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ZERO CARBON CITY- MASDAR CITY CRITICAL ANALYSIS

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Abstract

Climate has a direct impact on the performance of buildings and their energy consumption especially in hot arid areas. In these areas, the lack of water and energy sources forces people to build their houses with several strategies, based on minimum energy consumption as using the environment natural climatic strategies for coping with harsh conditions as vernacular architecture. In order to apply and achieve sustainable building in hot and humid climates, efforts must be put into understanding the local climate, and integrating appropriate building technologies into the architectural and urban designs. Today, the continuous progress in technologies offered new means towards achieving comfortable climatic conditions and efficiency in building. But these technologies result in high building costs, maintenance and depletion of renewable resources. The paper aim is to investigate the feasibility of using new technologies as nanotechnology beside other passive design strategies in desert zones .In addition to, assessing their adaption towards the extreme and harsh climatic conditions of the hot arid zones and their efficiency. The paper will illustrate the advantages and disadvantages of applying new technologies and materials to achieve sustainability in hot arid zones through analyzing Masdar City in United Arab of Emirates. The paper suggests that Masdar City still didn't achieve its goals and failed to be a model of urban environmental sustainability, to be replicated in other countries.

Keywords

Energy efficiency, smart materials, sustainability, desert architecture

ZERO CARBON CITY- MASDAR CITY CRITICAL ANALYSIS

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ABSTRACT: *Climate has a direct impact on the performance of buildings and their energy consumption especially in hot arid areas. In these areas, the lack of water and energy sources forces people to build their houses with several strategies, based on minimum energy consumption as using the environment natural climatic strategies for coping with harsh conditions as vernacular architecture. In order to apply and achieve sustainable building in hot and humid climates, efforts must be put into understanding the local climate, and integrating appropriate building technologies into the architectural and urban designs. Today, the continuous progress in technologies offered new means towards achieving comfortable climatic conditions and efficiency in building. But these technologies result in high building costs, maintenance and depletion of renewable resources. The paper aim is to investigate the feasibility of using new technologies as nanotechnology beside other passive design strategies in desert zones .In addition to, assessing their adaption towards the extreme and harsh climatic conditions of the hot arid zones and their efficiency. The paper will illustrate the advantages and disadvantages of applying new technologies and materials to achieve sustainability in hot arid zones through analyzing Masdar City in United Arab of Emirates. The paper suggests that Masdar City still didn't achieve its goals and failed to be a model of urban environmental sustainability, to be replicated in other countries.*

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1. INTRODUCTION

In the recent years, various proposals have emerged for designing and constructing "eco- cities". "Eco-cities" became a trend and were supposed to integrate high technology, improved building design, depend on renewable energy sources, self-sufficient and have the minimum environmental impact. One of these cities is "Masdar City". Masdar city main aim was to be the first zero carbon city in the world and to be a model city for other countries. Despite the promising potentials and goals of Masdar City in 2006, after almost 10 years, is subjected to intense criticism regarding its sustainable urbanism and incompatibility between achieving sustainable lifestyle and economic feasibility at the same time. The paper will investigate "Masdar City" energy efficient design, role of technology usage and disadvantages.

2. ZERO CARBON CITY

2.1 Definition

Most cities around the world depend on fossil fuel as the main source of energy leading to depletion of renewable energy sources and emitting high percentages of carbon and greenhouse gases to the atmosphere, causing critical environmental problems that threats the natural energy balance. Recently, there is an international perception of designing a whole "zero carbon cities" to tackle climate change. A zero carbon city is considered as green and sustainable city that depend entirely on renewable energy for its energy supply. "Zero-carbon" means no carbon footprint and doesn't have negative impact on the environment. Zero carbon cities promote optimal living conditions and lifestyles while reducing the negative environmental impact. Zero carbon cities include 7 main principles illustrated in Figure (1).

