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# Sustainability Criteria Used in Designing Energy-efficient Smart Cities - A study of Masdar City as a Model for One of The Smart Cities That Realize the Idea of Sustainable Development

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## ABSTRACT

The research aims to study the sustainability criteria used in the design of architectural and urban projects in order to achieve the idea of sustainable development. The study is also exposed to the mechanisms of applying sustainability when designing new cities with the aim of relying on renewable energy sources and reducing dependence on typical energy sources and thus reducing the negative environmental impact of these cities on the environment.

The research also deals with a study for the design of a smart city, which is Masdar City, as one of the cities that realize the idea of sustainable development, with the aim of identifying the design ideas used in the design of city facilities, as well as planning ideas, which aim to rely on renewable energy sources and thus achieve the concept of clean development that takes into account the right of future generations and preserves The environment.

The research aims to identify environmental design ideas that the designer can benefit from when designing an architectural project or a new urban project, through which he can apply the concept of sustainability and sustainable development.

**Keywords:** Sustainability - Sustainability criteria - Sustainable development - Smart cities - Foundations of energy conservation - Renewable energy sources.

## 1 INTRODUCTION

The concepts of sustainability in urban and architectural projects are represented in designing an environmental facility that does not pollute the surrounding environment in order to achieve the elements and requirements of sustainability, which is to take into account the use of renewable energy sources in order to rationalize the use of typical energy sources that pollute the environment. Also, consideration must be given to providing the facility with mechanical systems for the recycling of solid

and liquid waste. The building must also be provided with systems capable of eliminating toxins by reducing the emission of carbon polluting the environment, taking into account the provision of appropriate rates of natural lighting and natural ventilation when designing projects to provide an appropriate healthy environment. It must be taken into account that the project is complementary to the life cycle of the public site through the use of natural resources, such as setting up a mechanical system inside the project to collect rainwater for use in the water cycles. The research aims to identify the design ideas used in the design of smart city facilities that achieve the idea of sustainable development in order to define these ideas for the designer to follow when designing these clean cities compatible with the environment. Where the study deals with the city of Masdar in the United Arab Emirates as a study sample through the study of environmental design ideas in the facilities of Masdar City.

## **2 RESEARCH METHODOLOGY**

The proposed research approach to address the research problem depends on inductive reasoning by collecting a set of information and data from which a set of facts can be deduced through the theoretical study. With the aim of setting a rule represented in defining the sustainability criteria used in the design of smart, energy-saving cities, and then applying those ideas through an applied study on Masdar City as a study sample with the aim of identifying the design ideas used in the city and placing them as recommendations within a guide that the designer can benefit from when designing smart cities compatible with The environment.

The theoretical study aims to:

- A study of the concept of environmental architecture, sustainability and sustainable development.
- Identify the goals and principles of sustainable architecture.
- Study the sustainability criteria used in the design of architectural facilities.

The applied study aims to:

- Apply sustainability criteria to the study sample Masdar City.
- Determine the design ideas used in the design of Masdar City facilities in order to benefit from them by the designer when designing smart cities that are compatible with the environment and depend on natural energy sources.

### 3 RESEARCH STRUCTURE

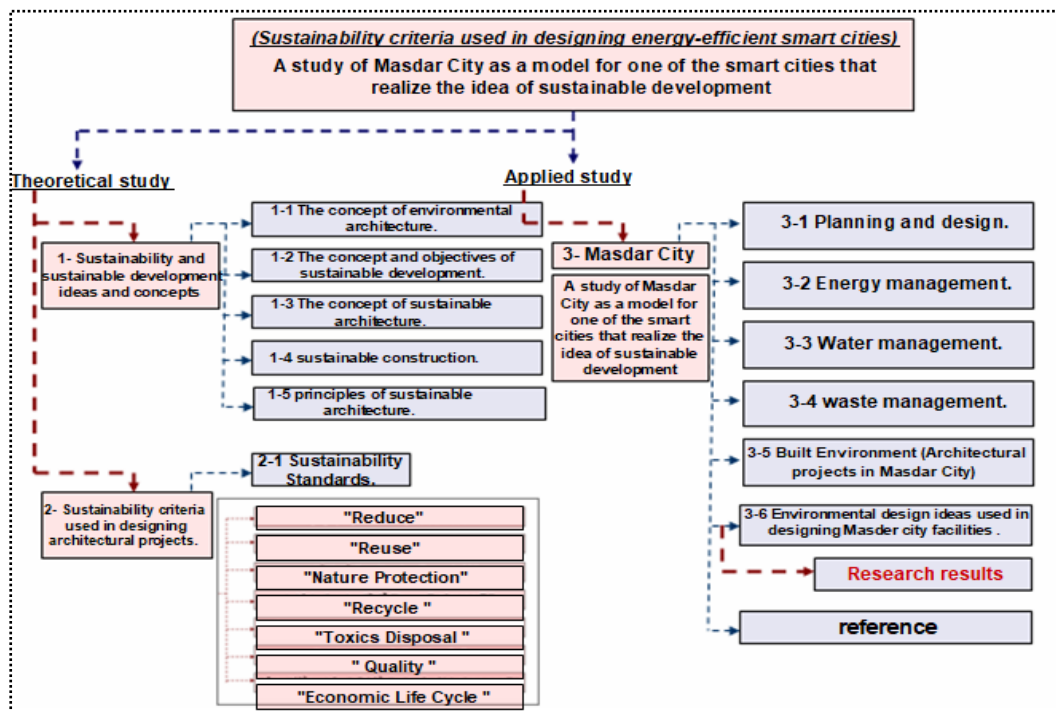


Figure (1): The Research structure (Source: Author).

### 4 SUSTAINABILITY and SUSTAINABLE DEVELOPMENTS IDEAS AND CONCEPTS.

#### 4.1 The concept of environmental architecture:

Environmental architecture is a process that ensures that the building is designed in a manner that respects the environment, taking into account reducing the consumption of energy and resources, as well as reducing the impact of construction and use on the environment and maximizing harmony with nature. It is also the architecture that is compatible with the environment so that it benefits from all the elements of the natural environment around it and meets the needs of the human being to protect him from all the surrounding natural conditions while providing the appropriate climate for him to perform all his living, social, religious and cultural activities and vary from place to place according to the difference in the natural environment. Environmental design means creating healthy buildings that do not affect or change much in the surrounding environment. An ecological building is a building that is established without saving in terms of economic cost, but its materials last over time to reduce maintenance costs and may change from average to high depending on the desired comfort level and the economic situation of the customer [1].

#### **4.1.1 Environmental Architecture depends on five basic elements [1]:**

**1- Achieving a healthy indoor environment:** All possible measures are taken to ensure that materials and buildings will not cause emissions or toxic gases.

**2- Achieving the principle of energy efficiency:** all possible measures must be taken to ensure the minimum use of energy in buildings.

**3- The use of environmentally compatible materials:** that does not cause damage or bad environmental impacts.

**4- Achieving design quality:** achieving efficiency and continuity in land use, movement lines and construction techniques, as well as historical symbolic relations, spiritual dimensions and connection to the land.

**5- Achieving the ecological form:** the design and projection are linked to the site, region and climate, and attention is paid to re-cycles, energy efficiency and homogeneity of the human relationship with the environment.

#### **4.1.2 Principles of Environmental Architecture:**

**1- Creating harmony between the building and the environment, saving energy and preserving the health of the population.**

**2- The main use of materials that are widely available in the local environment of the site and do not require a large capacity for processing (energy saving) and are not harmful to human health.**

**3- Ensuring the building's flexibility to accommodate potential changes in the future.**

**4- Orientation towards an efficient system to save energy (thermal insulation - natural lighting), relying on the local climate and using modern technologies such as solar panels and natural heat reduction tools.**

**5- Using materials that can be recycled and reused in the event of a building demolition. The facilities must be characterized by a breath-taking beauty and give comfort in the soul (sufficient lighting - natural colors) and achieve symbolic dimensions with history, land, culture and spiritual principles and the use of plants as an element of design.**

## **4.2 The concept and objectives of sustainable development:**

Development means that it is a conscious and time-bound planned process to create structural variables to raise the economic, social, cultural, urban and political level. There is no doubt that the development process has a final outcome, which is the improvement of human behavior, and this in itself is considered the most that the development process aims at. Of course, achieving this goal requires a change in the

material and non-material conditions of the standard of living for the better, in addition to the satisfaction of social and physical desires and requirements [2].

