A Multi-Pronged Approach towards Sustainable Building Envelope Design

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Abstract

As the cities are urbanizing rapidly, with substantial growth of population and deficiency in the availability of vital resources such as land, sustainability has become the need of the hour. India is competing in the race of becoming the developed economy of the world. With the concept of smart cities coming up in India, the work has started towards its accomplishment, demanding more emphasis on the importance of adopting sustainable ways of development of the cities, which can only be achieved by starting at a micro level i.e. bringing sustainability in the building envelope.

The research paper discusses about the building envelope design as one of the imperative ways of sustainable advancement in the field of environment responsive building designs, focusing on its needs, importance and numerous other factors linked to it. This is done by studying a sequential analysis of various development processes in India since independence and case studies from other success stories. This will help signifying the importance of sustainability. With the introduction of various initiatives regarding sustainable designs already in the country, it will further help in fulfilling the urgent requirements of establishing such projects.

Introduction

India is one of the emerging superpowers in the world today and is consistently progressing on the course of becoming one of the powerful economies of the world. It’s rapidly expanding economy, the latest trends of the demographics, rate of urbanization and other such attributes are contributing towards the strong advancement of the country.

India, today, is not growing only in terms of population and economy, but also in terms of the scale of problems due to these. The expeditious rise in the rate of urbanization in the country has led to various other environmental problems such as forest degradation, pollution, heat island effect and the increase in the carbon footprint. The mentioned environmental problems which were mere words a few decades ago, have now actually become serious issues. For these reasons, the concept of sustainable development is slowly emerging in India. Sustainable development refers to “meeting the needs of the present generation without compromising the needs of future generation”.

The main intent of the paper is to signify the role of building envelope in the process of a sustainable building design. This is done by the study of various developmental processes in India, introducing the concept of smart building envelope designs with various case examples from other successful sustainable designs. The research is
limited to the study in India and focuses only on the envelope of the building, neglecting other aspects responsible for bringing sustainability in a building such as water conservation, site potential, etc.

The Indian building industry has now started implementing sustainable measures in their designs in order to create environment friendly buildings. But still now, the pace of construction of these buildings is very low as compared to the level of urbanization and population growth which is dynamic.

In order to cope up with this, it is required to begin with a building, which is an essential element of urban development. Conventional building designs not only ignore the infrastructural necessities, but also neglect the harm that is being caused to the environment. In such a case, sustainable designs become even more significant and much required.

1.0 India’s Development since Independence

1.1 Timeline of India’s Growth Post Independence

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<thead>
<tr>
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<tbody>
<tr>
<td>1950 - 1960</td>
<td>N.A.</td>
<td>117</td>
<td>5.1</td>
<td>0.113</td>
<td>Mean Temperature (degree C): 24.18</td>
<td>17.3</td>
</tr>
<tr>
<td>1950 - 1960</td>
<td>N.A.</td>
<td>117</td>
<td>5.1</td>
<td>0.113</td>
<td>Average Rainfall (in mm): 1220.75</td>
<td>17.3</td>
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<td>1960 - 1970</td>
<td>N.A.</td>
<td>142</td>
<td>16.9</td>
<td>0.124</td>
<td>Mean Temperature (degree C): 24.12</td>
<td>18</td>
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<tr>
<td>1960 - 1970</td>
<td>N.A.</td>
<td>142</td>
<td>16.9</td>
<td>0.124</td>
<td>Average Rainfall (in mm): 1158.38</td>
<td>18</td>
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<td>1970 - 1980</td>
<td>5.4%</td>
<td>177</td>
<td>55.8</td>
<td>0.115</td>
<td>Mean Temperature (degree C): 24.17</td>
<td>19.9</td>
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<tr>
<td>1970 - 1980</td>
<td>5.4%</td>
<td>177</td>
<td>55.8</td>
<td>0.115</td>
<td>Average Rainfall (in mm): 1165.73</td>
<td>19.9</td>
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<tr>
<td>1980 - 1990</td>
<td>N.A.</td>
<td>216</td>
<td>110.8</td>
<td>0.099</td>
<td>Mean Temperature (degree C): 24.30</td>
<td>23.3</td>
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<tr>
<td>1980 - 1990</td>
<td>N.A.</td>
<td>216</td>
<td>110.8</td>
<td>0.099</td>
<td>Average Rainfall (in mm): 1073</td>
<td>23.3</td>
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<tr>
<td>1990 - 2000</td>
<td>4.4%</td>
<td>267</td>
<td>398.1</td>
<td>0.076</td>
<td>Mean Temperature (degree C): 24.49</td>
<td>25.7</td>
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1.2 Inferences