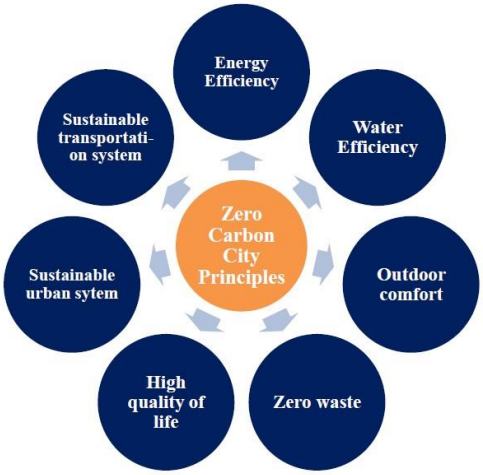

Fig. 1 Zero Carbon city Principles
Reference: The Researcher

3. MASDAR CITY

Fig.2 Aerial view of Masdar City,United Arab of Emirates
Reference: Stilwel and Lindabury, 2008

Table 1: Masdar City
Reference: Stilwel and Lindabury, 2008

Location	Abu Dhabi, United Arab of Emirates
Built Area	7 million m2
Population	50,000 residents and 40,000 commuters
Density	135 people/Hectare
Year of establishment	2006
Completion Date	2030
Architect	Foster and Partners
Goals	To diversify the economy of Abu Dhabi; To expand Abu Dhabi's position in global energy markets; To position the UAE as a developer of sustainable technologies; To make a meaningful contribution toward solving some of the world's most pressing problems; To create the first zero waste and carbon neutral city in the world.

3.1 Location

The world's first zero-carbon city is established in Abu Dhabi, located on the Arabian Peninsula between Saudi Arabia and Oman. Masdar city is about 11 miles southeast of Abu Dhabi city ,near to Abu Dhabi international airport as shown in Figure (3).The project makes Abu Dhabi the world's center for pioneering the first zero-carbon city and sustainable technologies with a total cost of 22$ billion dollars (Stilwel and Lindabury,2008).

Fig.3 Aerial view of Masdar City,map
Reference: Fitch, 2016

3.2 DNA of Masdar institute

The Masdar institute is the main component of Masdar city and it was first phase to be built in the city close to the city's main spine. The DNA of Masdar institute campus consists of a fabric form that reflects the Arabian identity of Abu Dhabi to cope with the desert climate as shown in Figure (4) (Abd elrazak, 2012):

- The walkways are always shaded through designing narrow streets to escape from the harsh sun especially in summer;
- Creation socially diverse places as open public zones, work zones and private zones;
- The orientation of the buildings optimizes the indoor thermal comfort.

3.3 Energy-Efficient Design

Every aspect in Masdar city was initially designed to fulfill sustainability, to achieve the city main goal to be the most sustainable city in the world. In order to do so, Masdar city depended on energy efficiency strategies as illustrated in Figure (4) to reduce energy and water consumption.

3.3.1 Orientation

The city buildings and streets are optimally oriented towards southeast-northwest axis as illustrated in Figure (5) to provide shading though the day, and minimizing thermal gain on the buildings facades .This has a direct impact on reduction of energy consumption for cooling needs (Abd elrazak, 2012).