### **4.3 Sustainable development:**

Continuous or sustainable development is a simple idea, but it is of great importance. It is to achieve a balance between the economic, social and urban goals of the environment with the available capabilities. It combines two basic principles, namely, meeting the needs of the present generation and not infringing on the possibility of future generations to meet their requirements in the future. Using natural resources without waste and protecting the natural environment [2].

#### **4.3.1 Sustainable Development Goals:**

Sustainable development aims to protect and preserve natural resources and the environment, manage energy, waste and transport at different levels (**the biosphere - the built environment - the social environment**) [2].

##### **4.3.1.1 At the level of the biosphere:**

1. Maintaining the integrity of the basic environmental processes in the ecosystems on which humans depend in the development of resources, such as the ability of the soil to restore its fertility.
2. Maintaining the inherited resources found in the world's organisms.
3. Securing the sustainable use of living organisms and ecosystems such as fish and forests.

##### **4-2-2-2 At the level of the built environment (technological):**

1. Selection of technical means with limited waste.
2. Relying on waste recycling.
3. Rationalization and good selection of industrial centers sites.

##### **4.3.1.2 At the level of the social environment:**

1. Keeping balance between the available resources and the basic needs of human beings in the long run.
2. Laying out development plans for renewable and non-renewable natural resources within a time frame that achieves justice between generations.
3. Achieving broad popular participation.
4. Rationalizing the consumption of all resources and setting priorities for different uses.
5. Regional and international cooperation to meet the requirements and problems of the environment.

### **4.4 The basic elements for achieving sustainable development:**

Sustainability is achieved through the three basic elements [3]:

**1- Environmental sustainability:** (reducing waste, reducing harmful emissions to the environment, reducing negative effects on human health, turning to renewable raw materials, getting rid of toxic materials).

**2- Social sustainability:** (providing health and safety for the scope of work, studying the effects on local communities and the existence of life, providing care to the disabled and homeless).

**3- Economic sustainability:** (creating and opening new markets and opportunities for sales growth, reducing costs through improving efficiency and lower consumption of energy and raw materials, researching the creation of added values for continued economic growth).

#### *4.4.1 Pillars of sustainable development [4]:*

**1- Unity of destiny and common future:** Environmental pollution does not recognize international borders.

**2- Sustainability and continuity:** Development must meet the needs of the present for all and continue without prejudice to the needs of future generations. This is done by satisfying the basic needs of the world's poor and preserving the environment and not depleting it within the limits of the environment's ability to renew through rationalizing resources.

**3- Equality and equal opportunity:** Justice must be applied in the interest of humanity to prevent the domination of big companies and prevent them from harming the interest of the majority and the interest of the environment.

**4- Popular participation:** It takes place through decision-making processes at the local, national and global levels in environmental concern and rationalization of the use of resources.

**5- Social justice:** for the success of continuous development, the costs of protecting the environment must be shared with fairness and equality between generations and must be redistributed and not concentrated in the hands of a minority and deprivation of the majority, which leads to the destruction and depletion of the environment.

**6- Values:** highlighting the values of justice, equality between generations, rationalization of consumption, aesthetic and human values, participation and cooperation, original religious values, and the need to refer to heritage and religions.

**7- Organizing and rationalizing the population:** Sustainability is linked to the population in three ways: counting - distribution - characteristics.

#### *4.4.2 The strategy that achieves the sustainable development goals:*

Caring for the land for the continuation of life depends on acceptance and harmony between people and each other and the surrounding nature, and the use of modern technology methods developed

provided that they do not harm the environment. There are a number of principles that must be followed to reach sustainable living [4].

**1- Respect and concern for the community of life:** development should not be at the expense of other groups or future generations. It aims at dividing the benefits and costs of using resources and achieving environmental protection. Life on Earth is part of an integrated ecosystem and its survival depends on each other.

**2- Improving the quality of human life:** Development aims to realize human potential, economic growth, and improve human life.

**3- Preserving the vitality and diversity of the land:** continuous use is the reason for the depletion of capacity, and this means preserving the components of the environment such as air, water, soil, and protecting plants and animals.

**4- Reducing the depletion of non-renewable resources:** such as minerals, oil, gas, coal, plants, fish and soil.... etc.

**5- Life within the bearing capacity of the earth:** Policies and careful management must be followed along with techniques that bring human life back to the balance of nature's capacity.

**6- Changing personal attitudes and practices:** to adopt morals and values that call for continuity.

**7- Enabling the population to take care of their environment.**

**8- Providing a national framework for the integration of development and protection:** setting stable economic and social laws and policies, setting a national program to achieve continuity, including all interests and avoiding problems.

**9- Creating a global alliance:** to achieve global continuity.

#### **4.5 The concept of sustainable architecture [5]:**

**1-** Sustainable architecture aims to achieve the appropriate built environment for human comfort without polluting the earth's environment and preserving it suitable for human life, whether at the present time or in the future.

**2-** Sustainable urban design means that urbanization belongs to the environment and is friendly to it, as it consumes its resources to the extent that achieves a healthy environment for its residents and does not prejudice the right of future generations to meet their needs from natural resources.

**3-** Sustainable development is development that meets the needs of the present without reducing the ability of future generations to obtain their needs from natural resources.

**4-** Sustainable development is the research and implementation of radical plans that enable society to succeed in its equilibrium interaction with the natural system (vital or abiotic) by maintaining a

certain level that allows its recovery. From the solidarity of all efforts in all disciplines to reach sustainability and preserve our world.

5- It is a highly efficient system that conforms to the environment with minimal collateral damage, and achieves efficient use of resources and energy. The concept of sustainable architecture is defined by addressing: sustainable construction, environmental architecture (ecological, green) as follows:

#### **4.5.1 Sustainable construction:**

Sustainable construction refers to creativity, built environment management, resource and energy efficiency, and taking the ecological dimension into consideration. Sustainable construction also aims to reduce its impact on the environment, and thus includes the following six principles [6]:

- 1- Minimum consumption of non-renewable resources, and reaching the maximum amount of reuse.
- 2- Relying heavily on new, renewable and recyclable resources.
- 3- Protection and improvement of the natural environment.
- 4- Avoiding the use of toxic substances.
- 5- Studying the concepts of quality in creating the built environment.
- 6- Relying on recyclable building materials is one of the principles of sustainable construction.

#### **4.5.2 Principles of sustainable architecture:**

Providing a healthy indoor environment through the use of building materials that do not emit what harms humans or the local environment and achieves good ventilation in addition to using plants that help get rid of carbon dioxide and produce oxygen [7].

Efficient use of energy sources in cooling, heating, lighting and other uses, through the use of design solutions that achieve thermal human comfort in a natural manner with the use of the least amount of energy, in addition to employing renewable energy sources to obtain clean electric energy needed to improve the local and internal environment. Use of environmentally friendly building materials that can be reused more than once and that they are produced from resources and raw materials from the natural environment such as clay, wood and others [8].

##### **4.5.2.1 Conserving energy:**

The building should be designed and built in a way that reduces the need for fossil fuels and depends more on natural energies, and ancient societies understood and realized this principle in many cases. All buildings, like living organisms, need effective skins to control their internal temperature during the day and throughout the year [8].



#### **4.5.2.2 *Adapting with climate:***

The building must adapt to the climate and its different elements. The moment the building is finished, it becomes part of the environment like a tree or a stone, and becomes exposed to the same effects of the sun, rain or wind as anything else in the environment. If the building can face the pressures and climatic problems at the same time It uses all available climatic and natural resources in order to achieve human comfort inside the building, so this building can be called climatically balanced. The problem of climatic control and creating an atmosphere suitable for human life is as old as humanity itself. Man was keen to include two main elements in his construction of the shelter: protection from the climate, and an attempt to create an interior atmosphere suitable for his comfort [9].

#### **4.5.2.3 *Minimizing new resources:***

This principle urges designers to take into account reducing the use of new resources in the buildings they design, as it calls upon them to design and construct buildings in a way that makes them themselves or some of their elements - at the end of the lifespan of these buildings - a source and a resource for other buildings, as there are few resources worldwide to construct buildings for future generations. Especially with the expected population increases, he calls on construction workers to take care of applying this principle with different and innovative methods and ideas at the same time [9].

#### **4.5.2.4 *Respect for the site:***

The main objective of this principle is for the building setting up on the ground in a way that does not bring about fundamental changes in the features of the site. From an ideal and exemplary point of view, if the building is removed or moved from its location, the site will return to its previous state before the building was built [10].

