Toward More Sustainable Buildings.
نحو مباني أكثر استدامــــــــــــــــة

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1. Abstract:

Sustainability within modern buildings is an important issue. Most of modern buildings, unlike traditional ones, are tall ones. Their designs does not consider environmental resources conservation.
The main scope of this study is the sustainability for tall buildings. It starts with defining the sustainability and the sustainable building. After this, the sustainability approaches in architecture were introduced with samples for each one of its trends. Different aspects affecting building impacts on its surrounding environmental conditions were explored. Form, openings, orientation, structure among several other architectural design parameters were discussed in detail. Moreover, building, passive and active, systems were presented in terms of lighting, ventilation and thermal control. In addition, available international environmental impact assessment tools were reviewed. Through the study, sustainability terms like green building, building life cycle, indoor air quality and sick building syndrome were explored and discussed in detail.
The paper concluded with a set of recommendations for designers and municipalities to improve buildings' environmental response through the building life cycle (design – construction – running). A detailed check-lists for calculating and predicting environmental impacts of proposed building during construction and operations were introduced to be used during developing the building design.

٢. الملخص العربي:

الاستدامة في المباني الحديثة تعد من أهم الجوانب الواجب مراعاتها. فعلى العكس من مبانينا التقليدية تتصف معظم مباني مدننا الحديثة بأنها مباني مرتفعة أو شاهقة الارتفاع. تصميمات تلك المباني لا تراعي الجوانب البيئية والصحية ولا تهتم بالحفاظ على المصادر البيئية أو الاقتصاد في استهلاك الطاقة. وتحتاج تلك المباني إلى العديد من التعديلات لتتلاءم بشكل أكبر مع البيئة من حولها.

يهتم البحث بقضايا الاستدامة للمباني المرتفعة. ويدخل في نطاق اهتمام الدراسة العوامل المؤثرة على أداء المبنى البيئي خلال دورة عمر المبنى وتأثير كل من هذه العوامل على الظروف البيئية المحيطة التي تنشا عن وجود المبنى.
بإلقاء الضوء على تطور مفهوم الاستدامة عالميا كما يتدرج إلى عرض تطور مفهوم الاستدامة في العمارة بشكل عام وفي المباني المرتفعة بشكل خاص ومن خلال ذلك يتناول البحث العناصر التصميمية المختلفة للمبنى وكيفية تأثيرها على أداء المبنى البيئي خلال دورة عمر المبنى والمعالجات التصميمية المختلفة التي تزيد من توافق المبنى بيئيا وتقلل من أثره السلبي على البيئة المحيطة. كان الشكل والتوجيه وتوظيف العناصر الإنشائية للمبنى من بين العناصر التصميمية المعمارية التي تمت دراستها. اصطلاحات مثل نظم المعالجات الايجابية للمبنى والنظم النشطة تم طرحها ومناقشتها فيما يخص قضايا مثل الإضاءة والتهوية والتحكم الحراري. هذا ولم تقتصر الدراسة على ذلك بل تضمنت عرض لوسائل وأدوات تقييم الاستدامة المتاحة والمطبقة عالميا.
خلال الدراسة أيضا تم طرح وعرض اصطلاحات مثل العمارة الخضراء ودرة عمر المبنى وجودة الهواء الداخلي وظاهرة المباني المريضة.
وخلصت الدراسة إلى قائمة لحساب التكلفة البيئية وتوقع الآثار البيئية الناتجة عن عمليات إنشاء المبنى وكذلك تلك الناتجة عن عمليات تشغيل المبنى. هذا بالإضافة إلى عدد من التوصيات للمصممين ومهندسي البلديات تساعدهم في توجيه التصميم خلال مراحله ليكون أكثر توائما مع بيئة موقعه وأكثر اقتصادا في استهلاك الطاقة.

3. **Keywords**:

Sustainability, Green Building, Environmental Assessment.

4. Introduction:

Since the earth has finite material resources and biological capacity, humans must live within the carrying capacity of the earth. As we exceed the carrying capacity of the earth's ecosystems, over time they are stressed, then go into decline, and finally collapse. They are expended rather than renewed. The construction and operation of buildings in our modern cities contributes to these environmental loads. Those who design and purchase buildings, however have no methods to assess the environmental impacts of their actions.

