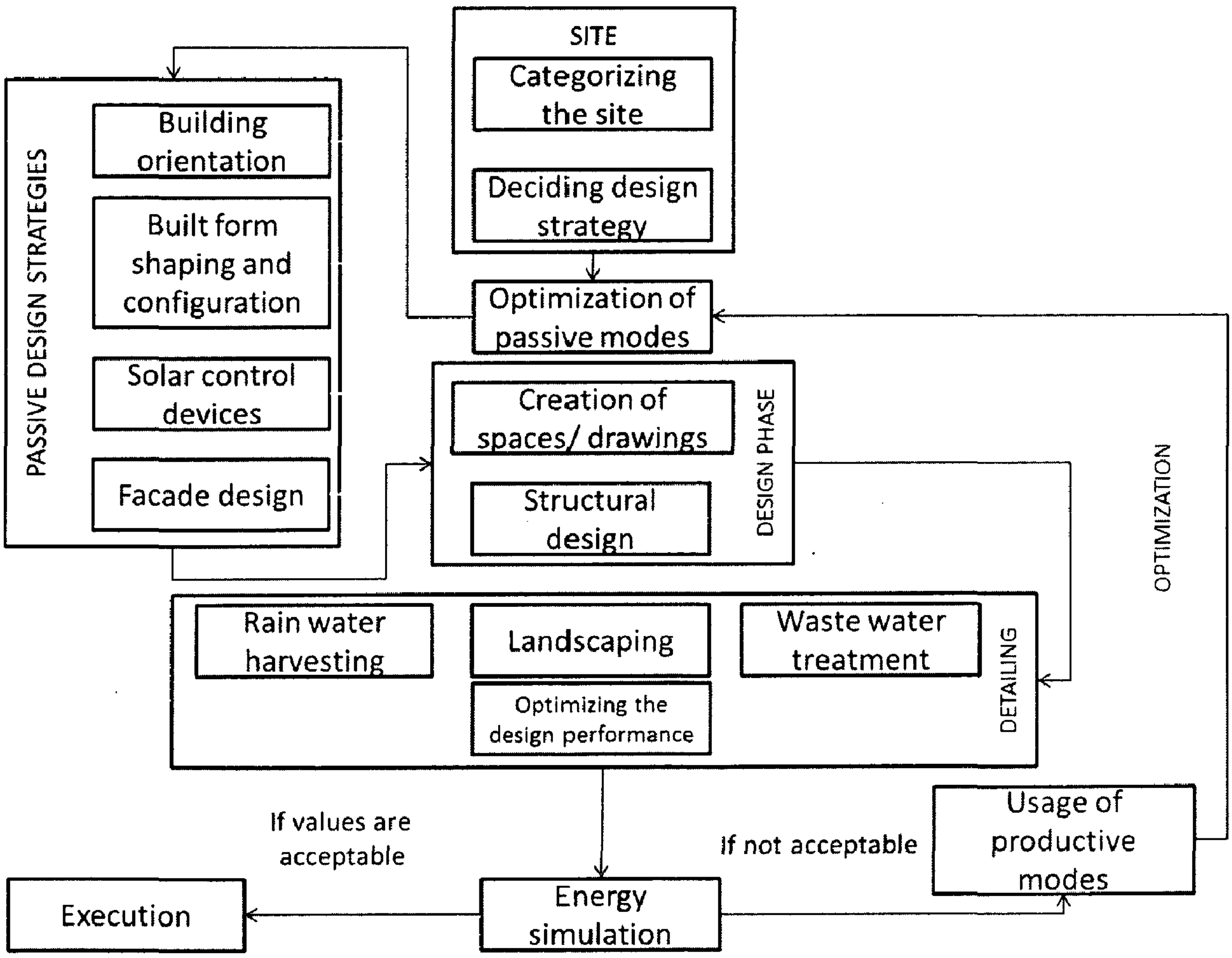


Figure 4.2: Ken Yeang's Design Methodology

Ken Yeang's process of ecological design is a revolution in the field of architecture. It has opened up a completely new ideology about designing and architecture. His process is one that predates all the other ecological design methods can safely be considered the benchmark of eco design.

The advantages of using Ken Yeang's process are as follows:

a) Lower operational costs of the building (cooling and heating loads)
b) Use of renewable energy reduce solar lead on the building
c) Water is collected at various parts of the building and harvested
d) Light is bounced back into the buildings reducing the overall energy demand
e) A lot of psychological benefits due to the constant interaction with nature
f) Replenishment of the ecosystem
g) No damage to the environment

Although environmentally friendly architecture is making impressive headway, there are still disadvantages:

a) These buildings cost a lot more than normal buildings to construct. Usually the total project would cost 30 – 40 % extra
b) People with lower budgets cannot use these concepts

"The costs of green buildings are in the added features, in the constructional methods and the precautions taken to reduce the impact on the locality's environment, etc." This is an important point, since there are other, less tangible benefits of more environment friendly design - namely, they are more human friendly too. While the benefits to the environment may be less obvious in the near term, anyone working long shifts in a cavernous office building can appreciate a little fresh air and sunlight. Thus it is safe to say that even with the huge increase in costs it is still advisable to go for Eco design and green buildings because if this is not done now, there won't be an environment for us to save later.

4.3.2 KARAN GROVER'S DESIGN METHODOLOGY

Karan Grover pays more attention to the building functions than the form of the building. The main function here to meet to goals of the client, i.e., making a platinum rated building, or a sustainable neighbourhood etc. the aim however doesn't just remain to stay within these constraints. Karan Grover aims to surpass the platinum rating and come up with something beyond that by setting his own set of standards which are focused primarily on waste minimization and energy optimization.

The following figure describes the design methodology followed by Ar. Karan Grover.

