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PATHS TOWARDS ZERO CARBON CITY USING NANOTECHNOLOGY

Tripoli city case study

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Abstract: The next generation of sustainable design ought to help us reduce the impacts on the environment in a challenge to live more ecologically on day-to-day basis. Architects and designers from all around the world are joining a movement to create buildings that mitigate global warming and climate change. Zero-energy and carbon neutral architecture has emerged as a top priority, although low-energy and low-carbon design is often more readily achieved [4]. The study examines Tripoli as a city-case study that suffers from high levels of toxic gas emissions mainly CO2. It aims to put the basic strategy toward Tripoli zero-carbon city on basis of zero carbon buildings that uses nanomaterials technology as a solution.

Keywords : Global warming, Decarbonization, Nanomaterial, Nanotechnology.

1. Introduction: Global warming has already taken place as the biggest problem of our time. The challenge is to find ways for the world to switch from a path of increasing gas emissions to a path of eliminating the gas emissions (mainly greenhouse gases) by adopting more high advanced technologies. Decarbonisation allows cities to develop as centres of healthy, multifaceted lifestyles with minimal environmental footprints. Tripoli is considered the second capital of Lebanon, after Beirut. The Tripoli Decarbonisation strategy could offer a foundation for custom designed plans for other suffering cities in the developing countries. To move forward, it requires more than new energy efficient buildings or new hybrid cars. The urban ecosystem should rely on the true integration of the city's elements (Buildings, waste system, water systems, energy networks, transporta-tion and infrastructure). Smart buildings rely on smart transit networks; smart energy systems rely on the creation of smart infrastructure [1].

Energy is used during constructing and operating buildings, but it mainly records high levels during the operation phase. This lays responsibilities on designers and building's inhabitants to adopt sufficient solutions to decrease energy consumption. The strategies adopted to reduce CO2 emissions during operation include: reducing energy consumption, switching to renewable energy and implementing new technology sources in design such as green nanotechnology. Aside of being a solution to decrease buildings' incorporation in different emissions of gases, nanotechnology helps to overcome environmental issues by developing built materials that do not pollute. One has to predict that new technology will be required to use in 21st century, thus it ought to be well understood to use in a right way in order to reach Zero Carbon cities.

Tripoli, like many other local cities, had scored in recent years a high percentage of CO2 emission. The traffic congestion is considered a main reason of pollution. But, buildings remain the major contributor in increasing CO2 levels in the atmosphere. To face the lateral problem, the study aims to adopt a Decarbonisation plan that concentrates on using new green nanotechnology in buildings. Relatively, two main questions are raised: -**What are the paths and strategies towards Decarbonisation Tripoli city? Moreover, how can we achieve a net Zero-carbon building through green nanomaterials?**

The object of this study is to put a comprehensive vision of how Tripoli can become more sustainable by adapting existing buildings with nanomaterials as solutions.

2. Current situation of Tripoli environmental pollution: Based on the World Bank study, the loss of human life in Lebanon because of both premature mortality and disability could be as high as 1.0 million disability adjusted life years (DALYs). Environment-related causes may be responsible for about 15 % of this total, with 87,000 DALYs lost each year due to poor water quality, lack of access to water, and sanitation and hygiene, and another 65,000 DALY's lost to air pollution and over-crowded housing [3].

A survey of emission contribution of each type of pollutants started in the three cities of the AL Fayhaa Community: Tripoli, Mina and Beddawi. The field questionnaires were prepared to lead to a reli-able data, where the collected data was then entered to GIS program. The calculation was implemented for the main pollutant emissions from the mentioned sectors. Seven main sources of air pollution were considered in the inventory: 1) Large, medium, small industries & small workshops, 2) Domestic heating & electrical generators, 3) Road traffic, 4) Shipping activities, 5) Fugitive emissions from road traffic, 6) Petroleum activities and 7) Others. According to urban community Al-Fayhaa, Tripoli city and its surrounding scored in 2001 (710967, 76 Ton/Year) of CO2 emission. The traffic congestion with stressful commutes in machines which powered by fossil fuels deliver untold metric tons of carbon into the atmosphere.