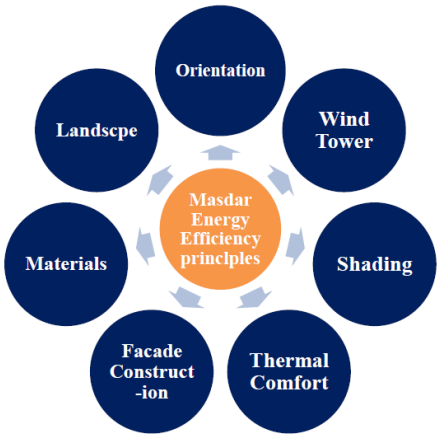

Fig.4 Masdar city Energy-efficiency principles
Reference: The Researcher

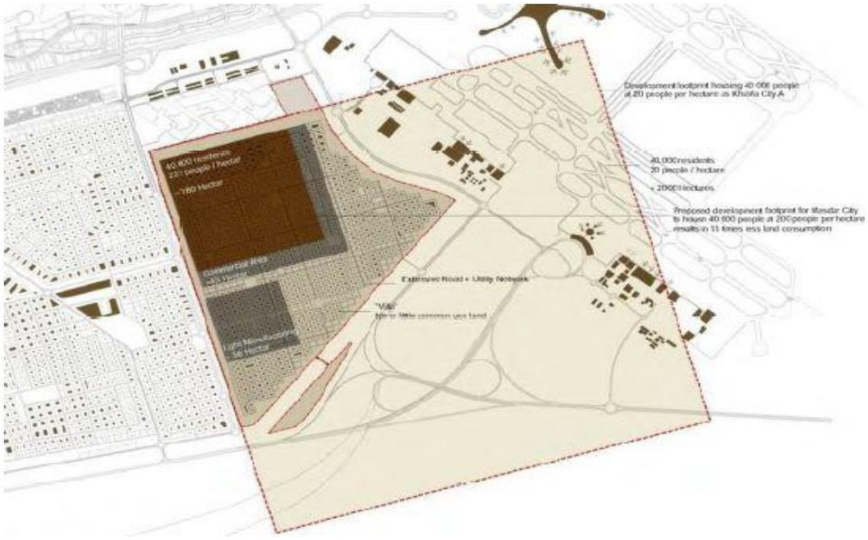

Fig. 5 Masdar city orientation towards southeast-northwest axis
Reference: Wagle,2014

In order to enhance air movement in linear parks and courtyards the city oriented in the direction of prevailing wind 38 degrees counter-clock wise of the north direction as shown in Figure(6) (Masdar Inistitute,2010).

Fig. 6 Wind movement at Masdar City
Reference: Wagle, 2014, edited by the Researcher

3.3.2 Shading

Masdar city is oriented on the south-east-northwest axis, thus providing shaded streets and walkways through the day. The shaded routes minimize thermal gain on buildings walls and provide cooler street environment .The shaded routes as shown in Figure (7) also encourages pedestrians activities and provides a healthy high environment for citizens with the lowest environmental impact or pollution (Masdar Institute, 2010).

Fig. 7 Shaded Pedestrian corridors in Masdar City
Reference: Wagle, 2014

3.3.3 Thermal Comfort

The comparative images below as shown in Figure (8) illustrate the difference between in radiant temperatures between Abu Dhabi and Masdar city. A typical Abu Dhabi street photographed by thermal imaging camera shows white hot sports while Masdar city streets is much cooler(Abd elrazak,2012).