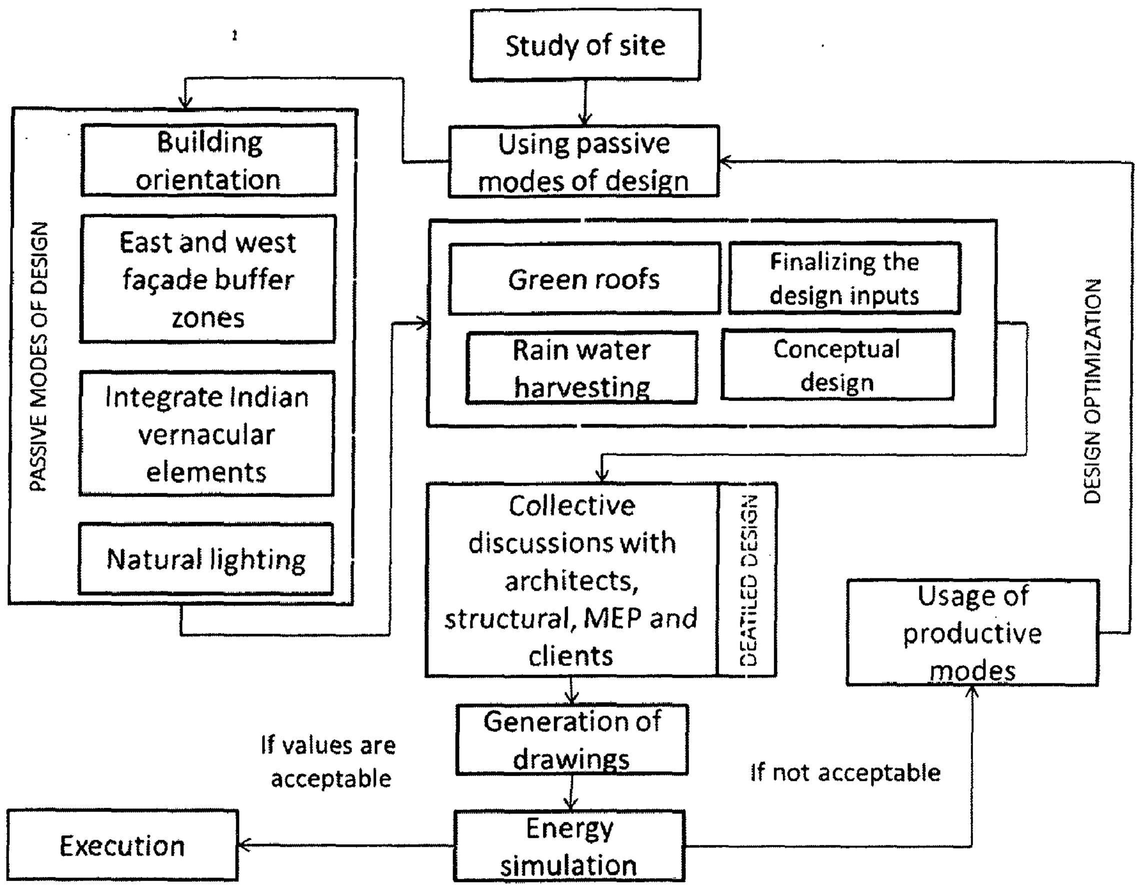


Figure 4.3: Karan Grover's Design Methodology

Karan Grover is working towards the need of practicing Green Architecture inspiring students and fellow architects to build beyond platinum buildings and set cutting edge benchmarks in the architectural fraternity. His approach towards design has the following advantages:

a) His process believes is founded around the motto 'First do no Harm' which reminds architects that they must consider the possible harm that any intervention might do to the environment in the process of designing a building

b) His goals of designing buildings 'Beyond Platinum' ensures that all the architects design buildings that are eco-friendly

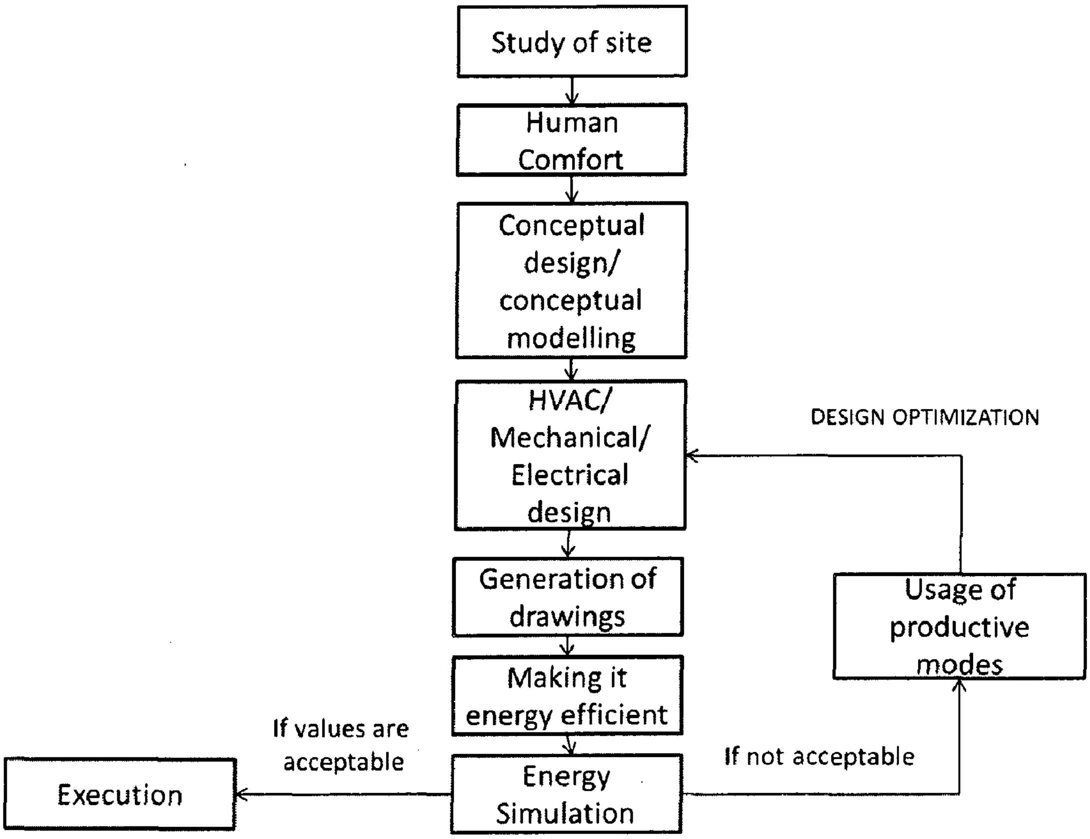


Figure 4.4: Vivek Rathore's Design Methodology

The advantages of this method are as follows:

a) The simplicity of the design is the most important feature. This ensures that there are no hassles in any phase especially the construction phase
b) The use of natural elements makes the building environment friendly
c) Keeping the needs of humans above all has its own advantages as it is after all them that we are making the building for.

This method too has its own disadvantages:

a) The fact that human comfort is kept above all the others, doesn't let the building perform as well as it could have if the focus had been sustainability instead
b) Here too the cost of the building increases around 20-30% from normal construction and design methods

rating and come up with something beyond that by setting his own set of standards which are focused primarily on waste minimization and energy optimization.

The following figure describes the design methodology followed by Ar. Karan Grover.