3. Application (Minkara Villa): A typical residential building in the South periphery of Tripoli city is chosen as case study building. The analysis of the building background, energy demand, used material, and energy efficiency is essential to specify the nanomaterial and nanotechnology needed to upgrade the building performance and to reduce carbon emissions. The project is located in Qalamoun at the South of the Tripoli, having a maritime temperate climate at 34^{o} 23' 44.44" North Latitude and 35^{o} 48' 4.77" West Longitude (Figure 1).

Figure 1. Minkara Villa Perspective design

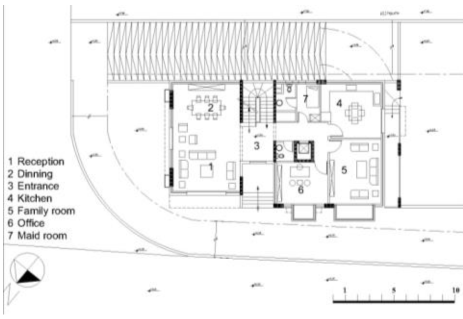
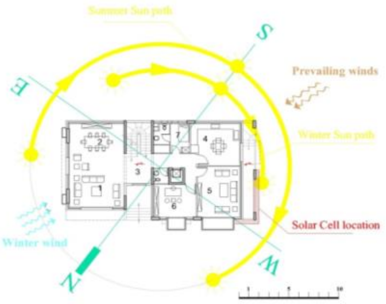


Figure 2. Ground Floor Design

The importance of this project is signified by its location and the usage of solar panel system as an electricity source. These two issues are considered the first step toward zero carbon architecture. The project site -Qalamoun- is considered a Tripoli suburban. Hence, it is noticed that CO2 emissions caused by vehicles are somehow very low. However, the project confronts the sea, possessing a high humidity level at this location. This constraint should have been considered in the first design. The project is around 540 m2, a total of three floors.



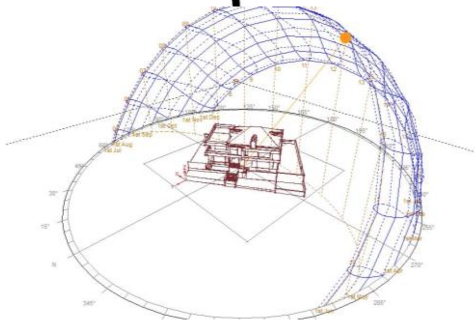


Figure 3, 4. Orientation of the project

The ground floor contains the reception area, kitchen and family room, with an extension to the outdoor garden. Almost each floor is about 180 m2 area (Figure 2). The project has a North South orientation with a grave deviation aligned with the land limit, 36º from a north-south axis. The North entry orientation is suitable. The South East elevation has a high thermal insulation with a small glass opening and 35 cm double insulated layered wall that decreases the heat transfer in the hot season. However, some architectural features found in the house are set in contrast with the sustainable principles ought to be followed during the design. The kitchen's position in front of prevailing wind is not quiet appropriate. It enhances the transportation of odors into the house (Figure 3, 4). In addition, natural ventilation strategies are not adopted in the project. Another conflict noticed during the analysis is locating PV panels in the west and north elevation, where it could be much effective if it is situated at the south elevation or inclined roof.

3.1. Curent case study building materials (as-built material): The structure used in this project is based on reinforced concrete structure with masonry block walls as internal wall partitions. The external walls consist of double masonry block walls with EPS insulation. The cladding is white cut stone (Figure 5) with composite aluminum cladding fixed at the north and west elevations. The building's envelope is composed of more than 80% stone, which reduces the opening glass area, most certainly in the South East Elevation.