#### **4.5.2.5 *Respect for customers and users:***

If green architecture pays attention to the issue of energy and resource conservation, as designers warn of the importance of respecting the environment in general, there is no doubt that it gives greater attention to those dealing with it, whether they are workers or users, then human safety and preservation is the paramount goal for it [10].

#### **4.5.2.6 *Holistic design:***

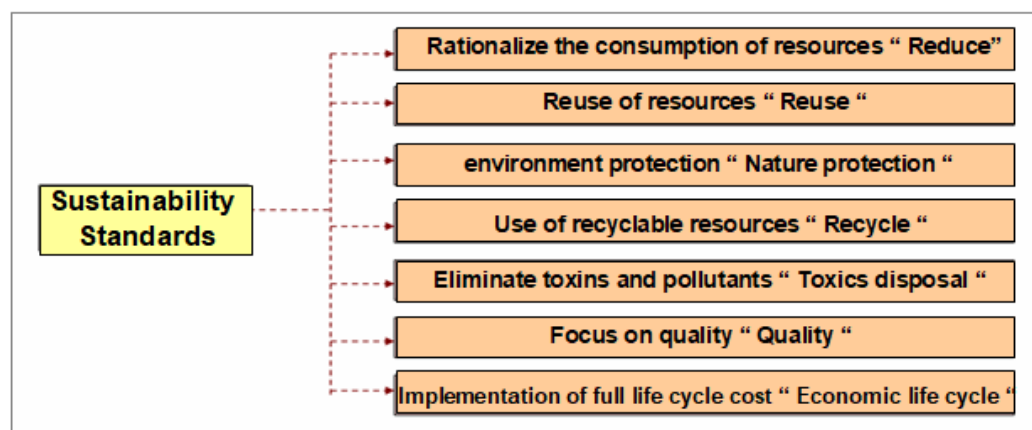
All previous principles of sustainable architecture must be taken into account in an integrated manner during the building design or city planning process, and it may be difficult in practice to

achieve all the previous principles, but with deep and careful study as well as the community's conviction of this thought, this will not be impossible [10].

Sustainability criteria used in designing architectural projects.

Sustainable architecture is one of the architectural trends that are concerned with the relationship between the building and the surrounding environment, which emerged as a result of the environmental and economic challenges that cast shadows on various sectors in the current era, the most important of which is the construction sector because of its great importance and impact on environmental development. Sustainable architecture is the design of buildings, taking into account environmental and sustainable development goals, and sustainable architecture seeks to reduce the negative effects of buildings on the environment by maximizing efficiency and moderation in the use of building materials and energy and developing spaces. Since all resources in the form of materials or energies must be taken into account if we want to achieve sustainable architecture [11].

Sustainable architecture is based on a set of criteria in order to achieve its goals of establishing and operating healthy built environments, and to achieve its goals depends on the efficiency of resources and environmental design, and these criteria can be clarified in the following elements **Figure (2)** [11]:



**Figure (2): sustainability criteria affecting the design of energy-saving smart city facilities (Source: Author).**

#### **4.6 “Reduce “reducing the consumption of resources [12]:**

1- Energy consumption in the building that is used for cooling, heating and lighting must be rationalized through the design of the facility, an environmental design that suits the surrounding environment, and relies on renewable energy sources such as natural light for lighting, and sunlight for internal heating.

2- The use of renewable energy reduces dependence on non-renewable sources such as fuel and reduces gaseous emissions associated with its use as a main source of energy.

3- Using photovoltaic cells that generate clean solar energy and integrating wind turbines and biomass in generating energy inside the facility.

#### **4.7 “Reuse “Reuse of resources [12]:**

1- Reusing the building through its dismantling and assembly in another place, or re-changing the building activity to another activity. Through the design of the building can be demounted and re-created Design for Deconstruction.

2- Reusing and employing the building structural Skeleton, and building products used in the building after the end of its useful life.

#### **4.8 Environment protection “Nature protection “[12]:**

1- Taking into account the impact of the surrounding environment on the shape and mass of the building.

2- Taking into account the orientation of the building to make the most of the natural lighting and ventilation.

3- Integrating Green Roofs when designing the building and linking with the surrounding environment.

4- Using the means of shading to protect from the sun's rays and employing light-colored sidewalks and roofs to reduce the heat loads resulting from exposure to the sun.

5- Evaluating the building materials used in the implementation of the building in terms of the environmental impact during the full life cycle of the building materials from production, installation, operation and up to the final disposal stage.

6- Reducing the use of materials that have a negative impact on the internal environment, such as volatile organic compounds and toxic substances such as lead, asbestos, and materials that contain CFCs, which damage the ozone layer.

#### **4.9 Use of recyclable resources "Recycle” [13]:**

1- Designing and innovating new methods for treating and recycling water waste.

2- Integrating rainwater collection systems into the building design with its various components, including rainwater collection and storage in water tanks in preparation for treatment and reuse.

3- Expand the use and employment of gray water (the water resulting from the use of showers and hand washing basins, which can be treated and filtered in biological filters to be re-used in irrigating gardens or even in toilets parcel boxes in some cases), as well as black water (which is the water resulting from the use of Toilets and kitchen sinks, which contain a high percentage of biological pollutants) in the work of landscaping the site and irrigating plants and trees.

4- Using standard water treatment systems that depend on biological treatment methods **Figure (3)** [13].

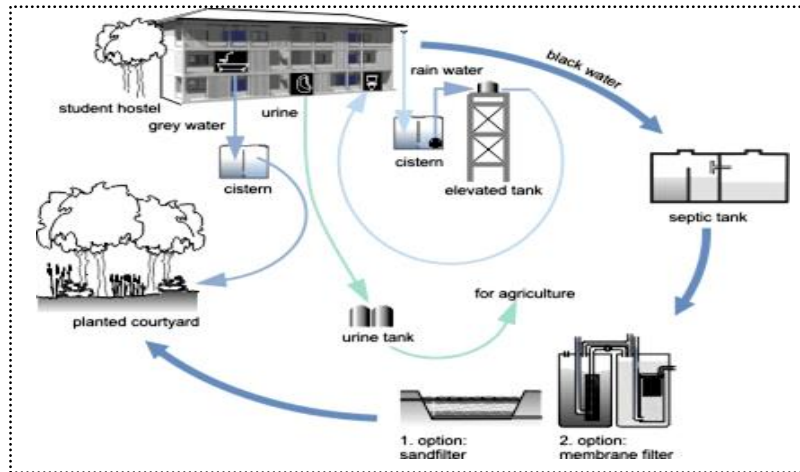


Figure (3): Methods of achieving water recycling and reuse in the building (Source: ref. [13]).

#### 4.10 Eliminate toxins and Pollutants “Toxics disposal “[14]:

1- Not to use building materials that contain a high percentage of volatile organic compounds (VOC), which are often found in products of adhesives and paints, which negatively affect the health of building users.

2- Avoid using building products that contain formaldehyde compounds, such as rug systems and some types of interior partitions.

3- Securing the indoor environment from pollutants affecting the public health of the users, such as bacteria and fungi that may spread through the indoor air and help spread diseases among the building users. By raising the efficiency of HVAC refrigeration and air conditioning systems by adding air treatment systems using purification filters.

4- Develop a mechanical system to get rid of the waste that results from the use of individuals inside the facility, such as using the output of those solid and liquid wastes resulting from the bathrooms in the work of cultivating the public site **Figure (4)**.

5- Reducing the emission of carbon and toxic materials through the use of materials that do not pollute the environment in the implementation of the building. As well as the use of mechanical systems to treat the heat emission resulting from the users of the spaces, which leads to the emission of toxic gases polluting the environment from the building materials used such as asbestos, so care must be taken to use environmentally friendly materials that do not lead to the emission of toxic gases [14].