Since Building impacts can be reduced through careful design and selection of materials and systems that are environmental friendly. It is important to have an assessment tool to evaluate the impacts of development activities on our environment in the present and future.

5. Definitions:

Since this paper deals with sustainability within tall buildings, it is needed to define at the beginning some of the used definitions:

5.1. Sustainability:

Through the last thirty years, the definition of "sustainable development" has been changed several times.

- In the 1970s, the term referred to maintaining natural resources [1 and 2].
- In the early 1980s the aim of sustainable development was satisfying human needs and improving the quality of human life on the one hand [3] and maintaining essential ecological processes and life support systems on the other [4].
- In the late 1980s, the approaches to sustainability emphasized social and economic aspects, which requires elimination of poverty and deprivation as well as the conservation and enhancement of the resources base.
- The most recent and common definition of sustainable development was defined by the World Commission on Environment and Development (1987): *The ability of humanity to ensure that it meets the needs of the present without compromising the ability of future generations to meet their own needs* [5].

5.2. Sustainable Building:

Sustainable buildings [6] can be defined as those buildings that have minimum adverse impacts on the built and natural environment, in terms of the buildings themselves, their immediate surroundings and the broader regional and global settings. Five objectives for sustainable buildings can defined as:

- Resource efficiency.
- Energy efficiency (including greenhouse gas emissions reduction).
- Pollution prevention (including indoor air quality and noise abatement).
- Harmonization with environment.
- Integrated and systemic approaches.

Sustainable building involves considering the whole life of buildings, taking environmental quality, functional quality and future values into account. It is therefore the thoughtful integration of architecture with electrical, mechanical and structural engineering resources.[6]

5.3. Tall Buildings:

The Council of tall Buildings and Habitat (CTBUH) defined a multistory buildings as follows: *"a multistory building is not defined by its height or number of floors. It is a building whose height creates different conditions in* *the design, construction, and operation from those that exist in "common" buildings of a certain region and period."*

In this case, the different conditions are those that most energy exchanges of the building with the outside environment take place via the façade. In multistory buildings, vertical surfaces (walls) usually represent the larger part of the total building surface. The higher the building, the more does this apply. When the ceiling of only one single floor of a multistory building is exposed to the exterior environment, exchanges taking place via the roof would not be very efficient (Figure 1).

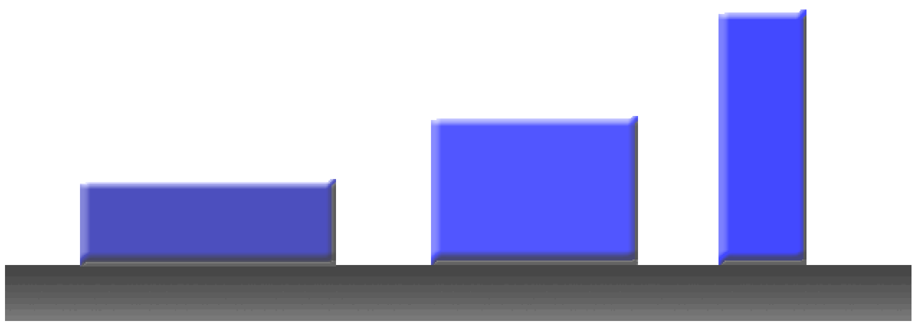

Figure 1: Higher Buildings Does Have Larger Surface Areas and More Energy Exchanges With the Outside Environment.

5.4. Sustainable Tall Buildings:

A Tall building is a complex product. The technology applied to such buildings involve almost every facet of pure and applied science. Its design and construction requires the involvement of various disciplines and trades. This type of buildings rely to a great extent on mechanical systems in order to achieve comfortable internal conditions.

To create a sustainable multistory buildings a lot of parallels may be drawn from a small one-story ecological building to a large multistory buildings. Energy concepts used by simple low-rise buildings could be transferred to demanding multistory buildings and Take all advantages of low-rise buildings in the vertical direction. Suitable approaches already known by simple, low-rise buildings could be picked out and applied to multistory buildings.