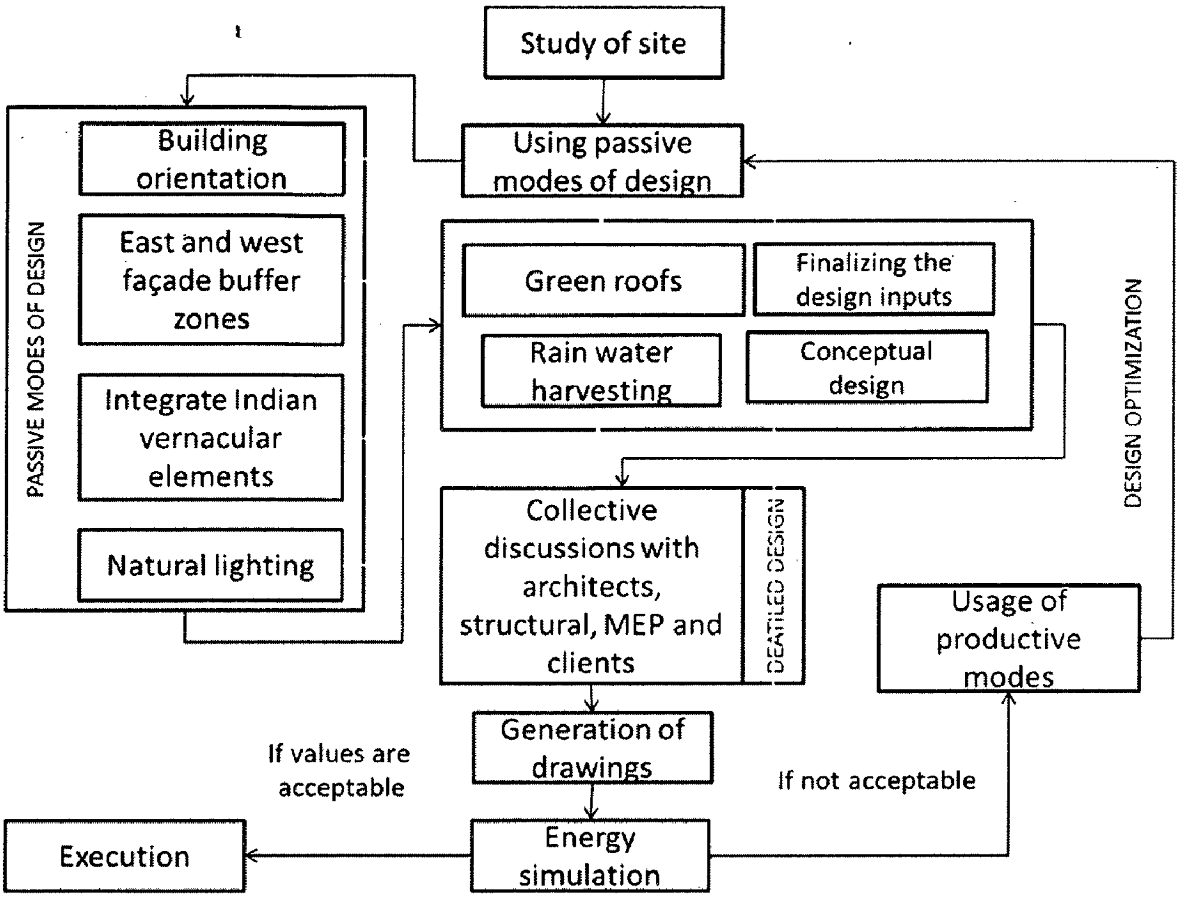


Figure 4.3: Karan Grover's Design Methodology

Karan Grover is working towards the need of practicing Green Architecture inspiring students and fellow architects to build beyond platinum buildings and set cutting edge benchmarks in the architectural fraternity. His approach towards design has the following advantages:

a) His process believes is founded around the motto 'First do no Harm' which reminds architects that they must consider the possible harm that any intervention might do to the environment in the process of designing a building

b) His goals of designing buildings 'Beyond Platinum' ensures that all the architects design buildings that are eco-friendly

c) The use of vernacular elements in his designs brings the glorious past of our country back to life

d) The reintroduction of the ancient design practices is one of the most important things that are done by Grover, this leads to enormous amounts of research.

e) One interesting feature about his design process is that he insists on all the people from different backgrounds sitting together under one roof and working out a problem. This reduces the time frame and keeps errors at bay.

Sadly, this method too isn't all gold, and it too has its disadvantages:

a) The buildings designed are very technical and sometimes lack the finesse of aesthetics

b) The addition of certain features like courtyards and keeping the height constrained causes the buildings to be wide spread taking up more ground coverage

c) Research in design is not done at all stages and is done more only in the initial stages

4.3.3 HOLISTIC DESIGN METHODOLOGY BY VIVEK RATHORE

Holistic approach adopted by Vivek Rathore combined with the layered format in which he works is one of the simplest ways to achieve sustainable design. His objectives are simple.

a) Keeping an idea of the big picture
b) Dividing it into the 5 layers
c) Optimizing each of the layers till they can no further be developed with the present technology
d) Keeping the design simple
e) Use of natural material
f) Use of local material and man power

The following figure describes his design methodology.

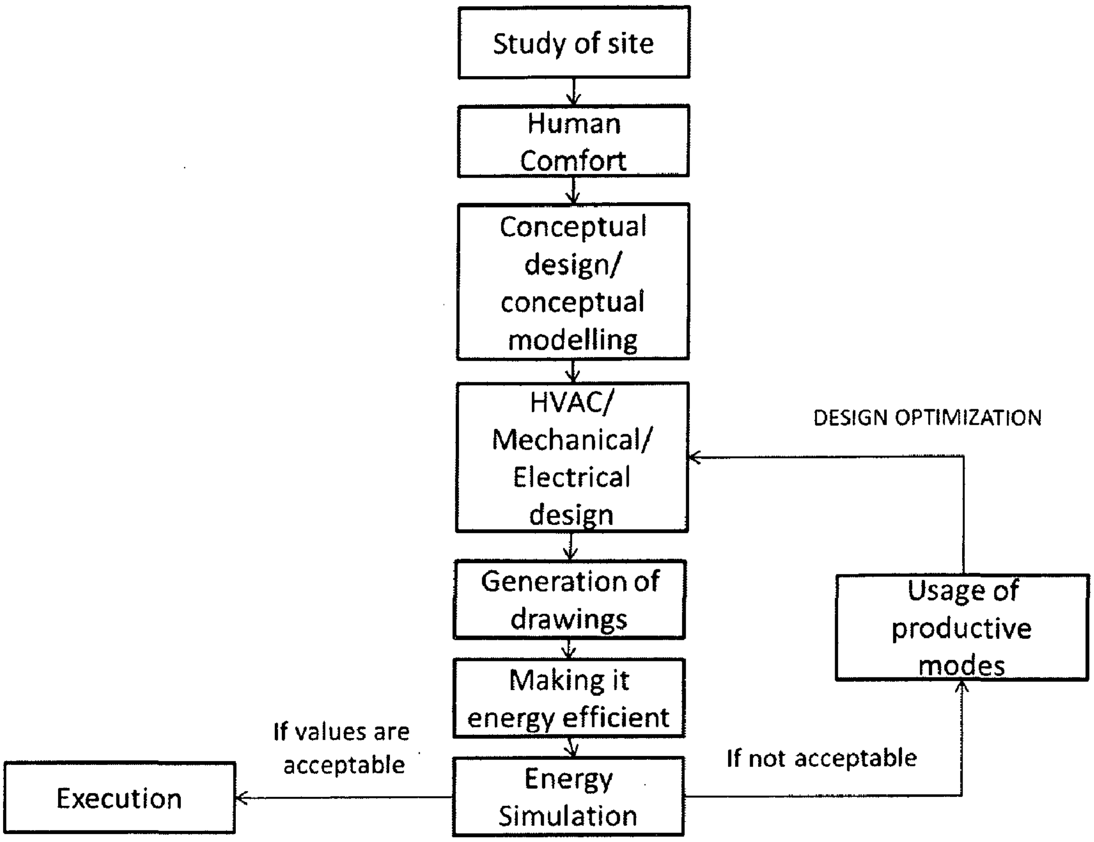


Figure 4.4: Vivek Rathore's Design Methodology

The advantages of this method are as follows:

a) The simplicity of the design is the most important feature. This ensures that there are no hassles in any phase especially the construction phase
b) The use of natural elements makes the building environment friendly
c) Keeping the needs of humans above all has its own advantages as it is after all them that we are making the building for.

This method too has its own disadvantages:

a) The fact that human comfort is kept above all the others, doesn't let the building perform as well as it could have if the focus had been sustainability instead
b) Here too the cost of the building increases around 20-30% from normal construction and design methods

4.4 CONCLUSION

Review of design methodologies followed by eminent architects form different parts of the world it is realised that each of these methods has certain advantages and certain disadvantages. Mainly, it is found that the analysis for energy efficient design is done only after the completion of the design in most of these cases, because of which, the process needs to be repeated a few times in order to achieve a building that performs well. Software that help analyse design are being used as simulation tools rather than design tools.