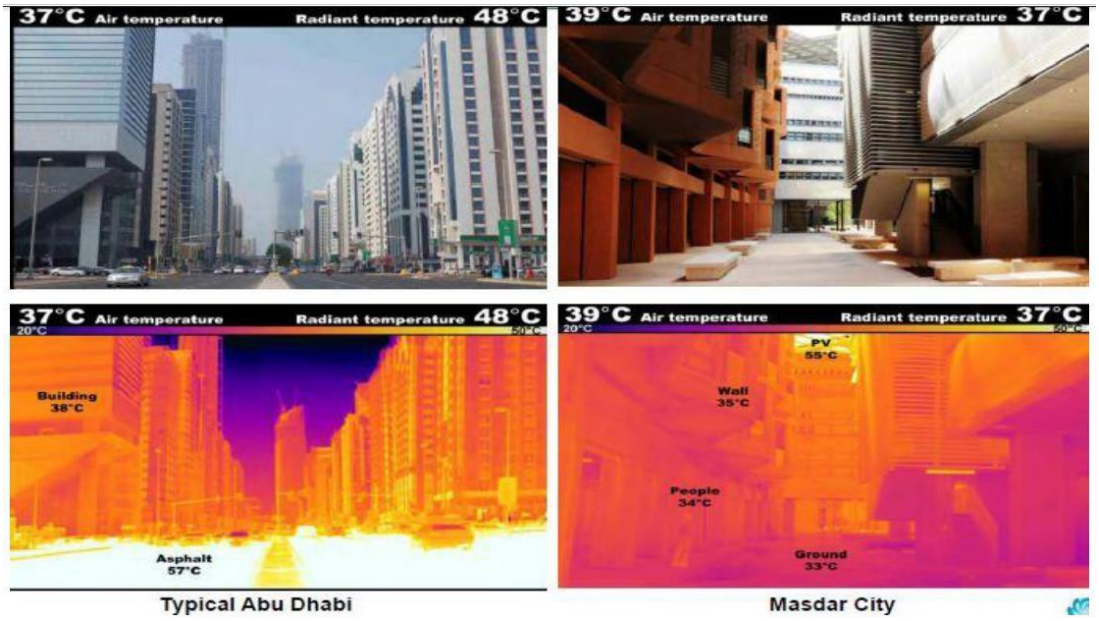

Fig. 8 Difference between Abu Dhabi and Masdar city temperatures
Reference: Wagle, 2014

3.3.4 Materials

There was a great emphasis on choosing the materials and products for Masdar city construction. There was a specific criterion for choosing materials in Masdar city (Abd elrazak, 2012).The materials should be:

- Recycled;
- Locally manufactured and sourced;
- Have low embodied energy properties,
- Low carbon emissions;
- Have high thermal mass;
- Low Volatile organic compound (VOC) content;
- Durable;
- Have low Maintenance/cleaning requirements.

In addition, Masdar city is working to minimize waste output during construction phase by reusing and recycling all steel waste, concrete and timber. All Masdar city waste is brought by contractors to onsite Material Recycling Center (MRC) for separation and processing.(MRC) as shown in Figure (9) is a 12 hectare site divided to areas of recycling concrete, wood, metal and other building materials. Wood is segregated and stockpiled for reuse .Steel beside other plastics are collected and sent offsite for recycling. Concrete waste is reused for construction process. Excavated sand is stockpiled for reusing as general backfill. Waste that can't be recycled will be used as fuel in a future waste-to-energy plant (Masdar Institute, 2010).

Fig. 9 Masdar Material Recycling Center
Reference: Masdar Institute, 2010

3.3.5 Landscaping

A remarkable aspect of Masdar city is the three "green fingers" or linear parks that traverse the city as illustrated in Figure (14).These parks are oriented to direct the prevailing wind into the city. The green fingers bring cool air into the center of the built environment. They also provide shade and seating areas for residents, workers and visitors. These parks as shown in Figure (10) encourage outdoor activities and social interactions and other recreational facilities. In addition, plants and trees in Masdar city are selected from indigenous species t can adapt with the harsh climatic conditions and have low water demand for irrigation (Masdar Institute, 2010).

Fig. 10 Masdar city Landscape Map
Reference: Wagle, 2014

3.3.6 Courtyards and street

The Masdar institute campus consists of series of streets and courtyards. Each courtyard is designed with a different theme derived from the regional landscape. There is a main "square" is the centre of all activities "family square". This square as shown in Figure (11) known as is considered a meeting point featuring cafes' and services providing the residents and visitors with seating areas and water features providing cooling effects in a waterefficient manner (Masdar Institute, 2010).

Fig. 11 Central Court cafes' and water features
Reference: Masdar Institute, 2010

Key landscape for Masdar city include (Abd elrazak, 2012):
Reduced air temperature in outdoor spaces through the shading of the building and plants;

- Accessible visually pleasant environment for residents and visitors;
- Native plants species from local sources to reduce the environmental impact of transportation;
- Strategically located water features to provide indirect cooling and create a relaxing environment.

3.4 Energy-Efficient Design

Masdar city main aim is to maximize the usage of renewable energy to fulfill its energy needs. Masdar city depend 100 % on renewable energy to cut carbon emissions and to improve the efficiency of its buildings. Masdar city is using the following technologies (Abd elrazak, 2012) as shown in Figure (12) and Figure (13):

- Photovoltaics;
- Concentrated solar power;
- Evacuated tube collectors;
- Waste to Energy;
- Geothermal.