Figure 5. *External wall with cut stone.*

a) Cavity wall with EPS insulation: The external wall in the case study project consists of a double cavity wall with 5 cm Expanded Polystyrene insulation (EPS) (Figure 6). EPS has a low to medium (Table 1). EPS, known also as the white polystyrene, has more than the half of the market-share; with an average of 61.3% of the thermal insulation market in Lebanon [5].

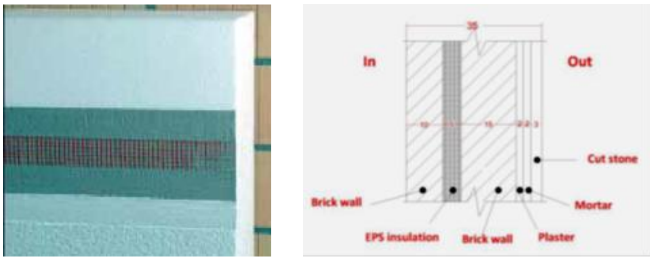
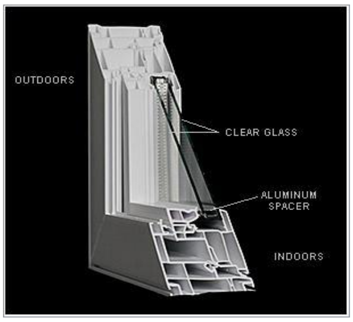


Table 1. Benefits and disadvantages of EPS insulation

Advantages	Disadvantages
• Excellent mechanical properties • High thermal performance • Low cost of this material • Rot proof (not biodegradable) • The ease of implementation	• Degradation characteristics in case of long exposure to UV radiations • Energy required to produce the material is big • Non-recyclable • Non-renewable resource • Poor long-term dimensional stability • Sensitive to water

Figure 6. *Double wall section with EPS insulation.*

b) Double Clear Glazing: It was used in the external windows and doors, and offers some thermal insulation. It is made of two clear glass panes separated by an air gap that acts as insulating barrier between the window panes, and it is considered an effective way to reduce the conductive heat transfer. Compared to single glazing, it can cut heat loss in half. The double-glazed unit with clear glass also allows the transmission of high visible light and high solar heat gain (U value= 0.47). It transmit 70% of solar heat (SHGC=0.70) and 79% of visible light transmitted (VT= 0.79) (Figure 7).



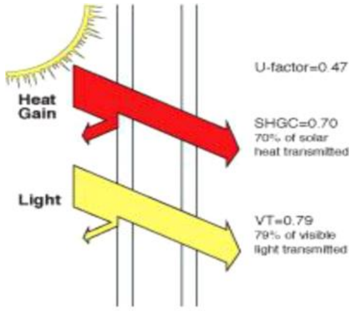


Figure 7. *Double clear glazing system with thermal absorption.* ***Figure 8.*** *Solarline heat pump system*

3.2. As-built solar system: The current system used in the building is the heat pump system from Solarline manufacture. The aim behind using this system is to provide heated water in winter time for the heating central system, where also the used water is reused in the cooling system in summer time. To reduce the use of non-renewable energy, Solar-line directly uses the "solar electricity" produced by the solar panels.The system is composed of 32 solar collector panels, battery, compressor and three water tank to storage the hot water (Figure 8). The solar collector is "Q-cells Q.Smart UF 85" from Q-cells Company(Table 2). The panel is sized 119 x 63 x 0.73 cm (Figure 9), 0.75 m 2 area. The 32 PV panels are set on a 24 m2 area, at the west and north façade of the villa (Figure 10). We need to calculate the necessary number of photovoltaic panels needed and the amount of electricity that should be generated by the panels. The first step in designing a solar PV system is to find out the total power and energy consumption of all loads needed by a Typical house. The máximum energy usage in the house is scored in August month due to the excessive need of cooling in this period. Therefore, the electricity bill, used as reference, belongs to July and August months .