Thus, a new methodology which incorporates these changes is necessitated which is described in the next chapter.

CHAPTER 5: PROPOSED DESIGN METHODOLOGY

5.1 INTRODUCTION

In order to propose a design methodology for sustainable high rise buildings, it is essential to understand various sequential stages of the basic design process, the various inputs and the stages at which they can be incorporated which will ensure the sustainability of the building design. Therefore various sequential stages of the basic design process are described at the onset of this chapter.

A study and analysis of various methodologies followed by eminent architects involved in environment friendly, energy efficient, sustainable buildings; and their advantages and drawbacks, led to the proposed design methodology which is discussed in this chapter.

5.2 SEQUENTIAL STAGES OF THE BASIC DESIGN PROCESS

A design methodology in general consists of several sequential phases. It is proposed that for designing a sustainable high rise building the design should consist of four phases, namely, Vision, Conceptual Design, Preliminary Design and Detailed Design followed by Construction as shown below.

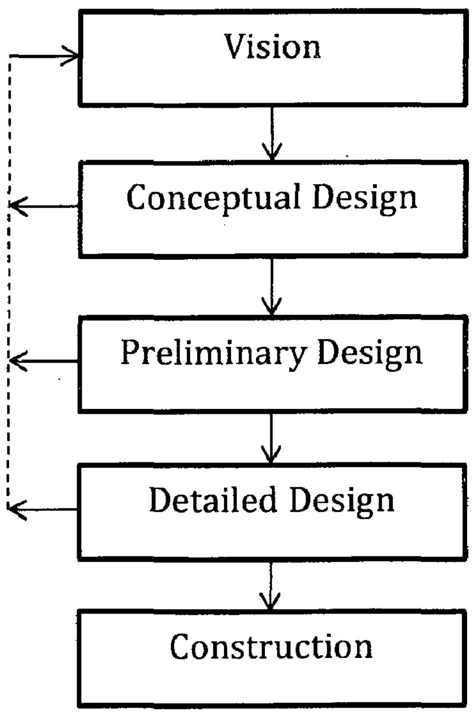


Figure 5.1: Sequential stages of the basic design process

This methodology it is presented as four phases. Phase 2, 3 and 4 feed back into the earlier phases.

a) **Phase 1: Vision**

This stage aims at deciding the vision of the project according to the client. It involves deciding the functional requirements of the project and its feasibility as shown in figure 5.2.

b) **Phase 2: Conceptual Design**

This stage aims at translating the vision into a set of design strategies of design and construction. It involves the stages of site zoning, building orientation and massing as show in figure 5.2.

c) **Phase 3: Preliminary Design**

The aim of this stage is to develop the set of conceptual ideas into a set of preliminary design ideas; and then to select the best for further development this phase involves developing a physical building from, designing the major spaces and areas in the building, defining the design interfaces, selecting the best preliminary ideas by testing against the draft specifications and developing detailed design specifications as shown in figure 5.2.

d) **Phase 4: Detailed Design**

The aim of this phase is to develop the selected preliminary design into the detailed building design ready for construction. This stage involves, designing the various components in detail, testing and refining of the design and integration of the design along with the design specifications as shown in figure 5.2

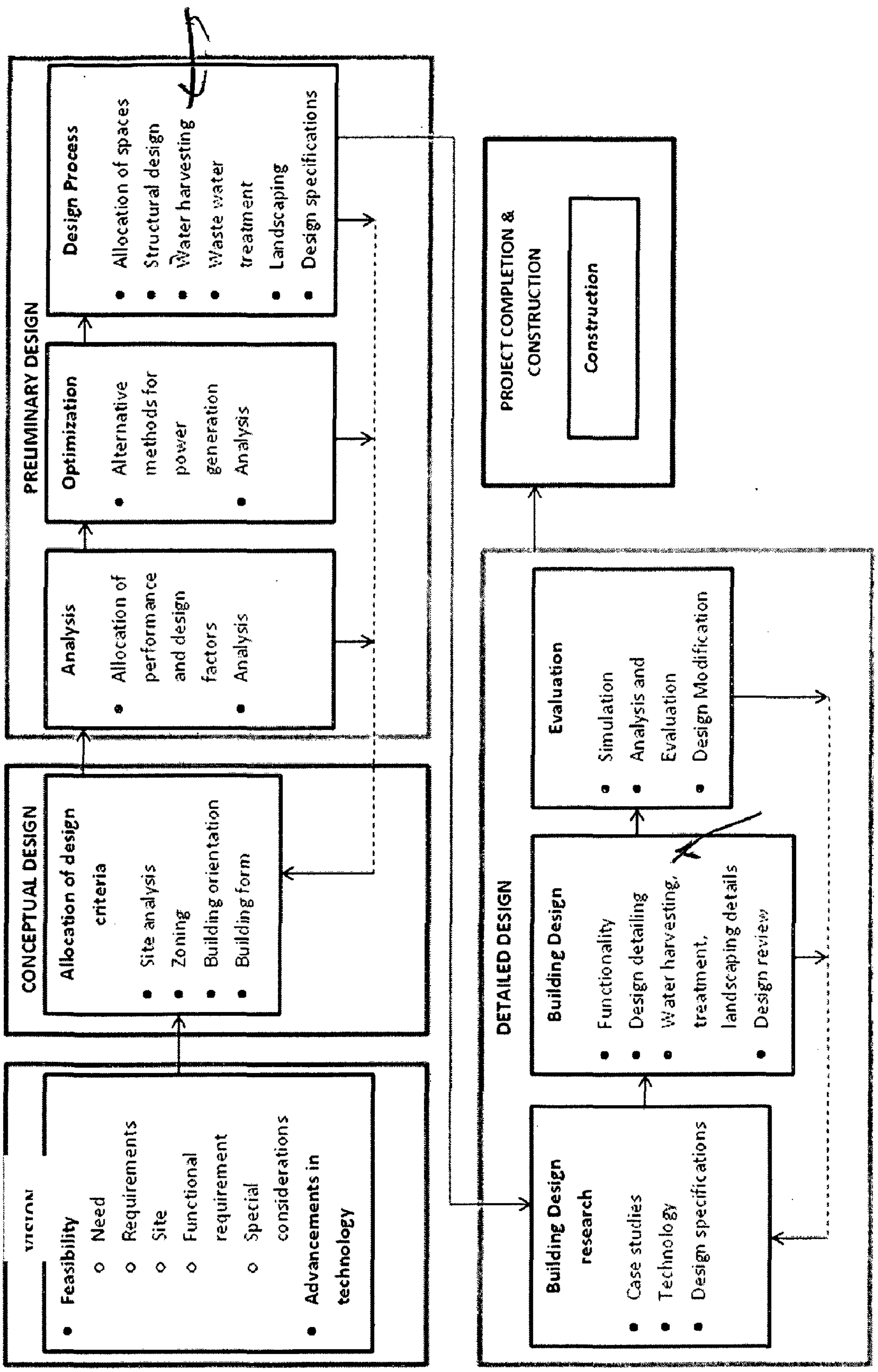


Figure 5.2: Detailed basic design process

5.3 DESIGN METHODOLOGY FOR SUSTAINABLE HIGH RISE BUILDINGS

Sustainability considerations are brought to the frontlines along with economic and performance considerations. Mainly, sustainability deals with resource use such as energy, material and water inputs and outputs; their biological impact and the effect on future generations. These considerations are incorporated into the specifications during the first Phase.