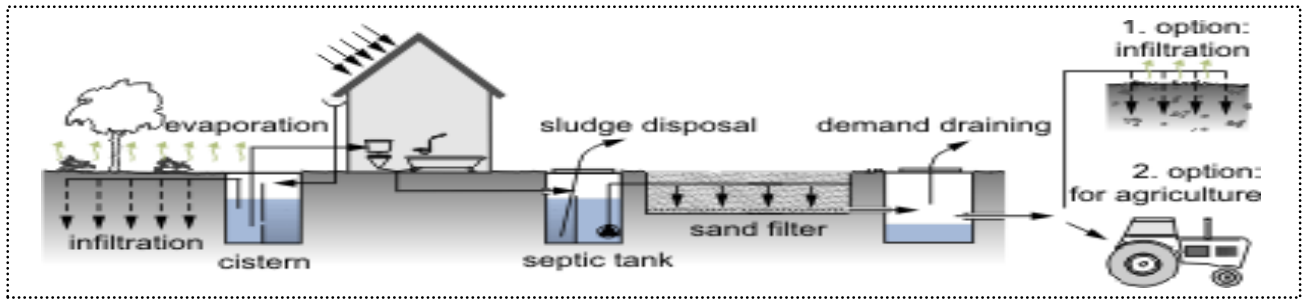


Figure (4): Use of solid and liquid waste products resulting from the building in cultivat the site (Source: ref. [14]).

#### 4.11 Focus on quality “Quality “[15]:

1- Paying attention to achieving internal environmental quality standards by providing flexible internal spaces that respond to the current and future needs of the building's users.

2- Achieving aesthetic standards in the spaces by providing views and aesthetic elements and integration between the internal environment of the building and the surrounding environment.

3- Ensuring levels of acoustic comfort, by providing the appropriate internal environment for users and reducing noise through the use of materials with appropriate acoustic properties of insulating and sound-absorbing materials in walls and floors in order to overcome the public's voice within the building spaces. Providing the building with appropriate levels of natural ventilation.

4- Ensuring that the ventilation and refrigeration systems meet the indoor air quality standards, which are regulated by the international bodies for standardization, such as the standard specifications of the American Society of Air Conditioning and Refrigeration Engineers, (**A.s. Standard**) [15].

#### 4.12 Implementation of full life cycle cost “Economic life cycle “[15]:

In general, the building should be part of the life cycle, so it should not be a source of pollution, but rather contain the capabilities that help to complete the natural life cycle on earth through the conservation and provision of drinking water and the recycling of water resulting from the remnants of human use of water cycles. Reuse of organic waste for plant cultivation. Collecting and storing rainwater for use inside the building. Reducing toxic emissions resulting from the use of the source. In general, the building must be integrated with the environment and be complementary to the life cycle of living organisms on Earth, and not be a source of pollution, leading to a disruption of the life cycle on Earth **Figure (5)** [15].

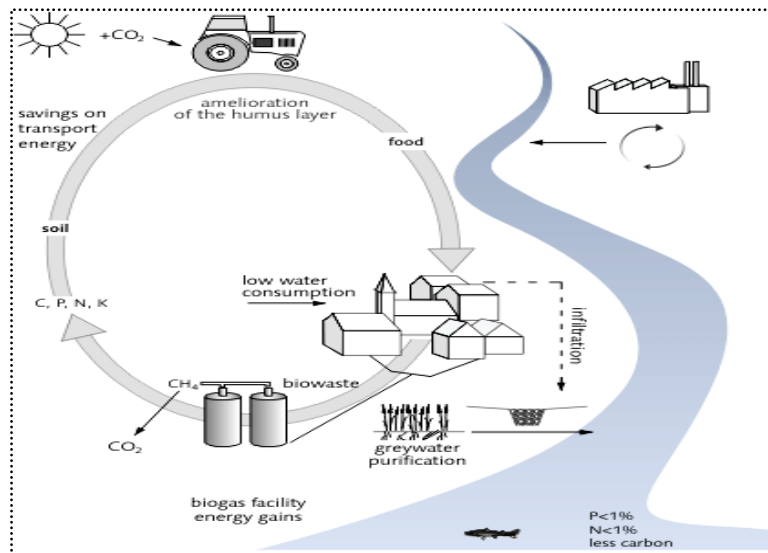


Figure (5): The building must be part of the sequence of the complete life cycle on Earth (Source: ref. [15])

Study of Masdar City as a model for one of the smart cities that realize the idea of sustainable development.

## 5 A model for sustainability criteria and the application of green architecture concepts in planning and designing an ecological city

Architectural design company LAVA won first place in the competition to design the center of Masdar City, which is located near Abu Dhabi Airport in the United Arab Emirates. Where the city center will be characterized by giant moving umbrellas inspired by the idea of the sunflower, to shade the squares and public places in the city center in the morning, as well as absorbing the heat of the sun, and then closing itself in the evening to release the heat that it absorbed **Figure (6)** [16].

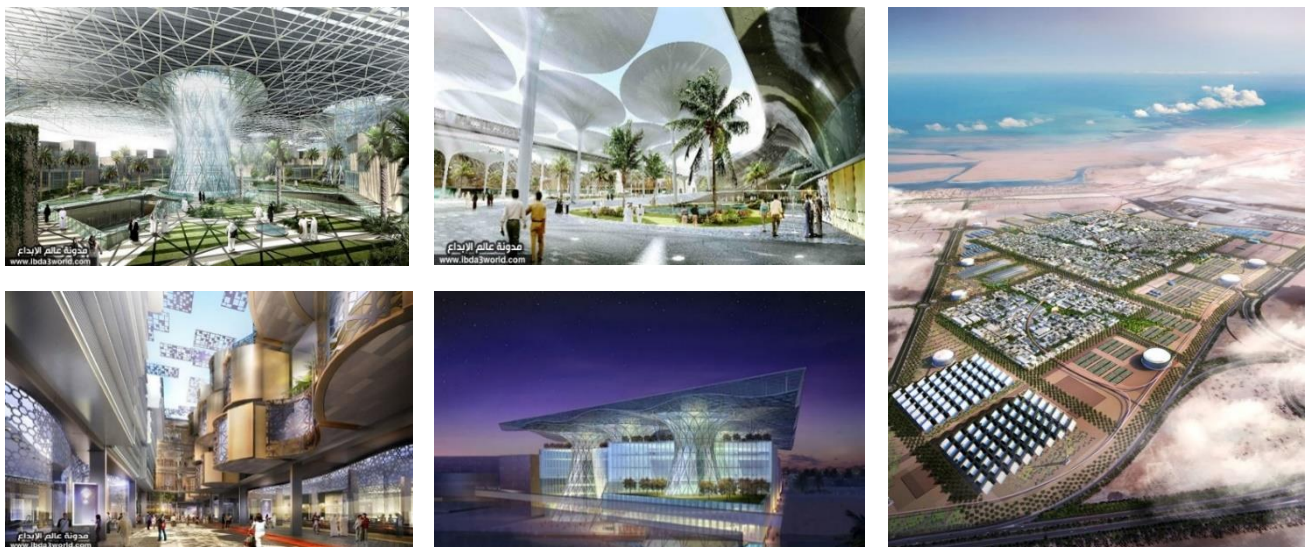


Figure (6): Masdar City is a model of sustainable cities (Source: ref. [16]).

Masdar City is the world's first zero-carbon and zero-waste city, It is also the first city full solar-powered, It comes within a very promising initiative called the "Life on One Planet" initiative, which

is summed up in a world in which people live a happy and healthy life, and each person enjoys a fair share of the earth's resources, which is what Masdar City achieves with distinction, and let's talk in numbers to understand this point [16]:

- Masdar City will need about 200 MW of clean energy, compared to more than 800 MW for a conventional city of the same size.
- The city will need about 8000 cubic meters of desalinated water per day, compared to more than 20,000 cubic meters per day for a conventional city.
- It will contain a solar-powered power Station, and its water will be recycled to be used in irrigation and agriculture.

This city will be built on an area of 6 km and will accommodate 50,000 people, at an estimated cost of \$22 billion. It will also be the headquarters of the world's largest alternative energy companies. 30% of Masdar City will be allocated for housing, 24% for the business and research area, 13% for commercial projects including light industries, 6% for the Masdar Institute of Science and Technology, 19% for services and transportation, and 8% for civic and cultural events [17].

The city has won many different international awards. In June 2007, “Masdar City” won the first global prize for clean energy from the “Transatlantic 21 Association” in the Swiss city of Basel. In September of the same year, the city was awarded the “Sustainable City of the Year” award at the Euromoney and Ernst & Young Global Renewable Energy Awards [17].

## **5.1 The project Introduction:**

Masdar City is a sustainable residential community under construction in the Emirate of Abu Dhabi, to use renewable energy. The Masdar Initiative is the global platform for joint action aimed at finding appropriate solutions to a number of the most pressing issues that affect human life in general, namely energy security and climate change. The Masdar Initiative is led by the Abu Dhabi Future Energy Company (Masdar), a subsidiary of the Mubadala Development Company. (Mubadala). And ways to develop human expertise in the field of renewable energy and sustainable development [17].