<table>
<thead>
<tr>
<th>EFFECTS</th>
<th>What is happening</th>
<th>What could happen/What is required</th>
</tr>
</thead>
<tbody>
<tr>
<td>Contribution of construction industry to India’s GDP</td>
<td>Second largest employer and contributor to economic activity, after agriculture sector. Present levels of urban infrastructure are inadequate to meet the demands of the existing urban population.</td>
<td>Construction sector in India will remain buoyant due to increased demand from real estate and infrastructure projects. Urban local bodies (ULBs) need to enter into partnership agreements with foreign players to provide quality urban services on a sustainable basis in Indian cities.</td>
</tr>
<tr>
<td>Population growth in India</td>
<td>India is the second most populated nation after China. Since 1950 to the present years, there is a gradual but continuous rise in population over years.</td>
<td>Hindrance to economic growth and development. Increasing pressure on accommodating a large population</td>
</tr>
<tr>
<td>Energy consumption in India (Electricity)</td>
<td>Energy production is dependent on sources such as coal, oil, lignite etc. which are non-renewable. The energy consumption graph is on a great rise, as seen after every 10 years.</td>
<td>Pressure on natural (non-renewable) sources of energy as they are depleting with the rise in demand with the passage of time. Sustainable measures need to be adopted instead of the conventional methods for the construction of future buildings.</td>
</tr>
</tbody>
</table>

Table 1: Timeline of India’s growth post-independence

<table>
<thead>
<tr>
<th>Year</th>
<th>Population Growth</th>
<th>Average Rainfall (in mm)</th>
<th>Average Temperature (degree C)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2000-2010</td>
<td>8%</td>
<td>325</td>
<td>499.5</td>
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<tr>
<td>2010-2016</td>
<td>6.3%</td>
<td>382</td>
<td>897.74</td>
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</tbody>
</table>
A\vailability of forest land  | The population growth has led to a downward trend in the availability of forest and agricultural land since the 1950s. | Forest degradation causing an adverse impact on the quality of environment by influencing the ecological balance and life support system. \\

Migration | Migration of a large population is taking place at a rapid pace due to various reasons such as urbanization, climate change. | Climate change effects and increasing urbanization may lead to an increase in the number of people migrating to new places, creating an imbalance in the distribution of population. \\

Climate change | India is already experiencing a warming climate as seen in these past 60 years. | With built-up urban areas rapidly becoming “heat-islands”, need to adopt measures to counteract this effect. \\

Changing rainfall patterns | A decline in monsoon rainfall since the 1950s has been observed. The frequency of heavy rainfall events has also increased. | Any sudden change in the monsoon can lead to over flooding or frequent droughts in many parts of India. Building codes will need to be enforced to ensure that homes and infrastructure are not at risk. \\

| Table 2: Effects due to the various factors governing India’s development post-independence. 
(Source: Author) |

1.3 Current Scenario of Sustainable Cities in India:

Any urban agglomeration in India needs to be efficient and smart in terms of infrastructure and city planning in order to meet the demands of the present population, keeping in mind the needs of future. A novel concept of ‘ecocities’ is flourishing which insists on sustainable development of the urban cities. It focuses on the overall development of a city i.e. infrastructure (social and physical), transportation network, planning and most importantly the buildings.

It is anticipated that by the year 2030, 40% of India’s population will reside in cities[10]. The ‘smart cities’ concept has been launched by the government of India in year 2015. It is an urban renewal and retrofitting program with a mission to develop 100 cities in India. It includes smart waste management, smart environment, smart urban planning, smart buildings, smart security, smart IT and communications and smart infrastructure.