6. Sustainability Approaches in Architectural Design:

Since the design of any building derives from considered response to climate, technology, culture, and site, all approaches to sustainable architecture have used nature as a model. Each designer employed nature's order in his own fashion, putting the main emphasis on a different field.

- Ken Yeang adopted the "bioclimatic" approach. This approach, strongly inspired by nature, studies the effect of climate on the health and activity of human beings. It focuses on the relationship between the architectural form and its environmental performance in relation to the climate of the place. "Menara Mesiniaga" is an example for this approach. Figure (2).

Figure 2: Menara Mesiniaga, Selangor, Malaysia- 1992.

- Norman Foster, pursued the "eco-tech" direction. Eco-tech is a combination of "ecology" and "technology". It makes use of high technology for ecological purposes. Moreover It involves several other scientific fields. For instance, makes use of intelligent systems to minimize electric energy consumption, as well as applying digital technology to optimize building forms in terms of energy. Hong-Kong and Shanghai Banking Corporation headquarters (1985), Business Promotion Center in Duisburg, Germany (1993), Figure (3). Foster’s Comniei'z bank headquarters in Frankfurt (1997) the first "ecological high-rise" world-wide Figure (4) are examples for the eco-tech approach.[7]

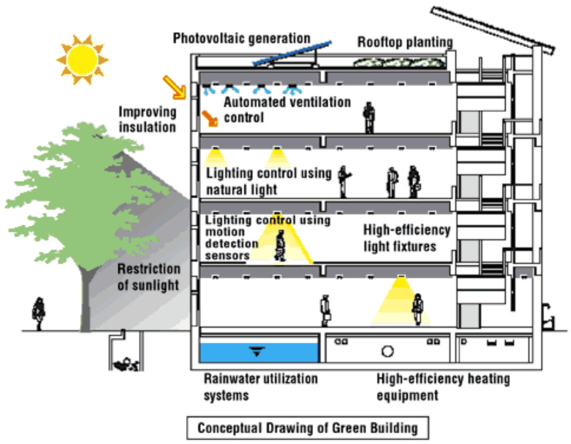

Figure 3: Climate Control Scheme, Business Promotion Center in Duisburg, Germany.

Figure 4: External view, Comniei'z Bank Headquarters in Frankfurt 1997.

- Many other established practitioners like Richard Rogers, Nicholas Grimshaw, and Jan Kaplicky developed similar approaches. "Green Building" was the prototype of the developed eco-tech. In "Green buildings", Depending on the conditions inside and outside, the skin of the building allows more or less air, light, and heat to pass through. Figure (5) illustrates a model for the suggested "Green Building" of London city hall building.

Figure 5: Model of green Building Project Designed by Future Systems.

- In 1999, a new generation of architects worked on eco-tech architecture, They adopted a concept for high-density "Zero Emissions Development Towers" (ZED Towers) incorporating passive and active energy strategies.

7. Different Sustainability Requirements For Different Buildings:

Different climates make different demands on lighting, solar control, ventilation, and temperature control. Generally, in warm climates heat is rejected while light and air are admitted, provided the air can cool and the light is diffuse. In cool climates light and heat are retained while air is not required for cooling.[8]

Architect must study the influences related to the location of the building. These include the macroclimate, topography, site dimensions and orientation, surrounding streets, adjoining buildings, building regulations, etc. The architect must deal with all these fixed considerations in his design. In order to reap maximal benefits of these facts, he must go into each case individually. The design of each project should respond to the particular climate and urban conditions of the respective site.

8. Sustainability Concepts Through Building Life Cycle (BLC):

Building Life Cycle starts with a development Plan and ends after the estimated life period of the building finished. Through this it goes through the following stages:

Design	Approval & Licensing	Construction
Occupancy	Post-Occupancy
Renewal or Demolishing.

Sustainability Concepts must be tackled through all the previously mentioned stages.

9. Sustainability Considerations Through Design Stage:

Passive Solar Design: It is a broad term used to encompass a wide range of strategies and options resulting in energy-efficient building design and increased occupant comfort. The following are the Renewable Energy Applications within buildings:

Passive Solar Heating	Passive Solar Cooling
Active solar Systems	Solar Hot water
Photovoltaic technology	Wind Integrated turbines.