The main objective of "Masdar" is to highlight Abu Dhabi's leadership as a global center for research and development of renewable energy technologies, and to effectively balance its strong position in the global energy market that continues to develop without stopping. Abu Dhabi is working to enhance its resources and extensive experience in the global energy markets, and to build on them in order to reach the technologies of the future.

A closely related goal is the commercialization and application of these and other technologies in the areas of sustainable energy, carbon management, and water conservation. Masdar will play a

crucial role in elevating the Emirate of Abu Dhabi from the stage of technology consumption to its production.

The initiative seeks to establish a completely new economic sector based on these innovative industries in Abu Dhabi, which would support economic diversification, develop knowledge-based sectors, enhance Abu Dhabi's record of achievements in the field of environmental preservation, and contribute to the development of the global community. Masdar City is located near Abu Dhabi International Airport **Figure (7) & (8)** [17].



**Figure (7) & Figure (8): Sustainable design ideas in Masdar City, a model for sustainable development ideas in an eco-city (Source: ref. [20]).**

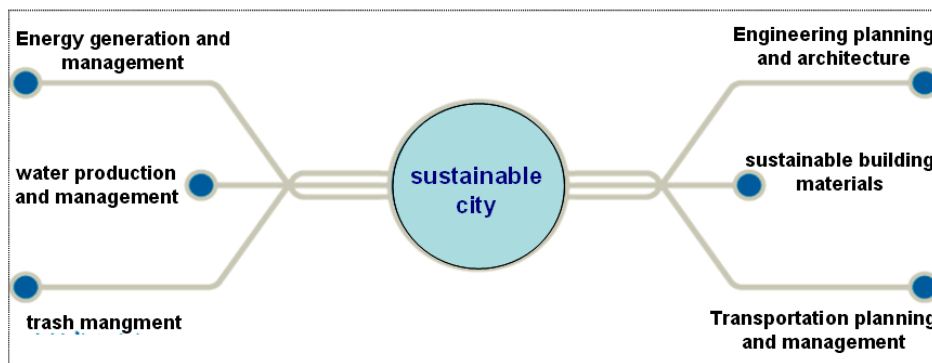
## **5.2 Sustainability criteria in the planning of Masdar City:**

The successful integration of urban planning and development with the management of cities and towns around the world is an essential part of the global response to climate change and to enhancing energy security. This is due to the fact that half of the world's population lives in cities today, and this percentage is expected to increase to 70% by 2030 AD, and because cities are responsible today for 70% of global carbon dioxide emissions.

But if sustainability does not become economically feasible, we will not find enough societies that are able to apply sustainability technologies and systems on a large scale to make remarkable progress in this field. Thus, Masdar City is not only committed to building one of the most sustainable cities in the world and making it an attractive place that people yearn to live in, but also pursues this goal in a commercially viable way.

Achieving any sustainable urban development or sustainable urban redevelopment requires a unique focus on all elements and areas of design, development and operation. The most important five components are: planning and design, energy, water, transportation and supply chains **Figure (9)** [18].





**Figure (9): Sustainability criteria in the design of Masdar City (Source: Author).**

### 5.2.1 Planning and Design:

**“Quality “The quality of design and planning contributes to the rationalization of resources:**

Every aspect of the city, whether in terms of urban planning, engineering or architecture, takes into account the issue of sustainability. More specifically, the planning seeks to facilitate reductions in the consumption of electricity, water, and other resources. The planners found that the most important environmental gains are achieved through the cheapest elements and the least need for intervention, including aligning the direction of the city or buildings in relation to the sun and prevailing winds **Figure (10)**. The second element in terms of effectiveness is to enhance the performance of buildings, such as the presence of an external envelope and effective systems **Figure (11)**, and the provision of smart management for them. As for the elements and controls that require intervention, such as providing renewable energy, they are the most expensive and have the least environmental impact. Therefore, the designers initially focused on aligning the trend and enhancing performance, which contributes to reducing energy demand significantly, at low costs, and did not think about applying other elements that require intervention until after that [19].

### 5.2.2 Energy Management:

**“Reduce “the rationalization of resources consumption:**

Masdar City reduces energy consumption by deploying world-class energy-saving and commercially viable technologies and setting strict building efficiency guidelines in areas such as thermal insulation, low-energy lighting specifications, glazing (in windows), and optimizing the use of natural light **Figure (12)**, and the installation of smart equipment, smart meters, smart building management systems, an integrated distribution management system, and a city-wide energy management system that controls the electrical load across the network from generation facilities to the consumer [19].

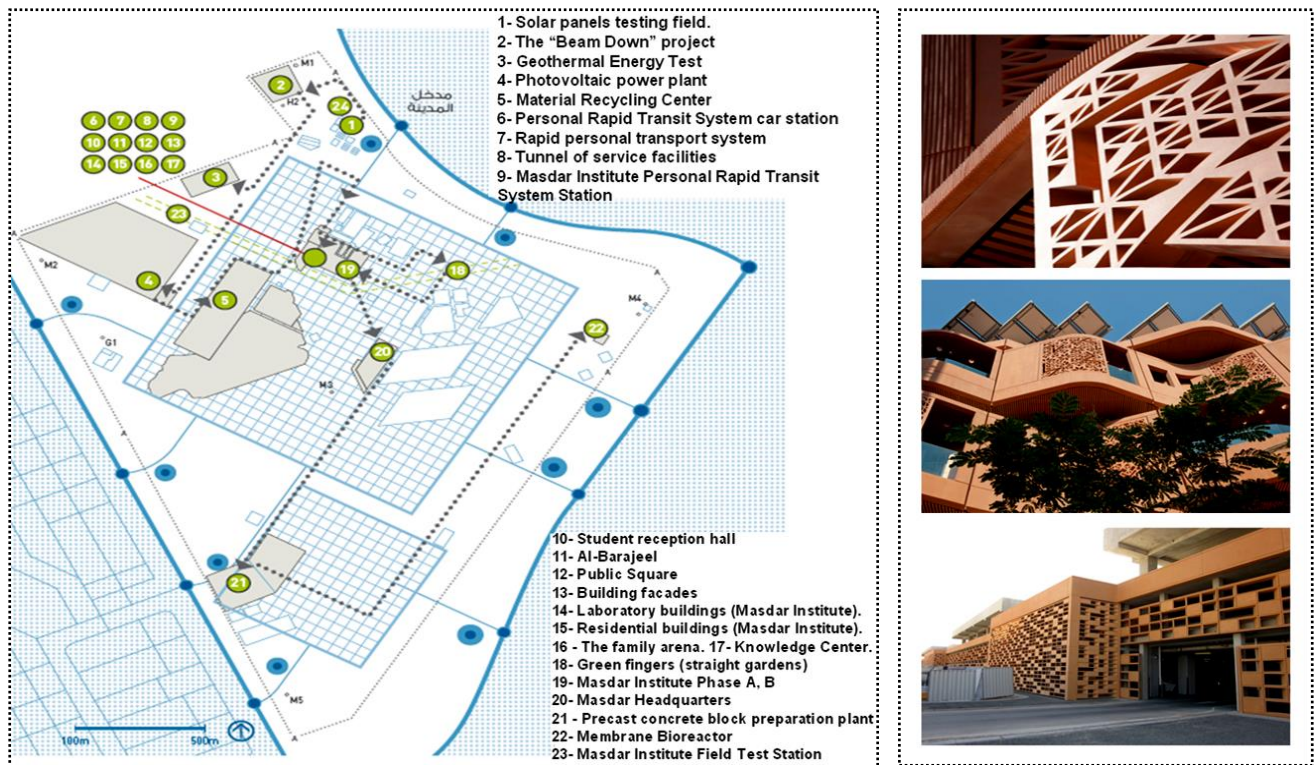


Figure (10): The general layout of Masdar City (the designer takes into account the environmental aspects)

Figure (11): The use of shades in front of Masdar buildings and solar panels contributed to the rationalization of energy (Source: ref. [20]).

The city is currently operated entirely on renewable energy that is generated in the city. But as the city grows, the situation will change with a medium-term goal of at least 20% of the energy supply coming from on-site renewable sources. The rest of the energy will come from external renewable sources. There are currently several renewable energy projects under implementation or still in their early stages in the UAE, which will provide the city with clean energy sources. In addition to photovoltaic panels, solar energy is harnessed through vacuum tubes that collect the sun's heat to provide hot water for homes. Furthermore, concentrated solar heat and geothermal heat are currently being tested to operate single- and dual-acting absorption chillers as potential solutions for city air conditioning. A 10 megawatt solar photovoltaic power station has already been commissioned in Masdar City, the largest of its kind in the Middle East. It provides power for the Masdar Institute buildings, the Masdar Interim Administration buildings and many of the ongoing local construction activities [20].