Table 2. Q.Smart UF 85 electrical characteristics

Nominal Power Tolerance (+5/-0 %)	P max	[W]	85.0
Short Circuit Current	Isc	[A]	1.68
Open circuit Voltage	Voc	[V]	73.1
Current at Maximum Power	Imp	[A]	1.49
Voltage at Maximum Power	Vmp	[V]	57.2
Maximum System Voltage	1000V(IEC) / 600V (CSA/UL).		

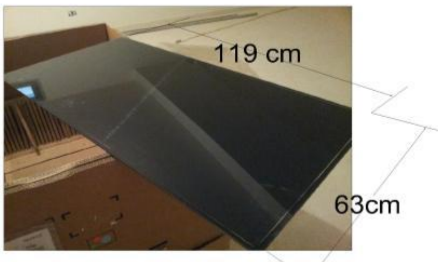


Figure 9. *Solar panel Dimension.* ***Figure 10.*** *South West and North West elevations*

- Calculate total Watt-hours per day. Referring to the electricity bill, there is a consumption about 653 KW during 2 months. We can conclude that we have: 653000 Watt through 60 days, so we have approximately 10,883 w/day. Multiply the total appliances Watt-hours per day times 1.3 (the energy lost in the system) to get the total Watt-hours per day must be provided by the panels.

10, 883 watt x 1.3 = 14, 1479 watt

- We have to consider "panel generation factor" which differs at each site location. In Lebanon, the summer day is of a long day length and high brightness intensity, amounts to average 7 hours per day (http://www.upsaps.com). Calculate the total Watt-peak rating required for PV modules. Then, divide the total Watt/hours per day needed from the PV modules by 7 to get the total Watt-peak rating needed.

14, 1479 watt / 7 = 2,021.12 wp

- To calculate the number of PV panels for the system, we divide the answer obtained by the rated output Watt-peak of the PV modules. Increase any fractional part of result to the next highest full number to get the number of PV modules required.

2,021.12 / 85 = 23.7 modules

Referring to the previous calculation, the number of PV panels needed to cover the electricity bill is 24 panels. However, the electricity bill doesn't represent the total energy used of the project due to the finance state incapability and the high price of fossil fuel. Therefore, the referred electricity bill represents 50% of the actual consumed electricity. On the other hand, the solar system is still not financial feasible. In this project, the solar panel system cost $100,000 as initial cost. To calculate the duration payback, we compare the initial cost of the solar system with the tariff bill cost, which scored an average of 0,05$/kW. The system used aimed to generate 8kw/h. Therefore, it aim to generate 8kw/h x 24 x 360 = 69,120 kW per year. This quantity cost 69,120kw x 0,05= 3,456 $/ year. **The number of year to payback** the initial cost of the system is estimated about $100,000/$3,456= **27 years**. Today, at least 90% of photovoltaic sales are made from silicon-based solar cells. Some experts believe that the pace of solar development will be slowed due to the rising cost of its primary raw material, silicon. [2]

3.3. Proposed Nanotechnology solutions: On behalf of the above mentined information, we seek to convert the villa to an environmental friendly building using nanotechnology. Besides, we foresee to retrofit the existing orientation with the environment of the existing building, so that it would respond effectively to undergoing climatic change. To achieve these two goals, we suggest three main categories of nanotechnology:

3.3.1. Solar Energy:

a) Nanosolar Utility Panel : In addition to the used Q-cell PV system, the Nanosolar Utility panel is chosen as alternative solar panel to generate the 50% needed of electricity in the Minkara house. It is characterized with a thin panel of 160-220 Watts (Table 3).