Figures 6 and 7 illustrates the applications of renewable energy (solar and wind) applications within tall buildings.

Figure 6: Photovoltaic Facade

Figure 7: Building integrated wind turbines

Day-lighting: is the practice of bringing light into a building interior and distributing it in a way that provides more desirable and better-quality illumination than artificial light sources. Figure (8) demonstrates the relation between the room depth and Illumination level in traditional window, while Figure (9) demonstrates a smart device to deliver indirect illumination to the room depth.

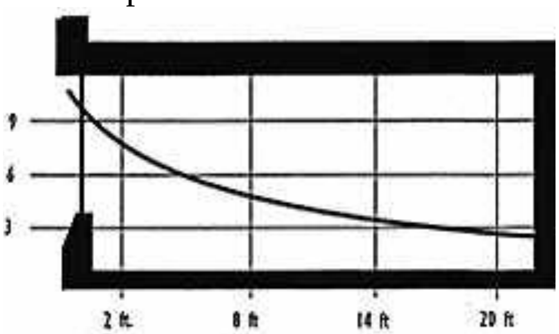

Figure 8: Illumination Relative to Distance into Room From Window

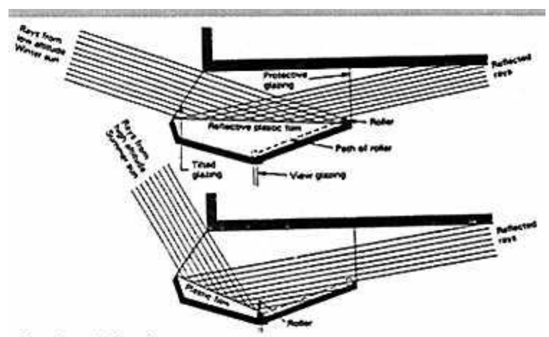

Figure 9: Advanced Light Shelf

- **Building Envelope:**

building envelope consists of structural elements and finishes that enclose space, separating inside from outside. This includes walls, windows, doors, roofs, and floor surfaces. The envelope must balance requirements for ventilation and daylight while providing thermal and moisture protection appropriate to the climatic conditions of the site.

- **Building Shape and Orientation:**

Building geometry determines the volume-to-surface ratio. The larger the surface area compared to the volume, the more energy can be exchanged between the external and internal environment.

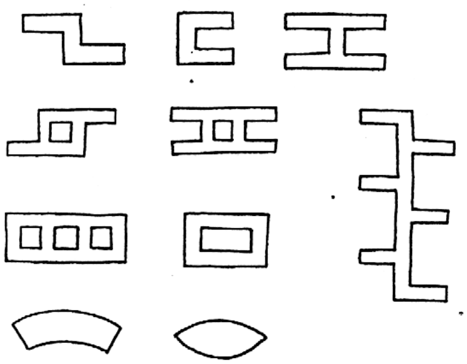

Figure 10: Plans Consisting of Long, Narrow East-West Strips

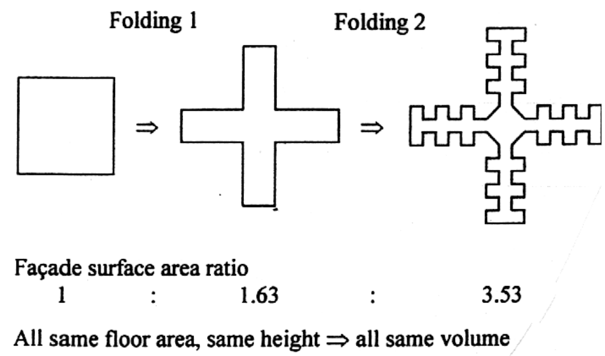

Figure 11: Different Plans With Different Façade Areas.

The building should be oriented towards the direction providing the most pleasant lighting, to maximize exposure to the required wind direction.

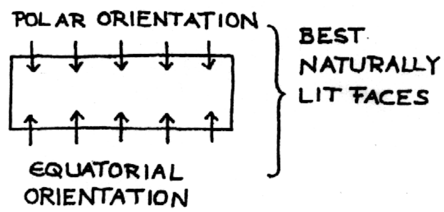

Figure 12: Long, Narrow East-West Plan.