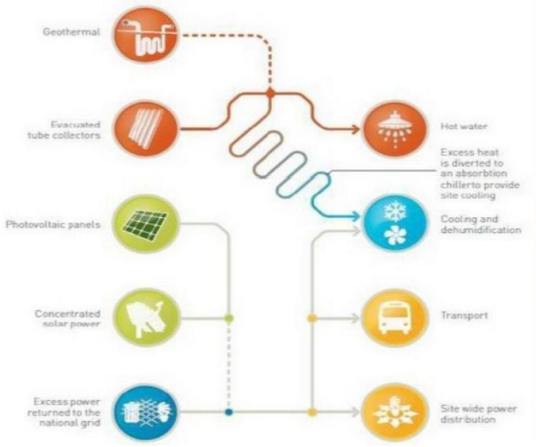

Fig. 12 Diagram illustrating the range of energy production methods planned at Masdar city
Reference: Faizal,2013

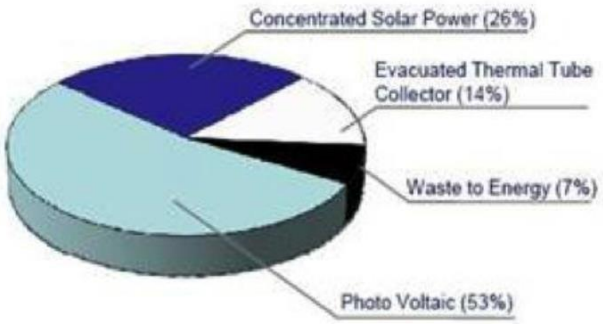

Fig. 13 Renewable energy power supply
Reference: http://www.museumofthecity.org/project/, accessed 17 April2017

3.4.1 10 Mega Watt Solar Photovoltaic Farm

The photovoltaic farm as shown in Figure (14) in Masdar city has 87,77 polycrystalline and occupy 22 hectare site at the outer boundary of Masdar city. This farm built in May 2009, is considered the largest grid-connected solar plant in the Middle East. The farm provides clean energy supply to Masdar institute of science and technology campus and Masdars' temporary offices in site beside other construction activities. The main disadvantage of this farm is the accumulated dust as it is a desert environment .The panels require continuous cleaning thus leading to significant costs annually. This farms aims to produce 17,500 Megawatt/hour of clean electricity /year, cutting about 15,000 of carbon emissions per year which is equivalent to 3, 3000 cars emissions (Masdar Institute, 2010).

Fig. 14 Masdar city photovoltaic farm
Reference: Masdar Institute, 2010

3.4.2 Roof Top PV Array

The photovoltaic arrays constructed above the laboratories and residential buildings provide 30% of electricity to the campus. The arrays as shown in Figure (15) also provide shading to the streets and help in reducing the amount of solar gain absorbed by the roofs (Abd elrazak, 2012).

Fig. 15 Roof top PV panels on Masdar institute buildings
Reference: http://www.fosterandpartners.com/,accessed 17 April 2017

3.4.3 Beam Down Project

The beam down project takes the conventional concentrated solar power (CSP) design and turns it on its head. Most (CSP) power plants use mirrors(heliostats) to direct the sun rays into the top receiver of the tower heating heat transfer fluid (molten salt or oil) ,generating steam for a steam turbine. Result showed that the 100kilowatt (kW) tower could generate 75- 85MWh of clean electricity/ year, enough to power 10-15 homes (Masdar Institute, 2010).

3.4.4 Geothermal Testing

Exploratory drilling deeply underground to test the availability of sufficient hot, geothermal water to be used in thermal cooling and domestic hot water, is considered the most exciting Projects at Masdar. The drilling wells are about 2,500 meters (m) where sufficient temperature and flow have been achieved .The rig finished drilling, and the wells will provide energy for Masda city with minimum environmental impact (Masdar Institute, 2010).