Research is one of the steps that has been emphasized in the early parts of Conceptual Design, Preliminary Design and Detailed Design phases. This is done to populate the database with possible technology, design options, latest technological advancements etc. that can provide opportunities to fulfill the requirements without compromising on the aspects of performance.

When one tries to incorporate sustainability factors into the given methodology, a lot more inputs go into the existing methodology.

5.3.1 PHASE 1: VISION

The aim of this phase is to develop an understanding of the design project at hand, its purpose and the attributes that will make it sustainable. There are three steps that must be considered here.

a) Customer requirements: What does the customer want the building to be? I.e. is he looking for a platinum rated building, is he looking for a zero energy building etc.
b) Service requirements: What services must the building provide?
c) Performance requirements: What are the performance requirements?

After this, the operating conditions of the building must be specified. They usually include temperature, pressure, humidity, geographic location, technological awareness of the local population. This is done by doing a complete climatological survey of the area through the wind maps, sun path diagrams etc.

One must follow a targeted approach to design. In the initial phase the qualities that one wants to associate with the building design must be defined in a realistic manner.

Sustainability is emphasized in the design process by setting some of these qualities depending upon the requirements of the project. These qualities could vary from minimizing material wastage, to maximizing energy efficiency, minimizing land use etc. to maximizing bio restoration in the project.

In addition to this one must make note of the limitations in existing systems that would hinder the process of creating a sustainable building. Limitations may include:

a) Excessive resource consumption
b) Sick building syndrome
c) Total dependence on mechanical/electrical services to keep the building comfortable

In addition knowledge of the existing advancements in the building industry and software that help in sustainable design must be reviewed.

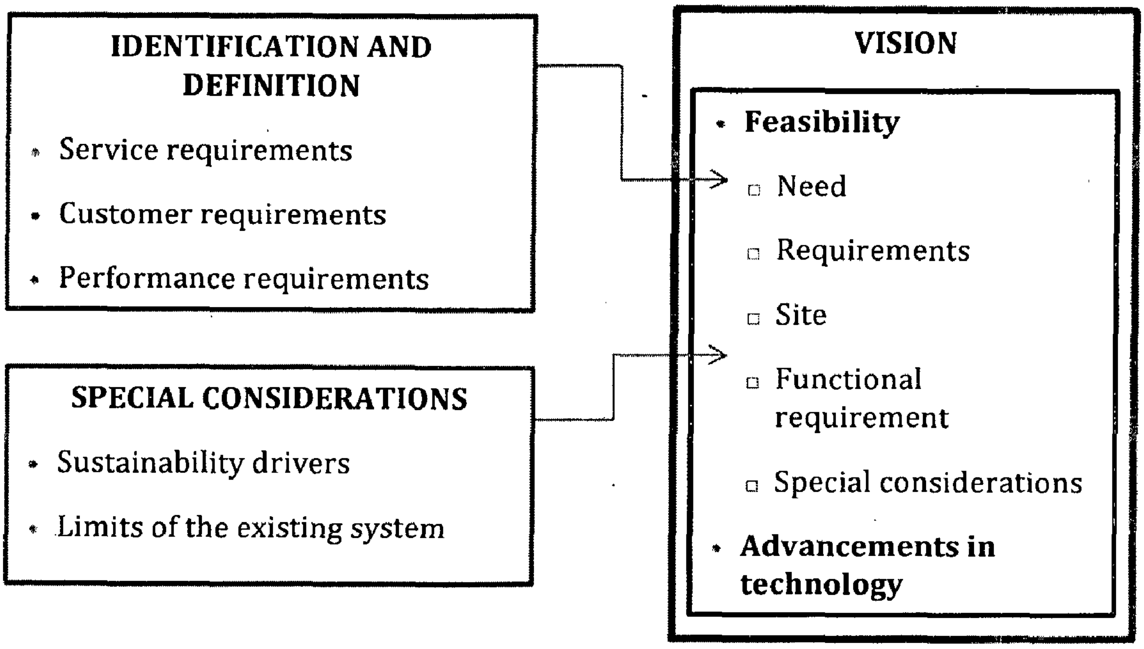


Figure 5.3 Phase 1: Vision

5.3 2 PHASE 2: CONCEPTUAL DESIGN

The aim of this stage is to thoroughly explore the solutions for all possible options that can fulfill the requirements of the project; and then to generate a set of conceptual ideas for further development. This phase typically involves:

- Research

- Generating conceptual designs
- Analysis
- Shortlisting

RESEARCH

Research is very important in understanding the different options one has at their disposal to fulfill the project requirements. In this phase the research focus is on reviewing the advances on technology and design concepts relevant to sustainable high rise building design. These concepts include:

- Bioclimatic design, i.e., design inspired from the nature shaped by the climate of the region.
- Green architecture, that involves designing in harmony with the environment
- Design concepts and technology that help one create a sustainable future such as inclusion of photovoltaic cells or wind turbines for power generation, automated louvers that adjust to the suns angle, etc.
- BIM and software like Ecotect, IES and Design Builder that help in analysis of the building model created.

This research usually brings about results that help architects create structural systems, power generation systems etc. the results are used to develop a database of technology and design concepts and their attributes towards sustainable architecture, important attributes to research include resource requirements, performance conditions, performance requirements, sustainability drivers, new construction technology/methods, capital cost etc.

GENERATING CONCEPTUAL DESIGN

Technologies and design concepts are combined to generate a set of conceptual ideas. A set of relationships are drawn, on the lines of, 'impacts the mass of the building', 'impacts the landscaping around it', and 'impacts the location of the rainwater harvesting equipment' etc. based on these concepts the building design progresses.

TESTING AND SELECTION

The set of conceptual ideas are tested against the draft set of requirements. These reveal how far below or above the specification the conceptual design performed. The best of the conceptual ideas are then selected for further development.