**Figure (12): Using natural lighting to illuminate the interior spaces in masdar buildings in order to save energy (Source: ref. [20]).**

### **5.2.3 Water management:**

#### **“Recycle” Use of recyclable resources:**

Masdar City's water needs are less than half that of typical buildings. In the first phase, the city seeks to consume 180 liters per day per person, which is much lower than the usual consumption rate of 550 liters per day per person. The city's ultimate goal is to gradually reduce this unit until it is 40% below the first stage when all facilities are completed. However, this does not include the water needed to cool the districts, which could double the amount of water needed for the city [20].

In order to achieve this reduction in consumption, the city uses a variety of technologies and systems that contribute to reducing water use. High-efficiency installations, connections and devices, smart water meters that inform residents of their water consumption, and smart meters that detect leaks in the network are already used. As the city pursues ambitious goals to reduce water consumption, additional strategies will be implemented, including setting up a tariff system that encourages more efficient use.

Also, 100% of treated wastewater is recycled for use in garden irrigation, which has contributed to a 60% reduction in water consumption per square meter compared to normal consumption, through a variety of strategies, including an efficient “economic irrigation” system. The design of green spaces in a way that reduces the process of leaching and water evaporation of plants, and the use of local plants and trees that consume less water [20].

### **5.2.4 Waste Management:**

#### **“Reuse” Reuse of resources:**

The solid waste management strategy in Masdar City aims to reduce the amount of waste that is sent to landfills, and improve the level of resource conservation by recycling and using this waste, composting it, and recovering energy from it. It is expected that the total volume of waste in the city

will reach 22,000 tons annually in the first phase; the strategy aims to prevent 50% of it from being sent to landfills.

Solid waste is classified in Masdar City according to three main categories: dry recyclable waste (such as metal cans, plastic waste, cardboard, paper, etc.), and wet recyclable waste (such as food scraps and other organic waste), In addition to the waste that does not clearly fall into the previous two categories, such as the remains of toothpaste containers, empty food containers, and others. There is also a fourth category, which represents a small percentage compared to the previous categories, and it includes bulky waste, hazardous waste, and other waste of a special nature such as batteries. Each of the city's buildings was provided with three containers in order to facilitate the separation of waste according to the three main categories mentioned above.

The Resource Recovery Center at Masdar City will include facilities that allow for more precise separation of dry recyclable waste before it is sent to local or regional processing facilities. This center also allows converting organic waste into fertilizer to be used in the city's green spaces, while the rest of the waste (private and non-recyclable) is sent to be managed in external sites [20].

#### **5.2.5 Transportation services:**

In response to the priorities of the Masdar City masterplan - which is to make the city a walking community - a wide choice of public and personal transportation will be available that will ensure easy and smooth movement in the city. As a result, walking and using self-propelled transportation will be the optimal mode of transportation to reach many places in the city. This will be the result of the planners' focus on constructing many sidewalks and wide shaded walkways throughout the city **Figure (13)**. As part of its search for appropriate and sustainable solutions for transportation service, Masdar City has adopted the “express personal transportation” system and the “fast charging” system, using self-propelled, single-cabin electric cars, and providing its users with the levels of privacy and comfort that characterize taxis, in addition to To the reliability and sustainability of public transport systems **Figure (14) [21]**.

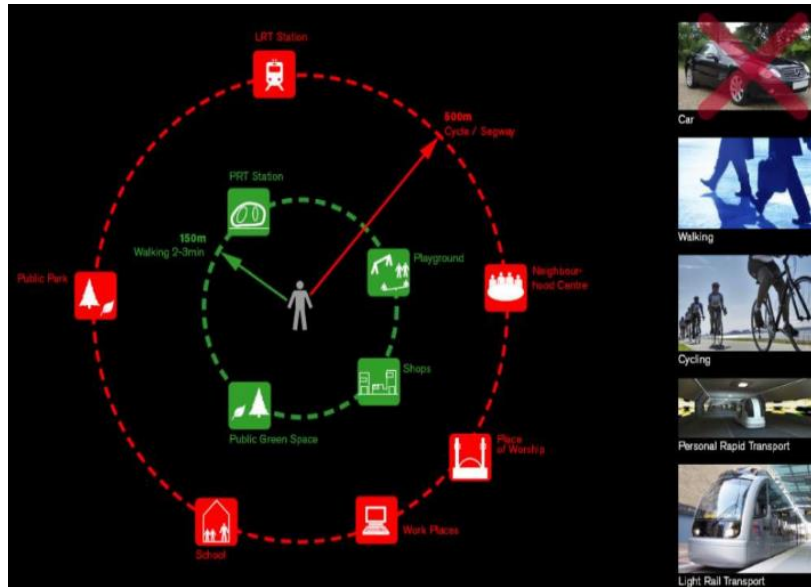


Figure (13): Dependence on the movement of foot traffic and bicycles to move within Masdar

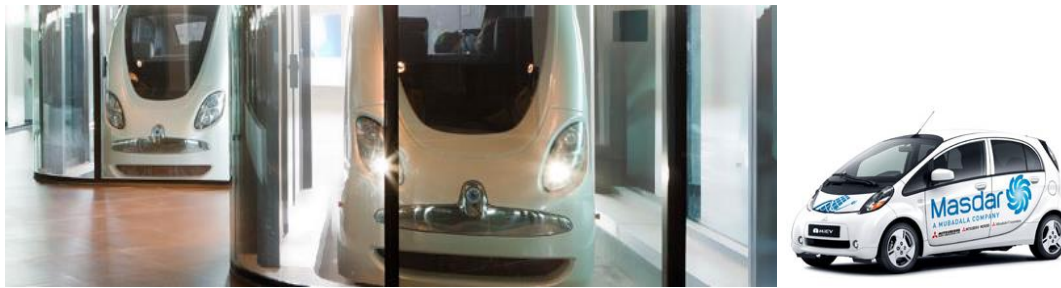


Figure (14): Electric transport cars to transport people within Masdar City (Source: ref. [22]).

### 5.2.6 6-2-6 Supply Chains:

#### “Toxics Disposal “Elimination of toxins and pollutants:

The carbon footprint of building construction is significantly reduced through eco-friendly supply chains. Through a detailed evaluation process for materials and products that include environmental, economic (including costs and quality) and social considerations, Masdar City contributes to reducing the general economic impact of the materials used in the city **Figure (15), Figure (16) [21]**.



Figure (15): Construction waste recycling center in Masdar City

Figure (16): Building materials supply chains in Masdar City (Source: ref. [22]).

In addition, the city's supply chain team collaborates with local and international suppliers to develop materials that are more sustainable and perform better than usual materials. This includes using slag concrete (industrial waste) to replace cement, which greatly reduces the level of carbon emissions caused by conventional concrete production, as well as providing better performance and greater strength. In addition, the recycled aluminum developed jointly with Masdar City has been tested and has achieved high levels of performance that exceed international standards [21].

**Examples of supply chain outcomes in existing buildings in Masdar City [20]:**

- 100% of the wood comes from sustainable forests.
- 90% of aluminum is recycled for use in interior facades.
- Concrete that uses slag reduces the environmental impact of carbon by 30-40%.
- The use of water-based dyes that do not contain volatile organic compounds that harm human health.
- Reinforcing bars are made of 100% round steel.

**5.2.7 Built Environment:**

The built environment plays a very important role in making Masdar City an attractive environment for companies and organizations concerned with renewable energy and clean technologies. By providing an atmosphere in which living and work mixes and encourages business growth and innovation, and provides a pleasant place in which to live and work, different organizations and their employees will find clear benefits from being concentrated in them.