3.4.5 Solar Cooling

Solar thermal cooling involves harvesting energy from solar thermal collectors to generate chilled water or dehumidified air. Remarkably reduces energy consumption by depending on

thermo-chemical process involves a mixture of water and special salts used as lithium chloride or lithium bromide. Solar thermal air conditioning systems is divided to two categories (Masdar Institute, 2010):

- Low temperature devices: which are powered by low-grade hot water produced from non concentrating flat-plate or evacuated tube solar collectors;
- High temperature devices: which require the usage of concentrated solar collectors using reflective mirrors to direct sunlight.

3.5 Water

Masdar City has smart and innovative water consumption systems in all of the city's buildings that are designed to consume 54% less water than the UAE's average building. In addition, 75 % of hot water is provided via thermal receptors also fixed on top of the buildings. Masdar Institute's campus buildings are in line with the best practices in terms of connection and the use of only the most efficient equipment. Irrigation water has also been reduced by 60 percent for each square meter through an efficient sprinkler system and an innovative landscaping method that alleviates water evaporation in plants, chosen from the local environment due to their low water consumption rates. 100 % of wastewater is reused for irrigation, which helps reduce total drinking water consumption rate. Rainwater is also handled via collection and efficient disposal channels (http://www.masdar.ae/, accessed 4 May 2017).

3.5.1 In the spotlight – Pilot Project for Water Desalination using Renewable Energy

Masdar is developing an innovative pilot project for extensively energy-consuming water desalination processes based on renewable energy. The desalination plants, still in the pilot phase and located in Abu Dhabi's Ghantoot area, add 1,500 cubic metres of potable water per day to Abu Dhabi's supply, enough to meet the demand of around 500 homes. The project is scalable, based on success of the pilot project. The long-term goal is to implement renewable energy-powered desalination plants in the United Arab Emirates, as well as the wider MENA region and to have a commercial scale facility operating by 2020 (http://www.masdar.ae/,accessed 4 May 2017).

Key Benefits:

- Increased energy efficiency;
- Diversification of energy supply;
- Cost reduction of desalinated water;
- Reduced environmental impact.

3.6 Waste

Masdar is adopting waste management best practices in the development of Masdar City in Abu Dhabi, one of the world's most sustainable urban development as illustrated in Figure (16). Its on-site construction waste management demonstration project reuses and recycles waste building materials from the City's construction, including metal, plastic, wood and construction aggregate.Masdar and Bee'ah signed a Memorandum of Understanding to collaborate on the development of new energy projects at ADSW 2016. The facility will incinerate up to 37.5 tons of solid waste per hour to generate 30 megawatts (MW) of energy. This will add more power to what is produced by Bee'ah's auxiliary waste-to-energy project, which will eventually produce a total of 90 (MW) supplied to the Sharjah electricity grid. The agreement will lead to more projects and bold initiatives that will help the partnership to ensure a sustainable and green future for the UAE.

Fig. 16 Masdar City Waste Mangamnet
Reference: https://www.academia.edu/, accessed 3 May 2017

Masdar's Clean Energy division is a leading developer and owner of utility-scale, grid- connected projects; remote applications providing energy access to communities away from the electricity grid; and carbon abatement projects. Since 2006, Masdar has invest ed in renewable energy projects with a combined value of US$8.5 billion; Masdar's share of these projects is US$2.7 billion. Masdar's renewable energy projects span the UAE, Jordan, Mauritania, Egypt, Morocco, the UK, Serbia and Spain. The electricity generating capacity of these projects, which are either fully developed or under development, is 2.7 gigawatts (GW) gross (http://www.masdar.ae/, accessed 3 May 2017).

3.7 Transportation

Masdar City's integrated transportation plan involves four initiatives as shown in Figure (17). An underground metro line and a Light Rail Transit system running through the center of the city. Both of these lines are part of larger systems in and around Abu Dhabi that also links to the nearby airport. Unfortunately, that is hardly a look into the future and demonstrates that financial hemorrhaging of 2008-2009 was a global affair that is still having ramifications even for a nation with one of the highest per capita GDPs (Abd elrazak, 2012).