Table 3. Nanosolar Utility Panel ™electrical characteristics

Nominal Power Tolerance (+5/-0 %)	P max	[W]	220
Short Circuit Current	Isc	[A]	6.4
Open circuit Voltage	Voc	[V]	53.2
Current at Maximum Power	Imp	[A]	5.5
Voltage at Maximum Power	Vmp	[V]	41.4

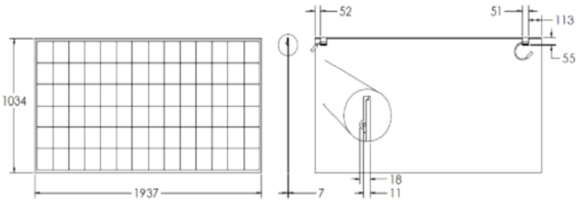


Figure 11. *Nanosolar Panel Electrical dimensions*

The dimension of Nanosolar panel is (1.9 x1.03= 2 m2). The number of needed panel on the roof (2,021.12 / 220 = 9.1 modules) is 10 panels (Figure 11). So, the total area needed on the roof is (10x2=20 m2) for installing the Nanosolar panels. The 10 Nansolar panels are to be placed at the Southern and Western elevation of the inclined roof with 25^{o} inclination. Six panels can be situated at the Southern side and the other four to be placed at the Western side. (Figure 12-13).Comparing to the current PV system, Nanosolar has high power per panel that reduces the installation cost, a high current design that enables longer panel arrays, the ability to reduce cabling and labour, a high-system voltage industry-first 1500V certification. In a market friendly scenario, Nanosolar claims to be able to produce electricity at 5-6 cents/kilowatt hour almost as cheap as power from coal and at about one-third the cost of other solar power.

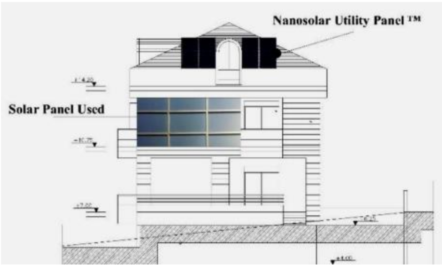


Figure 12. South Elev.with integration of 6 panels

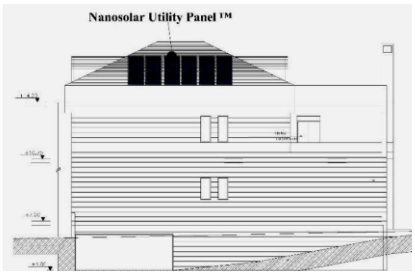


***Figure 13**. Westren Elev. with integration of 4 panels.*

b) Anti-reflective coating : The current disposition of the Q-Cells in the North elevation is not compatible with the sun path. Therefore, to maximize the module efficiency, the incident sunlight received should not reflected en route to the absorber layer. An antireflective coating is suggested to be added to the glass of the used Solar panel modules. It can improve the light transmittance of the glass by reducing the amount of reflection on the surface. Transparent nanoscalar surface structures offer not only an innovative but also a cost effective and efficient anti-reflective solution. A thickness of 150 nm is regarded as ideal. The degree of transmission at low angles of incidence can become much better than before, making such systems less dependent upon the angle of the sun. By reducing the amount of under utilise and therefore lost solar energy, the energy gain and efficiency of the photovoltaic systems is improved, resulting in overall performance gain of up to 15% [6]. AMD AR-coating PV glass increases the energy output of photovoltaic modules.

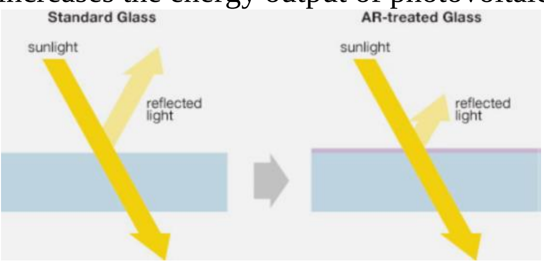


***Figure 14.** Comparison between conventional and ar-treated glass.*

Table 4. Proposed electrical generation by using nanomaterial

	Percentage of Energy covered	Cost
National electrical grid	50%	0.03$/KW
Current Q-cell system	50%	0.81$/KW
Proposed Nanosolar system	50%	0.05$/KW

By using the Nanosolar as alternative solar system, with maximizing 2% the efficiency of the current Q-cells system, we can achieve a 100% of energy depending on renewable sources (Table 4).