- **Zoning of Spaces:**

Generally, favorable conditions should be given to regularly occupied work and living spaces, while less favorable conditions are given to spaces that are only occasionally occupied or that have less demanding requirements.

- **Building Voids:**

Voids are spaces cut out from the building to enlarge its surface area, i.e. the exchange area with the exterior environment. Figure (13) illustrates how does voids can enlarge the surface area. These spaces can be horizontally oriented such as balconies and sky-courts, or vertically oriented such as courtyards, atria, and shafts. Voids are specially required in deep-plan buildings.[9]

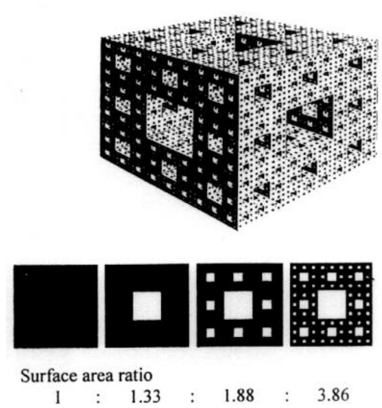

Figure 13: Voids Enlarging Surface Area

- **Openings' Design:**

When rooms are lit from the side, the amount of daylight and its penetration into the room obviously depend on the area (height, width) of the side-opening.

The higher the window head from floor level, the better light levels and uniformity will be (Fig.14).[10]

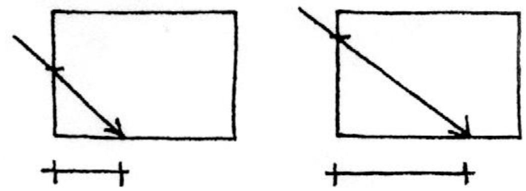

Figure 14: Head Height Determining Daylight Penetration

- **Building Structure:**

The use of projections and recesses in the design enables parts of the building to shade the openings of others. Projections and recesses are effective in the façade (for high-altitude sun) as well as in plan (for low-altitude sun). Examples for projections in the facade are balconies, bays, part of the facade width, or the whole facade width Figures (15, 16). There could be one single projection or several projections one above the other (stepped or staggered facade, Figures (17, 18).