Fig. 17 Masdar City Transportation Plan
Reference: https://www.academia.edu/,accessed 3 May 2017

The podcar system, designed by the Italian company Zagato and developed by Dutch firm together, that held the most promise. The plan proposed a driverless fleet of 3,000 free- moving, electric vehicles that could transport 2 to 6 passengers between 85 to 100 stations, tallying up to 135,000 trips a day along preprogrammed routes. This system of podcars was basically a replacement for taxis, providing privacy to passengers without the congestion common in other urban centers. A Wi-Fi network would maneuver the podcars through obstacles in real time as magnets along the path continuously pull the vehicle into alignment with little variance: if one is missed, the podcar continues but if two are missed, it comes to a stop. Ultimately, the podcars were to be powered by solar panel arrays on top of buildings (which was also axed from the budget) and thermal energy-storing molten salt technology allowing the vehicles to run 24 hours a day, seven days a week.

Today the 13 initial podcars in the prototype continue to shuttle students along an 800-meter stretch between a station and the post-graduate university, the Masdar Institute of Science and Technology, is at the hub of the city plan as shown in Figure (18). The air-conditioned vehicles have a maximum speed of 40 km/h and run on a lithium-phosphate battery, which can last up to 60 km on a 1.5-hour charge, or between 30 to 40 trips, before making quick stops at a terminal for recharge or parking overnight for a full recharge.

The initial goal of Masdar City was to have a "street" level that was a large vehicle-free pedestrian zone. Ultimately, the high cost of building the entire city on top of a platform to accommodate the podcar system was too costly. With the passing of Masdar City's solution to personalized transport, another of the three initiatives dies as well. Masdar City's plan involved using the same dedicated guide ways to run two-pallet flatbed vehicles as part of a Freight Rapid Transit program. The entire system was designed to run up to 5,000 trips per day, with each of the 810 vehicles having a maximum payload of 1,600 kg, delivering all necessities to residents and businesses (Abd elrazak, 2012).

Fig. 18 .Masdar podcars stations
Reference: Jill, 2011

4. MASDAR CITY CRITICAL ANALYSIS

Despite the positive and promising design and plans for Masdar city to be the first "sustainable city" that is ever built in the middle of desert in the United Arab of Emirates (UAE). Masdar city has some critical issues and criticism as illustrated in Table (2).

Table 1: Masdar City Critical Analysis
Reference: The researcher

Critical Analysis	Description
1. Lack of Inhabitants	The 22$ billion dollars city was designed to attract 50,000 inhabitants, 40,000 commuters and 1000 employees who were supposed to live and work at Masdar international companies and offices. According to a study in 2015, the city was empty with barely 100 people living there, which was a big disappointment, turning it to a "Ghost town" with deserted buildings
2. Masdar City Location	Masdar city is supposed to be the first "zero carbon City" in the world but some critics questions whether the Masdar city project elements are 100% sustainable or not .There is one criticism of Masdar city is that it is unsustainable in the first place as its idea revolve about constructing a new city in a resource-lacking place in the desert.
3. Water Resources	The Masdar city project, requires a massive amounts of energy, land space and water resources to construct and sustain. Its location in the desert with temperatures reaching 47 ℃ in the summer, result in very limited water resources especially for drinking .So, Masdar city must depend on desalination for its water supply.  Fig. 19 Masdar City Location in (UAE) Desert Reference: Mueller,2015