Under the smart buildings initiative, more than 3,124 green building projects, with a footprint of over 2.75 billion sq. ft. are registered with the Indian Green Building Council (IGBC), of which 617 green building projects are certified and functional [10].
Recently, with India being ranked number 3 among a list of the top 10 counties in the world by the US Green Building Council (USGBC) for LEED outside of the US, the ‘green’ initiatives of India have boosted up. IGBC’s vision has been to enable a sustainable built environment for all and, it is targeting 20 billion square feet of green buildings in India by 2025[11]

2.0 Urgency of Sustainable Building Envelope in India

Increasing demand for energy, deteriorating natural resources and ever growing population pose an enormous challenge to our developing nation. There is a huge opportunity for improving our built environment, by making it sustainable right from the use of materials to efficiency in energy in natural resources such as water, power and light.

Thus, in order to realize the initiative of ‘eco- cities’ or ‘smart cities’, the foremost step involves a consistent effort required to be invested in the outgrowth of sustainable buildings, i.e., development at a micro level.

The much-aspired dream of making India a sustainable realm and developed nations in the world can be achieved by promoting the idea of establishment of sustainable smart cities in the country.

For this, the core constituent of any settlement, that is a building, needs to be considered for the process of bringing environmental sustainability in a city. The work must start at building level in order to make the idea of eco cities a success. A building affects not only its indoor environment, but also regulates the environment of its surroundings, also known as the microclimate around the building. The most important part of a building that is primarily responsible for controlling its indoor as well as the outdoor environment is its envelope i.e. the building envelope.

Table 3: Factors affecting a building envelope design.
The Building envelope building enclosure is the physical separator between the interior and the exterior environments of a building. It serves as the outer shell to help maintain the indoor environment (together with the mechanical conditioning systems) and facilitate its climate control. Building envelope design is a specialized area of three main architectural functions of the building envelope[12]:

1) Support  2) Control  3) Finish

The connection between building envelope and building sustainability is shown as below.

BUILDING ENVELOPE + SUSTAINABLE ENVELOPE DESIGN = BUILDING SUSTAINABILITY

2.1 Sustainable Techniques in Building Envelope

The key roles of a sustainable building envelope are to provide shelter, security, thermal control, maintain indoor air quality, access to daylight, acoustics, cost effectiveness and aesthetics. With these varied functions associated with the building envelope, an integrated approach is required to come into action which supports an increased commitment to environmental stewardship and conservation and also results in optimal stability of cost, environmental and social benefits.

<table>
<thead>
<tr>
<th>FUNCTIONS OF SUSTAINABLE BUILDING ENVELOPE</th>
<th>SUSTAINABLE TECHNIQUES</th>
<th>EXAMPLES OF SUSTAINABLE TECHNIQUES EMPLOYED IN BUILDING ENVELOPE DESIGNS</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Optimization of Energy consumption.</td>
<td>Passive techniques:</td>
<td>Installation of effective Sun control and shading devices such as louver, vertical fins, light shelves etc. on the façade to control the amount of light and heat entering inside the building. Provision of efficient glazing systems (considering the percentage of opening in comparison to the floor area).</td>
</tr>
<tr>
<td></td>
<td>Active techniques:</td>
<td>Installation of Photo-voltaic panels on roofs to generate energy for the building.</td>
</tr>
</tbody>
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![Fig.1: IRRAD building, Gurgaon (Source: Author)](image)

Use of sun shading devices on the façade which correspond with the movement of the sun.
2. **Optimization of cost (including the Life cycle cost of the building envelope).**

| Use of low cost and locally available materials for the construction. |
| Use of recyclable materials and building envelope designs for disassembly. |
| Optimization of maintenance costs by use of resource-efficient and non-toxic cleaning products, supplies and procedures for building envelope elements. |

![Fig. 2: Facility at Sandia National laboratories, Albuquerque, New Mexico. (Source: Seppanen et al.)](image)

The building has increased energy efficiency by 20% and hence, reduced energy costs by implication of sustainable features in the building.