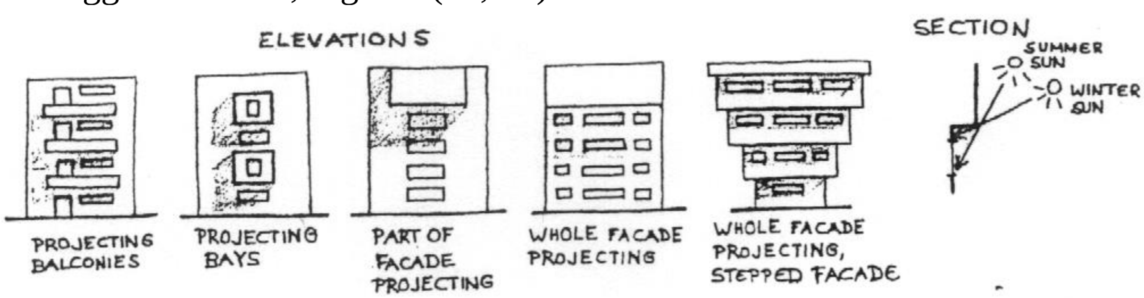

Figure 15: Different Types of Projections in the Facade

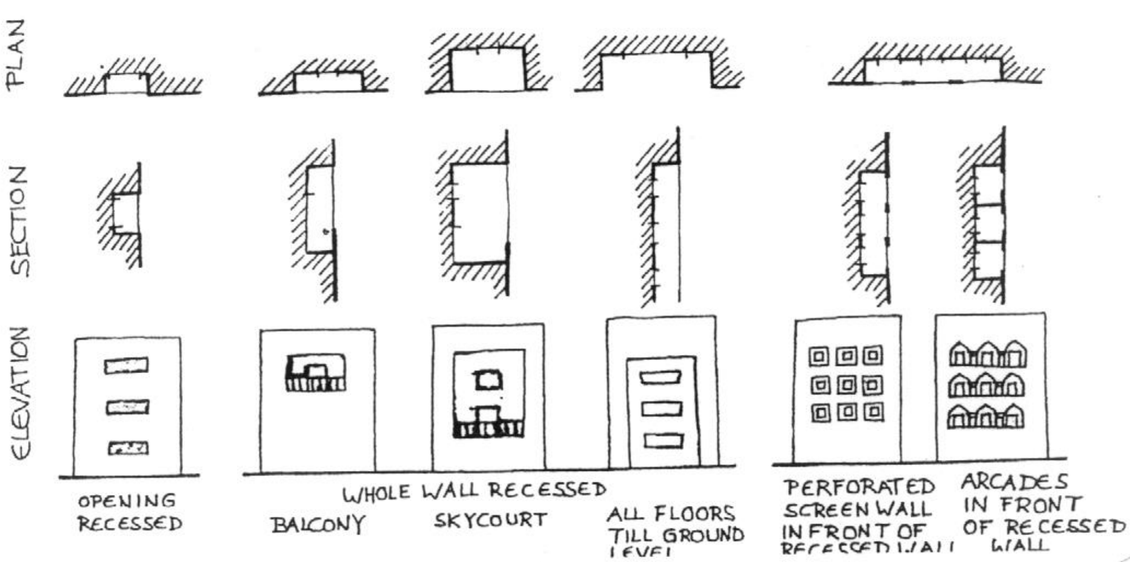

Figure 16: Different Types of Recess.

Figure 17: Projection Over Whole Façade Faculty of Engineering Alexandria, Egypt

Figure 18: Projection in Each Floor (Stepped Facade) Interior Ministry Building, Riyadh, Saudi Arabia.[11]

10. Building Systems and Indoor Air Quality Assurance:

Designing and installing environmentally sound and energy-efficient systems have a long-term impact on the cost-effective operations of a building and on the productivity of building occupants.

Indoor environmental quality needs to be reviewed, with a focus on indoor air quality (IAQ) and acoustics as two aspects that can affect building occupants' health and productivity.

10.1. HVAC (Heating, Ventilation and Air Conditioning Systems):

The amount of energy used annually by heating, ventilating, and air-conditioning (HVAC) systems typically ranges from 40 to 60 percent of the overall energy consumption in a building, depending on the building's design, the use of renewable energy strategies, climate, the building's function, and its condition. HVAC systems also affect the health and comfort of building occupants. These systems serve an essential function and are identified as problem areas more often than other occupancy issues. The following issues Should be considered during Building Systems Design stage:

- System Operation
- Indoor Environmental Quality
- Building Monitoring
- Thermal Comfort
- Energy Efficiency
- Maintenance Plans
- Air Quality
- Light Quality
- Noise control

10.2. Electric and Lighting Systems:

Electric systems' design should take the following considerations:

- Artificial lighting should be designed incorporation with day-lighting.
- Lighting should fulfill Occupants' needs for illumination.
- occupancy sensors should be part of the lighting systems.
- Energy efficient equipments and appliances.

10.3. Air Quality:

Sick building Syndrome (SBS) has become one of the most dreadful issues facing architects and mechanical-system engineers. Many of the IAQ problems result from some inappropriate operation or maintenance. As many as 75 percent of these failures stem from design and construction flaws because designers simply did not place enough emphasis on IAQ.

The quality of indoor air results from the interaction of many complex factors, each contributing different effects. The following table demonstrates the frequencies of occurrence of physical causes of problem buildings:

Table(1): The frequencies of occurrence of physical causes of problem buildings: [12]

Problem Category	Physical Cause	Frequency (%)
Design	System Problems	
	Inadequate outdoor air	75
	Inadequate air distribution to occupied spaces (supply and return devices)	75
	Equipment Problems	
	Inadequate filtration of supply air	65
	Inadequate drain lines and drain pans	60
	Contaminated ductwork or duct linings	45
	Malfunctioning humidifiers	20
Operations	Equipment Problems	
	Inappropriate control strategies	90
	Inadequate maintenance	75
	Thermal and contaminant load changes	60

For improved indoor air quality, design should involves four interrelated principles that should be implemented as a whole:

Source control: Contaminant Sources may originate indoors, outdoors, from occupants, and from within the mechanical system of the building.