4. Masdar City Fund	The 22$ billion dollars Masdar project is originally funded from revenues from oil and gas exports. The question here is, how can a city that is funded from a money made through selling oil to power industries that are responsible for green house gases and harmful emissions consider sustainable
5. Effectiveness in GHG Reduction	The UAE is one of the countries in the Middle East in terms of GHG emissions because of its oil and gas reserves. According to a "World Wildlife fund report", the UAE has the largest per capita ecological foot print (Zuberi, 2008).Abu Dhabi population is 1.5 million in 2015 and is expected to increase by 20% in the next 20 years (Environment Agency, 2007).Masdar is designed to attract 50,000 inhabitant only. So,Masdar will have a very marginal impact on reducing Abu Dhabi GHG emissions.
6. Masdar Utopia principles	▪ Masdar's potential to influence global sustainability as the "first zero carbon city" as a sort of "utopian eco-city" is questioned. "Utopian cities" do not have a good track of affecting large scale change in terms of sustainability. Ebenzer Howard, introduced a new kind of city that can be economically self-sustained, enhance social equity and integrate the notions of green belt mixing between town life and county life. Howard's perception of utopia city has been largely unsuccessful. ▪ Another examples is the Arcosanti ,Arizona in the United States. The eco-utopian city was founded in 1970s with aims and goals similar to Masdar city today including sustainable living and an inspiration for future developments.Arcosanti was designed to attract over 5,000 citizens. However, as a result of lack of funding, the city remained under construction till today and is threaten to be subsumed by the sprawling metropolis of Phoenix. Its current population ranges between 50-150 persons only.  Fig. 20 Arcosanti "Utopia City" attempt failed and turned into abandoned city Reference : http://www.atlasobscura.com/,accessed 11 May 2017
7. Masdar as a "Model City"	Skeptics have challenged the feasibility of Masdar city as a "model city" for other countries to apply. One of Masdar city initial goals was to transfer its design elements and technologies used to the globe. However, many critics question the feasibility of this point. Because not every country is capable of spending 22 $ billion dollars to invest in retrofitting cites with renewable technologies. In addition "not all countries around the world have the ambitions, knowledge and means to apply such concept. Only countries which are very rich and politically stable as the UAE .

5. CONCLUSIONS

This file provides a template as a sample for the format required to be submitted. Conclusions should be written as points numbered with letters A- B- C- Opinions and views that will be expressed in the published papers are strictly belonged to the authors. They do not necessarily represent views of either the Editorial Board or any faculty of the faculties of Beirut Arab University.

Masdar City is a new city which is built with the main purpose to be the first zero carbon city in the world. The land use is planned coherently with the transport planning (a wall around the city / green zones / high building densities around PRT stations).

It is a symptom of the new global energy market heading in the direction of green technologies because of the necessity to find solutions to oil depletion but desirous to keep the same standard of life that is, for now, synonymous with high energy consumption. The low- carbon development of Masdar City has an integral role in transforming Abu Dhabi's economy from an oil foundation to one with a knowledge and innovation base. It serves as a centralized test bed for global renewable energy and technology companies.

The positive ground-up approach that Masdar City has taken to ensuring a sustainable and enjoyable way of life for residents demonstrates that environmental responsibility need not be a hardship. A 10-megawatt solar photovoltaic plant and an array of building-mounted solar panels offsets nearly all of the electricity in Phase 1, reducing the need for power produced by fossil fuels. Streets maximize shade all day long, capturing cooling breezes and reducing the need for air-conditioning.

A mix of educational and recreational, housing, retail, manufacturing, and office spaces give commuters and residents easy access to everything they need, reducing transport needs. Buildings are densely populated, allowing residents to live and work in the same location.

This reduces heating, cooling and internal transportation needs. Water conservation is ensured by high-efficiency appliances, low-flow showers, a water tariff, smart water meters and treated wastewater, which is recycled for plant irrigation.

No project is perfect but no one can deny that Masdar City is a step towards sustainable cites and developing green technologies, even if it is not a model city for other countries.

6. RECOMMENDATIONS

Masdar "Zero Carbon City" is a large scale project that develops promising green technologies. Even if the city as a whole, proved to be not useful for existing cities to model. Masdar City can deliver the Personal Rapid Transit (PRT) system or the widespread deployment of solar and zero waste technologies .These green technologies can be applied on larger scale throughout the world for more sustainable cities.

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