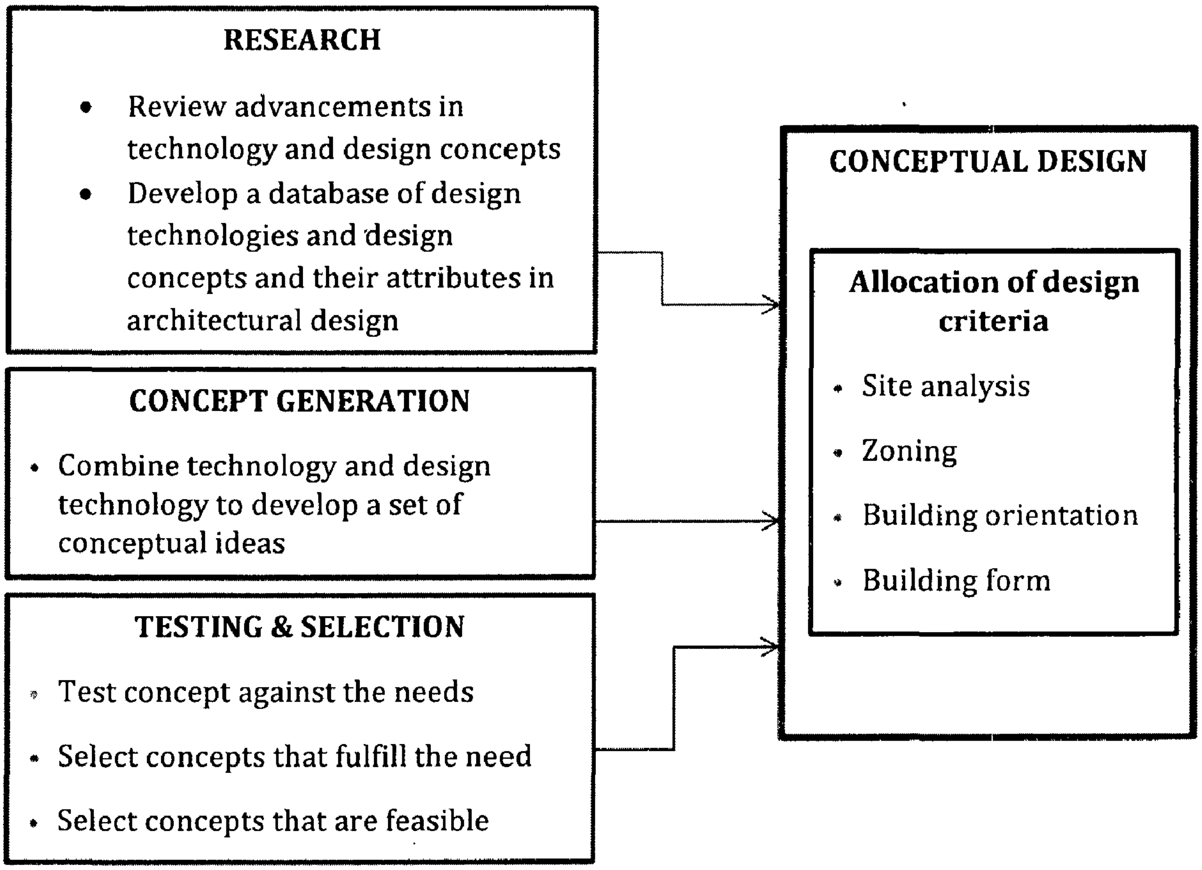


Figure 5.4 Phase 2: Conceptual Design

5.3.3 PHASE 3: PRELIMINARY DESIGN

The aim of this stage is to develop the set of conceptual ideas into a set of preliminary design ideas; and then to select the best for further development this phase involves:

a) Research
b) Designing the building systems
c) Testing
d) Selection and review

RESEARCH

In the preliminary stage the design focus is on reviewing the advances in the fields of technology and design concepts relevant to the design at hand. These refer to the types of technologies and design concepts assigned to selected parts of the design such as 'insulated walls', 'double skin facades', 'pressure and occupancy sensors', 'vertical landscaping'

The results are used to develop a database of technology and design concepts and their involvement in specific areas of design.

DESIGNING THE BUILDING SYSTEMS

In designing the project, it's very important to design it in the right sequence. A flaw of the popular methodology of designing components in isolation is that one does not check the impacts of each of these systems on each other and on the whole.

Thus a sequence for designing and optimizing the individual design components like the structural system, mechanical services, electrical services etc. must be developed. Firstly the approach towards design must be decided with a lot of emphasis on passive modes of design. The various systems that shall be part of the design must then be designed. The probable best sequence will have the various building systems designed in their decreasing order of impacts on the building.

Each building system is designed in a sequence, the technology and design concepts required are selected upon how well they fit the design criteria. In addition technology and design concepts are selected such that the system can the integrated with minimum performance loss.

TESTING

The performance of the current design is analyzed and checked if it works in theory. Emphasis is laid in testing the building as a whole, not each building system separately. If the building fails any tests, the previous steps of the design process are revisited to correct the faults. It is possible that some decisions that seemed trivial earlier may seem influential at a later stage.

SELECTION AND REVIEW

The best design is then selected for further development and testing. Selection criteria include:

a) The potential to meet the targets
b) Feasibility
c) Capacity to provide best options for future generations

Now that the building systems, technologies and design concepts have been finalized the specifications can be updated with a detailed version. Genuine targets can be changed from being defined as 'maximize' and 'minimize' to a more quantified level such as, 'reduce pollution by half', 'reduce greenhouse gas emission by 80%'.