3. **Thermal control and indoor air quality.**

| Provision of Green roofs, cool roofs etc. to maintain the indoor as well as outdoor environment. |
| Maintaining the indoor thermal comfort by direct or indirect heat gains such as trombe walls, water walls, sunspaces, etc. and by providing optimum sized fenestrations, windows and ventilators for effective ventilation and stack effect. |
| Providing insulation in the walls and roof of required R-value such as blanket, concrete block, insulating concrete forms, spray foam, rigid foam, polystyrene sheets and natural fiber insulation, so as to attain the required indoor temperature. |
| Use of advanced glazing systems such as energy efficient glass windows, film coated glass, double or triple-paned glass windows so as to control the heat gain inside the building. |

![Fig. 3: IRRAD building, Gurgaon (Source: Author)](image)

Provision of screened wall allowing wind movement inside the building.

![Fig. 4: CII-Sohrabji Godrej Green Business Centre, Hyderabad. (Source: Velazquez)](image)

Green roofs provided in the building for maintaining thermal comfort inside and reduce heat island effect.
<table>
<thead>
<tr>
<th>4. Sustainable or green materials</th>
<th>Use of low-embodied energy materials. Use of recyclable and green materials. Use of smart materials. Sustainable materials suitable for the envelope elements: ROOF AND TERRACE – White broken china mosaic on terrace for reflection of incident rays, removable covers on top, vermiculite concrete, WALLS – compressed earth blocks, local stone, cavity walls, etc. FLOORS – local stone, Bamboo, Coconut timber, rubber, etc. FINISHES – Light and smooth finishes reflecting the sunlight. Dark colored finishes such as exposed to absorb the sunlight. FENESTRATIONS - double or triple paned glazings, use of chajjas, louvers, fins etc. for protection from direct sun.</th>
<th>Use of certified wood for door and window frames. Use of double glazed glass for windows. Locally available stones used for cladding on walls and floor. The brick used for construction are compressed earth blocks made on site itself from the earth excavated from the basement. On the terrace, white broken china mosaic tiles have been used to reflect the incident rays.</th>
</tr>
</thead>
<tbody>
<tr>
<td>5. Access to Natural light</td>
<td>Provision of skylights, light shelves, light tubes, etc. to bring inside the daylight. Properly positioned, sized and oriented windows and glazing systems need to be provided ensuring diffused natural light entering inside the building.</td>
<td>Use of glass bricks for inducing daylight in the basement. Light shelves provided with glass bricks on the façade to bring diffused daylight inside the building.</td>
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</table>
2.2 Smart Systems Contributing To Sustainability in the Building Envelope

The modern building system comprises of three main components:

1) Structural components; the bones of building system
2) Service components; the organs of building system
3) The Envelope components; the skin of building system.
The envelope components are accountable for protecting the building from harmful exterior environments and maintaining comfortable indoor conditions. But the main drawback of building envelope innovations in today’s time is its inability for self-detection and self-adjustment to new environmental conditions. This necessitates the need to design smart building envelopes that will perform under all types of weather conditions and will take the loads due to differences between the exterior environment and the interior conditions of the building.

Smart materials refer to the newest type of materials used for construction which are able to perceive their surrounding events or conditions and react according to them. Unlike common construction materials, these materials are dynamic in nature and respond well to the physical or chemical effects of the surrounding environment in various ways such as changing their form, shape, color and inner energy. The foremost advantage of smart materials is that their use in building construction can help optimizing the energy consumption and hence, it becomes possible to regulate the increasing global demand for non-renewable and expensive energy resources and raw materials.

2.3 Some Examples Of Smart Building Envelope Designs

AL BAHAR TOWERS, Abu Dhabi, UAE
The skin of the towers is made up of thin glass façade which is covered by secondary skin of a series of transparent umbrella like shading devices, which open up and close in response to the solar direction, thus helping in reduced glare, improved daylight penetration and over 50% reduction in solar gain resulting in a reduction of of carbon dioxide emissions[18].

THE BIO INTELLIGENT QUOTIENT BUILDING, Hamburg, Germany
The façade of the building is comprised of microalgae cultivated in glass elements that make up the ‘bio-skin’ of the building envelope. The bioreactor façade powers the entire structure, making it the world’s first algae-powered and building ever. The building is coated on its two sun-facing sides with glass-plated tanks of suspended algae. The microscopic algae plants are provided with nutrients, oxygen and direct sunlight for biomass production which helps in heating the water, and that heat is harvested by the system and stored for use in the building[13], [19].