Ventilation control: Ventilation control involves many systems that need to be designed and modified as necessary to provide energy efficiency and adequate ventilation for building occupants.

Occupant activity control: IAQ problems may occur because of the thermal load generated by the occupants, their activities, and their equipment exceeds the HVAC system's capacity to control the heating and cooling to ventilate the space.

Building maintenance: AIQ in poorly maintained buildings can deteriorate quickly. Materials, products, furniture, and HVAC systems need regular maintenance, cleaning, and inspections to ensure that they function as designed and to prevent indoor contaminants from developing within It.

11. Building Sustainability Assessment:

Buildings have a direct impact on the environment, both during the construction process and its use. It is almost imperative that the environmental issues are tackled right from the design stage. But, what are these issues that make a building sustainable? This is the important question. Architecture is not a building alone, but a building in its environment. Hence, the site is also an important issue. While a building inevitably consumes materials and energy resources, the technology is available to use methods and materials that reduce a building's environmental impacts, increase operating efficiency, and increase durability. For environmentally responsible buildings, Architects must think in an integrated way.

A number of principles that can be synthesized in the creation of sustainable built environment. Certain parameters should be part of the analysis and design decision-making process.

These parameters are: land development; building design and construction; occupant considerations; life cycle assessment; volunteer incentives and marketing programs; facilitate reuse and remodeling; and final disposition of the structure[13].

12. Assessment Tools

Two main different categories of assessment tools are known in this field. One of them is well established and adopted by many governments around the developed world. the following are samples of such systems:

BREEAM Tool (U.K.): *"Building Research Establishment Environmental Assessment Method"* (commonly referred to by its acronym BREEAM) was launched in the UK in 1990 to provide an environmental assessment and labeling scheme for buildings. It is a voluntary market-oriented assessment of a building's environmental performance allows licensed assessors to perform assessments to maintain a consistent level of quality and objectivity. Buildings are assessed for both construction and operation. Metrics include environmental impact, energy efficiency, and health. Assessments are scored in terms of "credits earned" for good performance on water conservation, carbon dioxide emissions, etc. [14]

BREEAM credit system for existing buildings:

Part I: Building envelope and system		**Part II: Operation and management**	
Global issues		*Global issues*	
CO_2 / energy	12	Environmental policy	3
Acid rain	1	CO_2 / energy	7
Ozone depletion	5	Ozone depletion	2
Recycling of materials	1	Building maintenance	2
Local issues		Local issues	
Water conservation	2	Microbial contamination	1
Microbial contamination	1	Noise	1
Transportation	2		
Indoor issues		Indoor issues	
Lighting	1	Lighting	1
Air quality	3	Air quality	3
Hazardous materials	2	Hazardous materials	1
Radon	1	Microbial contamination of DHW	1
Indoor noise	1	Healthy building indicator	3
Microbial contamination of DHW	1		
Total	**33**		**25**

LEED (U.S.A.): It is a similar assessment system known as "Leadership in Energy and Environmental Design" or "LEED". It does have the same elements of the BREEM checklist.[15]

GBT (Canada): "*Green Building Tool"* (GBT) is an evolving assessment system sponsored by National Resources Canada that has generated substantial interest. Both LEED and GBT are scoring systems that use code compliant built environments as baselines to evaluate the environmental performance of the building being assessed

The second category of assessment tools are referred to as nature-based checklists. This includes "*Malcolm Wells Wilderness-based checklist*", the *"Net Positive Change"* analysis, and the *"Tadoseec"* checklist. All these methods share the concept that natural systems provide services we desire, and we should rate our interventions for their ability to also provide those services. In addition, each of these checklists provides the ability to rate an intervention positively as well as negatively, setting the stage for regenerative design rather than only reducing impact. These checklists have the advantage of being design oriented, i.e. providing direction and information for designers in the design stage. They are also simple, and do not require extensive research or expense to complete.[16]

New tools have emerged for identifying individual critical impacts caused by building construction and operation. Buildings utilize the raw materials generated through ecosystem services and depend on the waste assimilation and climate regulation provided by ecosystem services. Two metrics could be thereby generated; the "*index of building sustainability"* (IBS) and the index of *"efficiency in sustainability"* (IES). These two metrics can be applied to assess both construction and operational impacts.[17]

13. Proposed Evaluation Check-list:

Constructing a building has an environmental cost. Running the building has an environmental cost as well. Developers, designers and builder should pay attention to the environmental cost of their design decisions. The paper suggest a check-list for those and municipalities to help in evaluating of the environmental impact of every proposed building.