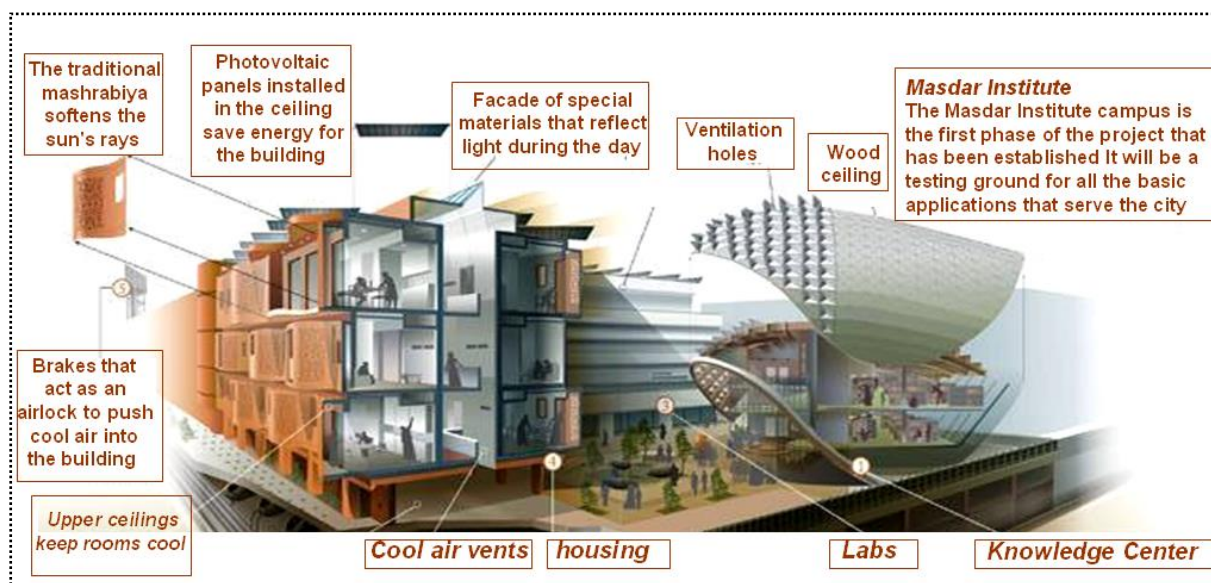
**5.2.7.1 Masdar Institute Campus:**

The first six buildings comprising the Masdar Institute campus are the first to be completed in Masdar City and are a model for sustainability. Its cooling need is less than half the rate of similar buildings in the rest of the UAE, and residential buildings provide 54% of drinking water. 30% of its energy needs are met by a set of photovoltaic panels with a capacity of 1 megawatt, which not only shade the buildings, but also provide shade for the streets below [20].



**Figure (17):** Buildings currently built by Masdar Institute (Source: ref. [22]).

The Knowledge Center at Masdar Institute the buildings and surrounding infrastructure offer world-class technologies in the field of building insulation. Almost all hot water needs are supplied by solar heat collectors via rooftop vacuum tubes. Fresh air vents are located at shaded street level, and the latest low-energy lighting specifications are used. These and other technologies will be evaluated, and the buildings themselves will be a testing ground for technologies that will help Masdar City achieve its sustainability goals. All buildings are equipped with energy and water metering systems that monitor consumption and produce ready-made data that students and faculty can view. Another unique aspect of the city is the encouragement of walking - even within buildings - as a way to reduce energy use and promote a healthy lifestyle. For example, the staircases are prominently positioned while the elevators are in the background **Figure (18)** [20].



**Figure (18):** An analysis of the architectural elements and spaces of Masdar city Institute buildings (Source: Author).

### 5.3 Sustainability Ideas and Experiences at Masdar Institute:

A set of ideas were designed at the Masdar Institute for Energy Efficiency and Reliance on Renewable Energy Sources, in addition to conducting experiments to develop the use of renewable energy sources to achieve sustainability within the city. The ideas were as follows:

#### 5.3.1.1 Masdar Headquarters Building:

The Masdar Headquarters building, designed by (Adrian Smith & Gordon Gill Architecture) , will be the world's first to break free from zero in natural energy consumption, and the first in the scale of positive energy mega mixed-use buildings. It will use pioneering techniques, never before seen before technology, to create an aesthetically stunning building, making it an elaborate and functional experience for the project that will represent the city **Figure (19)** [21].

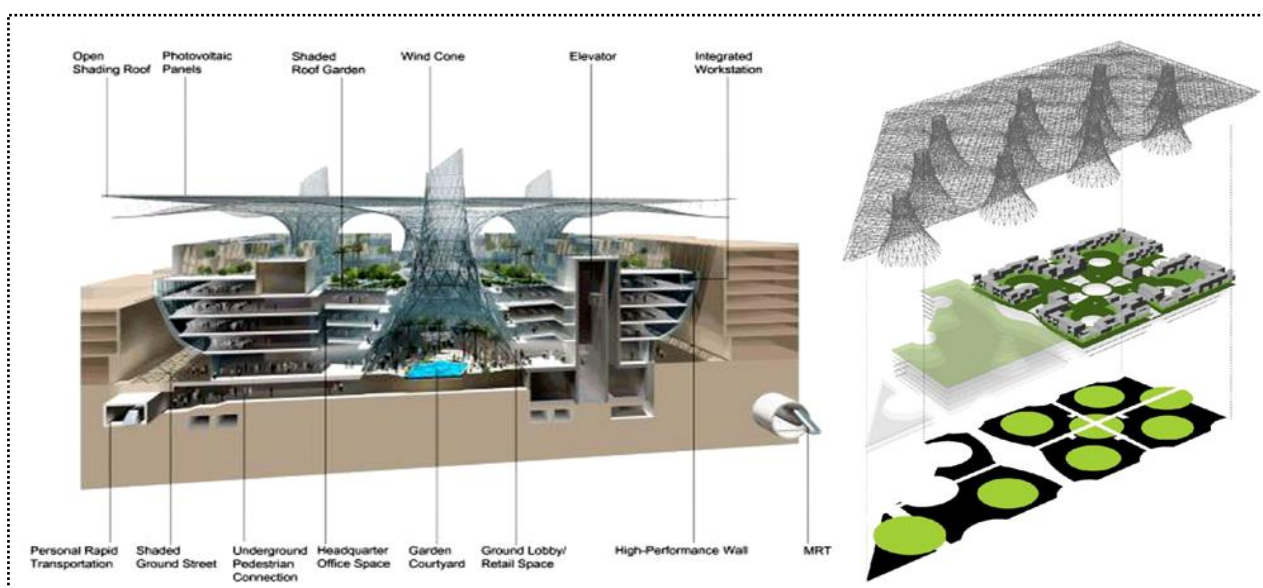


**Figure (19):** Masdar Headquarters Building (Source: ref. [22]).

The building takes its ideas from centuries of original architecture, with a successful marriage with historical strategies used to deal with this climate without forgetting the latest innovative technologies and building systems, including some of the techniques specially devised for this building.

The design, which includes several systems that will generate a surplus of energy from the building and eliminate carbon emissions and reduce liquid and solid waste. will use sustainable materials, integrated wind turbines, an air quality monitoring unit and one of the largest arrays of solar panels in the world. Compared to mixed-use buildings of the same size, this headquarters consumes 70 percent less water than its equivalent.

There are also modern wind towers, which are considered one of the symbols of the traditional Islamic architecture in the building, and form the basis for a number of features in the design of the building. They serve as wind towers, getting rid of hot air and naturally ventilating the building (Fig. 20), as well as bringing cool air through the city levels below [20].



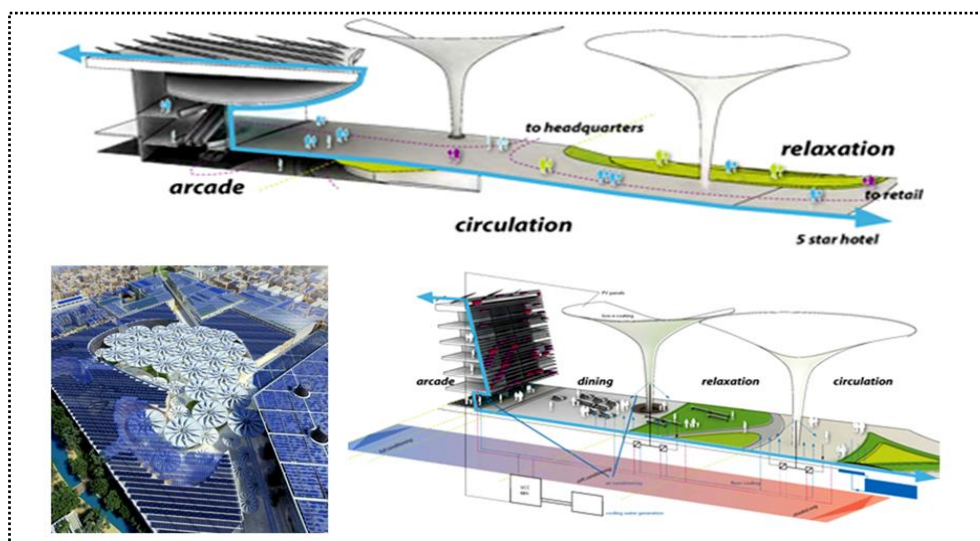
**Figure (20):** Wind towers get rid of hot air and work on the natural ventilation of the building (Source: ref. [20]).