THE TORRE DE ESPECIALIDADES, Mexico City
The hospital building comprises of a 300 feet long façade of sponge shaped structures which function to filter the air entering inside the building. The material used is titanium dioxide, which effectively cleans the air of toxins by releasing spongy free radicals that could eliminate pollutants. The sun screen façade creates turbulence and slows down air flow around the building, while scattering the UV light needed to activate the chemical reaction of destroying any existing pollutants, thus, leaving the air cleaner for the patients inside.[13]
3.0 Factors Responsive To a Sustainable Building Envelope

A Building envelope that is ideal, responds to three main aspects; social, culture and context. The most promising strategy for the sustainable building envelope is based on various factors such as the health, safety and comfort of the occupants, thermal performance of the building, energy efficiency, climatic response etc. All these factors together contribute towards the social, economic and environmental sustainability of the building.

3.1 Social Responsiveness

The effects of sustainable building practices on occupants are the primary social benefits. The social aspects are mainly linked with the occupants of the building and their comfort, health, satisfaction, safety and security. The building envelope design should be such that it very well responds to the social requisites of the occupant.

The building environment can have both negative and positive impacts on the occupants' quality of life. Negative impacts include illness, absenteeism, fatigue, discomfort, stress, and distractions resulting from poor indoor air quality, thermal conditioning, lighting, and specific aspects of interior space design (e.g., materials selections, furnishings, etc.) which directly or indirectly are dependent on the quality of building envelope. Sick building syndrome is one such issue of concern found in buildings which lack the approach of occupant health in their designs. Reducing these problems through sustainable design often helps in improving health and performance. Improved indoor air quality and control of temperature and ventilation have strong positive effects.

Psychological effects such as comfort, well-being and satisfaction are also one of the prominent factors determining the social worth of a building envelope. The psychological interpretation of the environment has impacts on the work performance and productivity of the occupant. Various building features are responsible for psychologically favorable environment inside a building. Some of them are: day lighting and artificial lighting, thermal satisfaction, air quality and overall satisfaction (Thermal mass, Stable and comfortable temperature conditions, Operable windows, Views out, etc.).

Another social issue affecting buildings is security. There needs to exist a synergy between building security and sustainability features. Tighter building envelopes not only reduce energy losses but also reduce the entry of airborne hazards released outside the building. More number of day lit spaces, up gradation of existing windows for blast resistance, improving particle air filtration are some of the ways of improving the building envelope to ensure security against anti-social, biological and chemical agents.

3.2 Climatic and Contextual Responsiveness

Building context refers to the surroundings of a building; the place where it is located, the climate of the place, its architectural image and the urban fabric. Individual building is always seen as a part of the whole. So it should have a strong and eloquent relationship with its surroundings, not only visually, but also in consideration with the climate of that place.
With the unpredictable changes taking place in the global climate, Climate responsive architecture is coming into light. For a building envelope to be sustainable, it is now strongly required that along with being energy efficient and green, the building should also be responsive to the climate it is located in.

Climatic response of a building envelope plays a major role in making a building belong to certain place. With the energy use being the primary contributor to the global warming, climate responsive designs becomes an obvious way to mitigate the climate change. This takes in regard the seasonality, the solar position and sun path, natural shade that is provided by the topography of that place, various environmental factors such as wind, rainfall, humidity, etc. and also the climatic data, that is, the temperature, climate change and patterns etc.

Contextual responsiveness enables a building envelope to adapt its form, shape, color or character responsively, i.e. in response to the environmental conditions of the place. A contextually responsive approach to design is an important part of creating ecologically sustainable buildings and development.

The main motive of such an approach is to harmonize the building envelope design with the site and the climate, hence, reducing the ecological impacts and achieving energy efficiency along with providing human health and comfort and creating opportunities for a socially interactive and productive environment.

4.0 Benefits of a Sustainable Building Envelope

A sustainable building envelope is not just a design of the envelope; it is an approach to the building that fulfills the demands of the present time, where its relevance and importance will only continue to increase. The advantages of a sustainable building envelope are multifold and can be broadly categorized into 3 categories: - Environmental benefits, Economic benefits and Social benefits.