Science each development plan goes through certain stages, sustainability should be in mined through those stages. The following proposed checklist goes through theses development stages to help in assessing environmental price of the development actions:

13.1. Building Construction Environmental Cost:

In this section, the needed amount of energy and Co2 emissions to manufacture the building construction materials. The following table presents the proposed form to calculate the environmental cost for building construction:

Table 2: Environmental cost for building construction materials:

Material	Amount (units)	Energy Needed for total units	Energy to produce material	Emissions of Co_2 to produce material	Recycling Factor
Concrete					
Steel					
Wood					

Masonry					
Aluminum					
Plastic					
Carpet					
Ceramics					
Glass					
Finishes					
Furnishing					
Total for building Construction Materials' Effect:					

Through the previous table, both the total needed amount of energy and **Co_2** emissions needed to manufacture the building construction materials would be calculated. It is suggested to develop a set of charts:

First set of these charts relates both emissions and energy needed to manufacture different construction materials.

Second set of charts combine a bench mark charts for average emissions and energy for different building types per square meter.

Putting the result values from table 2 on these charts, building environmental impact could be assessed.

13.2. Building Running Environmental Cost:

Both Inputs and outputs of building operations defines its environmental impacts.

Input Elements:

Despite operation input depends on the building type, energy and water constitute the basic entry elements in any building operation.

The energy needed to run all the building mechanical and electrical systems. These systems include: Lifts, Air-conditioning, lighting and Home Appliances. This energy should be calculated per square meter of its area and compared to the standard Benchmark. This will give a good idea about its environmental impact.

Output Elements:

Output elements vary according to building type. In general, each output type should be calculated separately and compared to bench mark. The main issues that should be considered in the environmental impacts proposed checklist are:

Solid Waste: the amount of the expected solid waste, its collection System and solid waste treatment.

Liquid Waste: the calculated amount of liquid waste, the type of that waste (Acidic, alkaline, ….), Treatment for that waste, recycling of the liquid waste.

Gaseous Waste: Any expected resulting gaseous wastes should be estimated.

Electromagnetic Waste: The power and range of magnetic, electric, radio fields generated from the building systems and equipments. The building treatment to contain and isolate such emissions.

Noise: levels and places of noise sources within building should be identified. Their effective range should be identified. The treatment suggested to reduce their impacts.

Traffic impact of the building: (estimated car parking needed for building users verses available car parking lots within building premises).

More socioeconomic factors could be added to this checklist like the number of work positions created during the both construction and operation of the building.

The main issues that should be considered in the environmental impacts proposed checklist are in the following table:

Table (3): Running Environmental Impact:

Material	Effective range	Amount per area unit	Treated Percentage	Treatment Method	Recycled Amount
Solid Waste					
Liquid Waste					
Gaseous Waste					
Electromagnetic Waste					
Noise					
Traffic impact of the building					

14. Conclusion:

- Considering Sustainability in every aspect of our civilization is our obligation to the next generations.
- Green Building Approach should be considered while developing any modern building and its modern systems.
- Traditional and low-rise sustainable concepts and treatments are can be adopted in any tall building.

- Sustainability should be adopted through the whole Building Life Cycle.
- Building design should be a direct response to the macroclimate of the location, its microclimate and the building site. Each case must be treated individually, going into the particular conditions.
- If maximum use of available natural resources were targeted while deigning, completely different design solutions will appear.
- Environmental cost to build and run any Building should be estimated and compared to approved benchmark.
- Designers should carefully consider design factors affecting building environmental impacts.
- Building laws should encourage building owners and designers to take environmental impacts of their design and construction decision.
- Local authorities should adopt the proposed environmental impact checklists proposed through this study.
- Local authorities should encourage developers to consider green building approaches while developing their projects.

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