The conical shapes provide maximum natural daylight throughout the building, and the controllable windows on the cones allow the occupants the option of natural ventilation of the interior spaces. Structurally, the cones supported the roof bearing and allowed the creation of a shaded flat on the top of the building. In terms of spatial employment, it creates garden yards in public areas that contain lit pools of water. Each courtyard was employed differently, for convenience and to provide public space for the occupants. The building was designed to be sustainable and efficient from the first moments of construction. The cones and roof can be built first, creating a shaded microclimate for the remainder of the construction. The roof is covered with solar cell panels, to provide enough energy to build the remainder of the building. The building includes offices, residential and commercial spaces and public gardens, as well as a prayer hall and direct access to the city's transportation systems [20].

### 5.3.1.2 Sunflower canopies in Masdar:

The idea of Canopies that open and close is similar to the idea of a sunflower plant that opens during the day and shades the squares and stores the sun's heat, which in turn spreads it at night in the squares to heat the city **Figure (21)** [21].



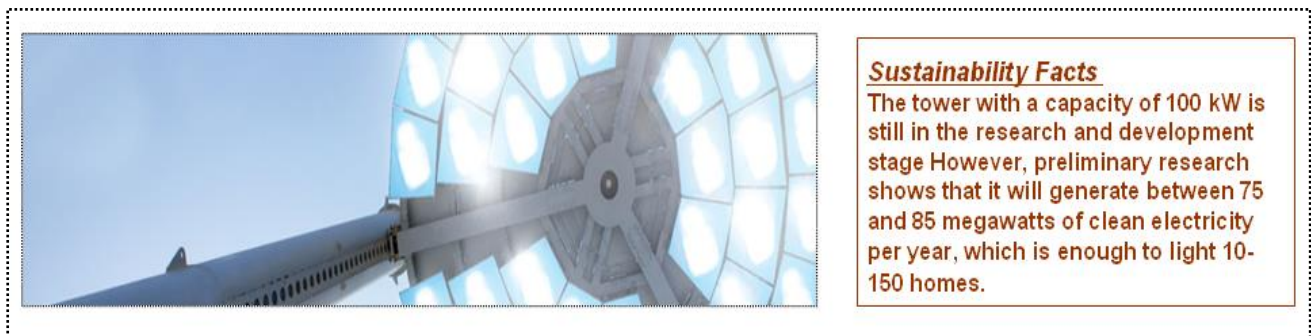
**Figure (21):** Using the idea of sunflowers in the design of canopies in Masdar, with the aim of shading during the day and heating at night (Source: ref. [20]).

It is also depend on the water stored inside underground pipes to cool the external walls of the buildings during the day.

### 5.3.1.3 Renewable energies experiences in Masdar and empirical projects:

#### 1- The "beam down" rays project:

According to the adopted reception technology, the temperature of the heat carrier fluid in the tower can reach 700 degrees Celsius, which is two or three times more than the heat reached by the central heaters **Figure (22)** [21].



**Figure (22):** The “beam down “rays’ project (Source: ref. [22]).

Known as Beam Down, a downstream technology project is a joint research project with the Masdar Institute of Science and Technology, the Japanese petroleum company Cosmo Oil, and the Tokyo Institute of Technology, And the tower takes the concentrated solar energy design and turns it on its head. Most Concentrated solar power towers use mirrors (heliostats) to direct sunlight to the receiver at the top of the central tower in order to heat a heat-transmitting liquid (such as melted salt, oil or water) in order to release steam that operates in a steam turbine cycle. The Beam Dawn plant, under the management of the Masdar Institute, has the ability to convert sunlight into electricity in a more efficient and cost-effective manner [21].

## 2- Barjeel "wind towers":

The tower's lighting colors change to inform residents, students, professors, and visitors if they are consuming large amounts of energy in the buildings of the Masdar Institute or are consuming it appropriately **Figure (23)**.



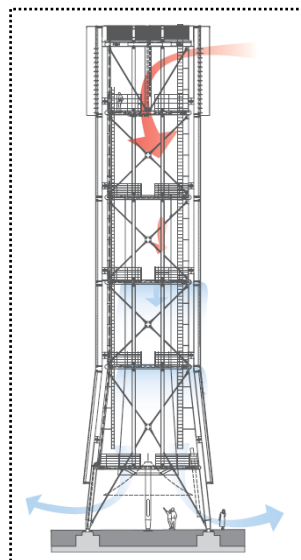
**Figure (23):** Wind towers in public squares in Masdar (Source: ref. [22]).

The Barjeel is a modern embodiment of one of the traditional urban landmarks in the region, at a height of 45 meters from the podium, and it is one of the most prominent landmarks next to Masdar Institute. The height of the tower means that it can catch the high winds and turn it into the open air public square located at its base. Sensors at the top of the steel structure operate high louvers to open

in the direction of the prevailing winds and close in other directions to divert the winds to the bottom of the tower **Figure (24)**. The "Poly tetra fluoro ethylene" membrane directs the wind downward, while the mist generators at the top contribute to the cooling of the breezes. It is noteworthy that "Poly tetra fluoro ethylene" is the scientific name for the famous "Teflon" material. A combination of cooling techniques by evaporation and air movement helps to modify Perceptible air temperatures, thus increasing personal comfort It should be noted that Masdar Institute is using the tower as a platform for its scientific instruments, including weather measuring instruments and air quality testing instruments **Figure (25)** [21].



**Figure (24): Use of wind towers to ventilate the squares in Masdar City**



**Figure (25): Section of the cooling towers showing the path of air movement inside the squares in Masdar City**  
(Source: ref. [22]).

## 6 CONCLUSION:

We conclude from the research study that sustainable development is the primary goal of smart cities compatible with the environment and that realize the idea of relying on renewable energy sources and rationalizing the consumption of environmental resources. The sustainable city is the one that adopts a plan to recycle and manage waste, as well as a system for energy generation and management, and a system for rationalizing water consumption and recycling in the irrigation and cultivation of the elements of the public site. It is also the city that depends on building materials compatible with the environment and that works to reduce carbon emissions, as well as city planning must be taken into account. Relying on means of transportation such as electric vehicles, bicycles and pedestrian paths, the designer must also provide the city's facilities with environmental ideas and climate treatments, which contribute effectively to reducing the consumption of typical energy used in heating and cooling, which reduces the city's total energy consumption.

We conclude from the theoretical study that sustainable fourth generation cities must achieve the concept of sustainable design by relying on recyclable building materials that contain less energy involved.

The ideas of energy conservation must be followed when designing smart city buildings through the use of air stands and collection yards, which help reduce the temperature and thus contribute to reducing the energy consumed in cooling work within the interior spaces as well as relying on solar cells to generate the consumed energy.

Depending on recycling through water recycling and collecting, storing, treating and reusing rainwater, whether in cultivating the site or using inside the building in the internal bathrooms.

We conclude from the applied study of the applied model of the study of Masdar City, which is one of the models of smart, sustainable, energy-saving cities (fourth generation cities) that when planning a new city, the following ideas must be provided:

Reliance on clean transportation within the city in order to reduce carbon emissions within the city and to preserve the environment by relying on cars and electric buses as well as traveling using bicycles.

- Use of recyclable building materials in the construction of city buildings.
- Follow the interconnected planning with the environment and respect the movement of air within the city.

- Reliance on sources of electrical energy production from renewable environmental sources, such as using windmills and solar cells in the production of electrical energy, as well as relying on the sun's heat for water heating and internal heating to reduce typical energy consumption.
- Recommendations:
- The research study recommends relying on sustainability criteria when the Egyptian government plans a new city in order to preserve the environment.
- The study recommends integrating green transportation within cities to reduce greenhouse gas emissions in order to reduce the phenomenon of global warming within the city in order to preserve the environment.
- The study recommends integrating solar cells inside cities in order to reduce typical energy consumption.
- Adopting and applying green assessment systems in the development or design of any building within the city, with the aim of preserving the environment.

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