4.1 Environmental Benefits

- The whole purpose of a sustainable building envelope is to conserve the environment and avoid the depletion of natural resources.
- A sustainable building envelope improves the indoor air quality and the micro-climate around the building.
- The protection of biodiversity and ecosystems is one of the major issues being faced today. A building envelope can be designed in a way such that it helps in safeguarding the ecosystem existing around it.
- Water conservation, energy efficiency, temperature control or thermal comfort is some other important features of a sustainable building envelope which make a building self-sufficient.
- A sustainable building envelope ensures reduction in hazardous emissions from a building, thus contributing to a healthy environment.

4.2 Economic Benefits

- A sustainable Building envelope provides financial rewards for building owners, operators and also the occupants.
- Sustainable building envelope has lower annual costs for energy, water, maintenance or repair and other operating expenses. The initial cost may be lower or same, but the lifecycle cost is typically lower than that in traditional/conventional buildings.

- A sustainable building envelope can also provide indirect benefits to the building, the owner and the occupants in terms of better health, comfort, well-being and hence, the increased productivity.

- Sustainable features offer economic benefits from lower risks and longer lifetime of buildings. It also ensures community acceptance and support for more sustainable projects and increased asset value.

- Sustainable building envelope also indirectly benefits the economy of a country by reducing the costs from air pollution damage and lower infrastructure costs such as avoided landfills, waste water treatment plants etc.[14]

4.3 Social Benefits

- The social benefits of sustainable design of a building envelope are related to improvement in health, quality of life and social well-being.

- Social benefits can be realized at different levels – building, the community and the society. At building level, human benefits are centered mainly on three primary topics – health, comfort and satisfaction.

- A sustainable building envelope creates a building environment that ensures positive impacts on the occupants’ quality of life. It creates positive psychological and social experiences.

- At community level or society level, the benefits include transfer of knowledge and values, improved neighborhood quality and reduced health risks from pollutants associated with building energy use.[15]

5.0 What Can India Learn From Other Asian Cities?

India

LIC Building, Delhi

Building type: Office building

The Building Envelope: The building envelope of the building comprises mainly of glass, which is a high-embodied energy and highly reflective material.

Singapore

SOLARIS

Building type: Research and business park

SOLARIS has been certified BCA GreenMark Platinum which is the highest possible green certification granted by Singapore’s sustainable

Bangkok

Hansar

Building type: Residential and Hotel building

The Building Envelope: The skin of the building is a double layer envelope system.

Sky gardens, equivalent to 30% of site area, have been provided
The building envelope is not responsive to the climate and the context.
The material used in the envelope is accountable for adding to the heat island effect in the surroundings and the carbon dioxide emissions.

building benchmark.[21]

The Building Envelope: The building envelope of SOLARIS stands as a demonstration of a sustainable model with the introduction of various features such as creative use of skylights, a sequence of roof gardens with sky terraces that interpenetrate the building’s façade.

The project has a climate-responsive façade design with the provision of extensive sun-shading louvers, which also double as light shelves.

which serve to bring cool and natural relief inside the building.

A metal screen protecting from the direct sun with greenery on it has been provided which also act as privacy screens for the units.

Other than this, internal light wells planted with green walls have also been provided for provision of daylight in the interiors.

[20]

6.0 Conclusion

The various factors such as population, energy consumption etc. responsible for the development of India in terms of economy, social and environment depict an adverse graph line resulting in various unfavorable effects due to them which hinders the overall growth of the nation. This emphasizes the crucial need of sustainable development for an environmentally flourishing India. The present picture of sustainable growth in India though portrays an optimistic impression for the future development. The building envelope, being the core element of a building, owns a responsible position in the course of designing sustainable and environment friendly structures. Various green construction techniques can be implied in the envelope design for making it sustainable. The latest introduction of smart building envelope design systems is encouraging the technological advancements in the architecture discipline. Social, climatic and contextual aspects when brought into consideration while designing a sustainable building envelope can award numerous benefits to the building in long term. A number of success stories such as Singapore[16], [17], have become a source of novel ideas and inspiration for rest of the world, which can be taken into account for progressing on the path of sustainable growth of the country.

7.0 Bibliography