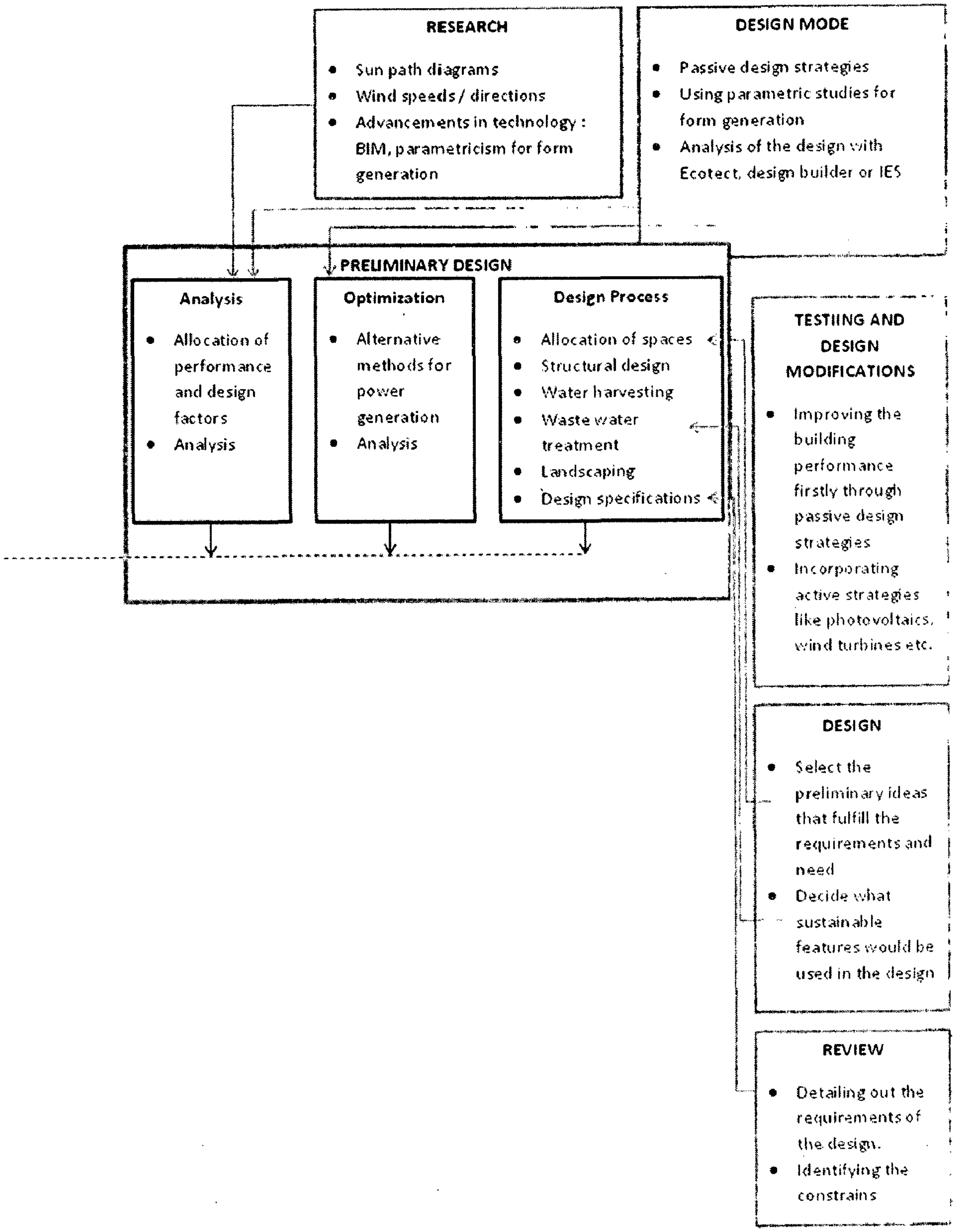


Figure 5.4: Phase 3: Preliminary Design

5.3.4 PHASE 4: DETAILED DESIGN

The aim of this phase is to develop the preliminary design into the detailed one by optimizing the individual systems. There are three steps to this:

a) Research
b) Optimization
c) Testing

RESEARCH

In the detailed design phase, the research focus is on reviewing the technologies that have been shortlisted to be used on the project and to gain all knowledge about their intricacies. It is important to obtain detailed specifications of the technologies, such as performance graphs, performance specifications. Basic specifications usually reveal little information about performance or about the change in performance with time.

OPTIMIZATION

This is the stage where the design is completely detailed out, i.e. allocation of sizes to spaces, detailing out the building subsystems etc. Each building system is detailed out in sequence. The emphasis is now on meeting the now quantified list of specifications, meeting the new practical constrains and providing options for the future generations.

Most importantly, technologies are selected to meet the interface specifications i.e. the control points from where all the existing building systems shall be controlled by their users. It is only after this that the systems integrate to form the detailed building.

Testing

The detailed building is tested to verify if it works in practice. Tests reveal with good accuracy the potential for this building to meet the needs of the project. If this fails, the previous steps are reviewed and revisited to correct the faults. If any individual system fails to meet the benchmark standards, improved are incorporates individually.

Going through each step until no improvements are further possible will optimize the entire system for the available technology. After this the building is ready for construction.

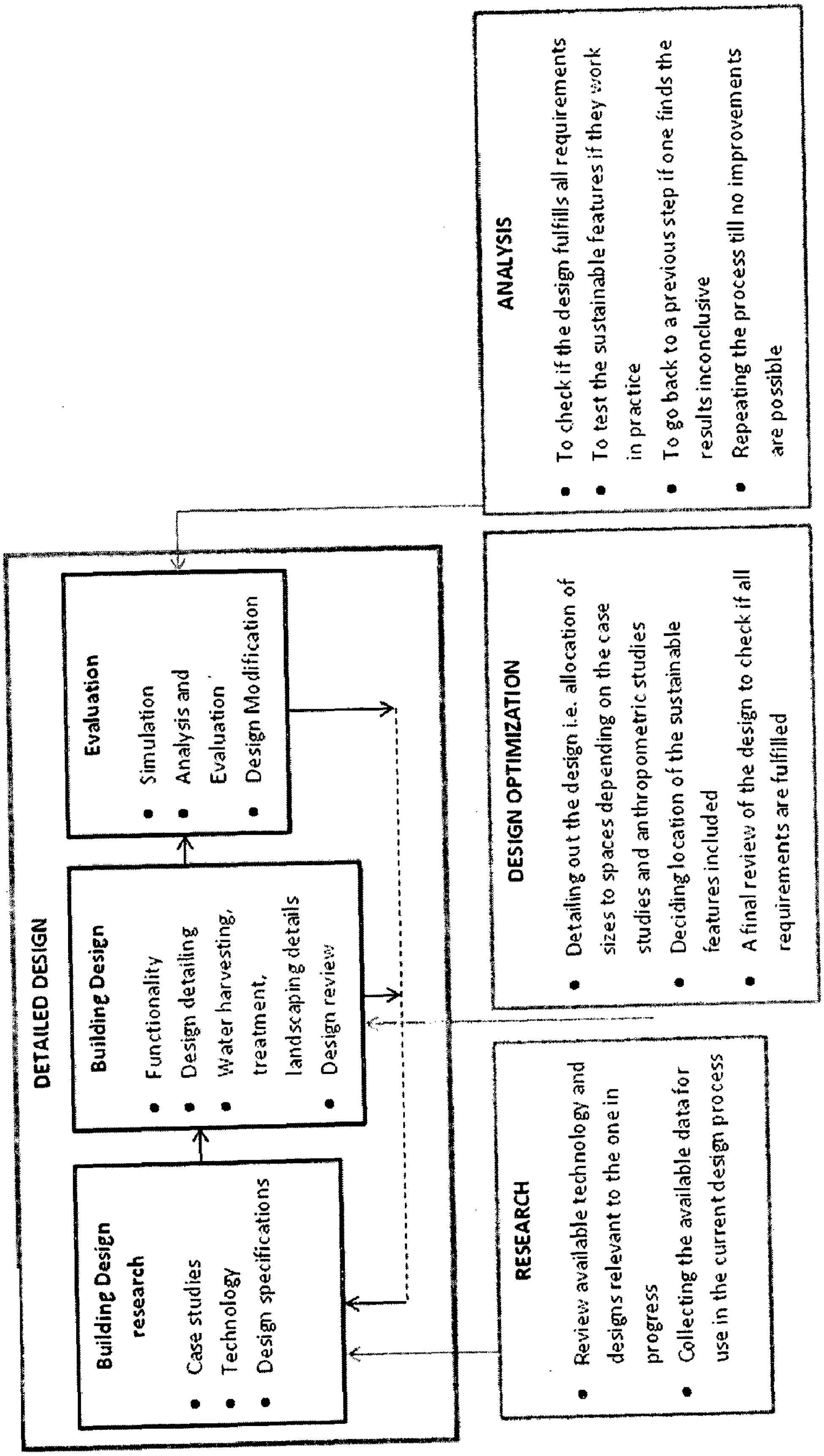
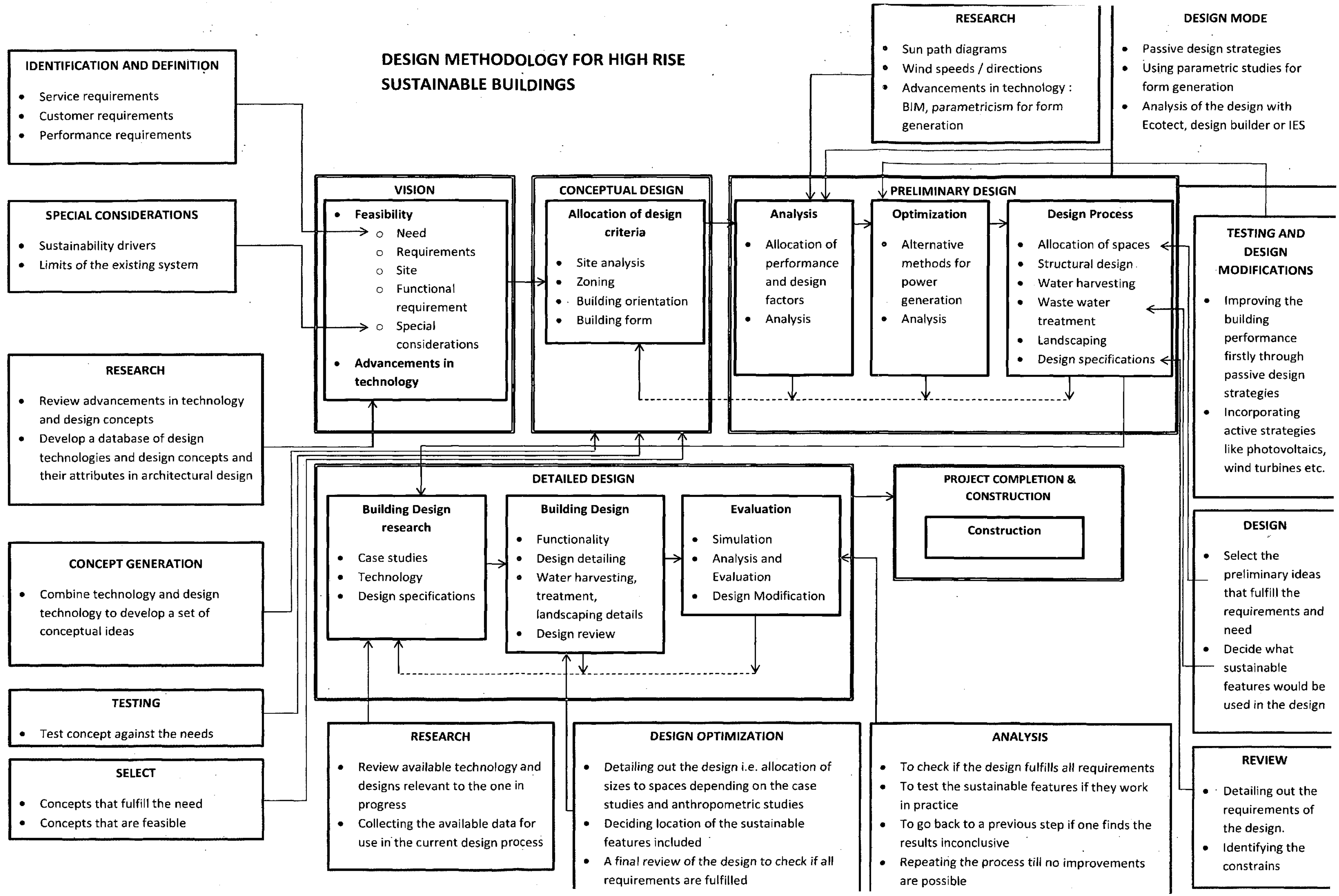


Figure 5.5: Detailed Design

DESIGN METHODOLOGY FOR HIGH RISE SUSTAINABLE BUILDINGS



5.4 CONCLUSION

Taking into account the factors of sustainability, technological advancements and development of new software a design methodology was developed for sustainable high rise buildings. Research and analysis play a major role in any design process. It is these steps that keep the designers updated about the latest developments and technological advancements in architecture. Also, it is research which becomes the major driving force behind any process.

This methodology too could become obsolete in a few years, so, one needs to follow a few steps so that one can always leverage the greatest benefits from any design process. These steps are:

a) Having the right vision
b) Constant review of the system for improvement
c) Tracking the innovation in technology
d) Designing while keeping the future in mind.

CHAPTER 6: CONCLUSIONS AND RECOMMENDATIONS

6.1 INTRODUCTION

This report intended to formulate a design methodology for sustainable high rise buildings. The report could be referred for any information regarding high rise buildings, their design processes, the design methodologies followed by eminent architects and sustainable design. The conclusions of this study are discussed in this chapter

6.2 CONCLUSIONS

a) **Changing forms of architectural design**

- The process of designing is changing since the time of Frank Lloyd Wright and Le Corbusier, the focus no longer remains just aesthetics, structural considerations and functionality.
- The major focus of any design these days are the construction cost, running costs, energy consumption, sustainable design methods, carbon footprint etc.

b) **Conventional design methodologies**

- The conventional design methodology followed by architects used to base the building form from two different set of considerations, structural considerations like aspect ratio, structural systems and architectural considerations like functions, gross area, vertical transportation, floor height, span, space efficiency etc. Using these they use to work out details on the core dimensions, base dimensions, building height, total areas etc.
- We here notice that factors like ecological awareness, sustainability, energy efficiency, new tools for design and development of new processes were not taken into consideration. These processes are still used by a majority of architects and are taught in the architectural education system.

c) Thus, the need to have a new approach to design sustainable high rise buildings is established.

d) New design methodology

Aims of the new methodology should be:

- Making use of the latest tools and technology available in the field of architecture and building physics
- Incorporating research and analysis into all stages of the design
- Creating energy efficient buildings that do minimal or no harm to the environment.
- Creating buildings that are ecofriendly while keeping the aesthetics in mind
- Creating buildings that keep the inhabitants peaceful at a psychological level

e) Factors to be incorporated in the design methodology

Basic factors that are to be incorporated in the new proposed design methodology are

- The structural system is the one that defines the form of the building
- The form plays a large role in improving the efficiency of the building
- .Sustainability should be one of the major objectives of this methodology. The designer should aim to create buildings that are self-sufficient do not affect the environment

f) Contemporary practices in the design of high rise sustainable buildings

- Parametric methods provide new and innovative ways to create multiple forms in little time. These forms could be analyzed to choose those which are efficient.
- Eco design methodology followed by Ar. Ken Yeang's must be incorporated
    - Studying the sites ecology beforehand
    - Major usage of passive modes of design
    - Making ample use of the sunlight and wind to the advantage of the building
    - Incorporating strategies of rain water harvesting and water treatment in the building and site
    - Using renewable sources of energy through technology i.e., photovoltaic panels, wind turbines etc.

- The vernacular ideas from Ar. Karan Grover's process could be used to give the building a traditional look and certain benefits of the properties
- The motto ' First do no Harm' must be incorporated
- The building design must be done as a holistic process keeping in mind all the goals in mind

g) **Steps of the design methodology**

The major steps to be taken in the design process are:

- Dividing the entire process into four phases. Vision, Conceptual design, Preliminary design and Detailed design
- Incorporating three major sub steps in each phase; research, design and analysis
- Incorporating the field of research, design and analysis into each phase to keep errors at bay.
    - The research phase aims at acquiring knowledge about the new technologies and design concepts
    - Design phase helps in incorporating the research elements into the design
    - The analysis phase helps analyse the work done so far verify it against a benchmark. If it is satisfactory the process proceeds to the next phase and if not, the steps are traced back till there is no more improvement necessary with the available technology

6.3 RECOMMENDATIONS

a) In professional practice the following practices must be followed for the design of sustainable high rise buildings

- Use of parametric methods for form generation to create multiple forms in shorter time
- Use of four major phases in the process of design that are inter related with each other i.e. provide feedback to each other; namely, Vision, Conceptual Design, Preliminary Design and Detailed Design.
- Making research and analysis compulsory in all the phases of design
- Following ecological design and not harming the environment

- Ensuring that the buildings are sustainable
- Verifying the energy efficiency of the building at constant intervals of the various phases.
- A lot of research must go into construction too not just designing the building

b) These design methods and methodologies must be incorporated into the academics of UG and PG architectural schools

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