3.3.2. Thermal insulation: Nanotechnology promises to make insulation more efficient, less toxic. Manufacturers estimate that insulating materials derived from nanotechnology are roughly 30 % more efficient than conventional materials [2]. Insulating nanomaterial may be sandwiched between rigid panels, applied as thin films, or painted on as coatings. In the case study project, we propose Thermablok Aerogel Insulation.

a) Thermablok Aerogel Insulation blanket (ThAI): ThermablokSP Aerogel is a flexible, nanoporous aerogel blanket insulation that reduces energy loss whilst conserving interior space in residential building applications. It works by breaking the thermal bridging link whilst being totally breathable, ensuring a healthy, durable working building with a natural ability to repel liquid whilst allowing the passage and release of moisture vapour. ThAI is hydrophobic, and is therefore not affected by moisture or age. A single 10mm thickness of ThAI increases the insulation factor by up to 67%.

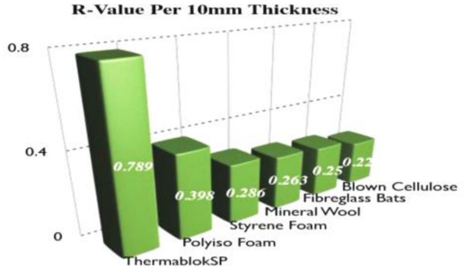


Table 5. Comparison between Thermablock proposed and current EPS used

	Thermablock	EPS
Density (Kg/m3)	150	16-24
Thermal Conductivity (W/mK)	0.013	0.03-0.038
Fire Resistance	Euro Fire Class – Class C-s1,d0.	Moderately flammable
Energy reduction	900 KWhr/yr	

Figure 15: *R value of Thermablock Aerogel with other insulation material.*

ThAI provides the highest R value / lowest U-value of any insulation material for maximum energy efficiency in walls (Figure 15). By comparing the physical characterstics of the Thermablock with the EPS current insulation used in the external wall, the thermal conductivity is twice more efficient (Table 5). Therefore, it estimated to reduce the energy needed to cooling and heating.

b) Nanoseal wet look: This product is used to protect walls from water to overcome the problem of efflorescence and algae / fungus formation on the surface. It can be applied on vertical new or restored surfaces including high porosity concrete (split faced block, brick, adobe, limestone, granite, sand-stone, terra cotta, stuccos, mortar).

3.3.3. Solar protection: Solar protection against heat gain from solar radiation is offered by Low-e glass that can replace the used double clear glass in the opening of the case study project.

a) SOLARBAN 60 Solar Control Low-e Glass: Solarban Solar Control Low-e Glass is a spectrally selective glass option that reduces long (ultraviolet) and short wave (infrared) radiation, and allows visible light to be transmitted through the glass. It can control solar heat gain, which is essential to minimizing cooling costs. With a very good Solar Heat Gain Coefficient (SHGC) of 0.38, Solarban 60 glass blocks 67 percent of the total solar energy while allowing 70 percent of the visible light to pass through. This combination produces an excellent Light to Solar Gain (LSG) ratio of 1.85, along with exceptional insulating performance, as evidenced by its 0.29 winter night time U-value. Corresponding carbon emissions from the building can be reduced by more than 300 tons per year, which eclipses the total carbon emissions generated by 31,000 gallons of gasoline.

Table 6. Performance comparison between As-built system and Nano-retrofitting proposed.

	As-built	Nano-retrofitting	Energy reduction
Energy demand	21,666w/day =7,000 Kwhr/yr	Thermablock insulation + SOLARBAN® 60 Solar Control Glass	18.5% =5,700 Kwhr/yr
Energy supply	Q-cells Solar panel 10,833 w/day= 3,899 Kwhr/yr	AMD AR Nano-coating 2% =4,678 Kwhr/yr	135%
		Nanosolar panel 3,600 Kwhr/yr	

Figure 16*. Project design with the proposed materials and treatment.*

By using the previous proposed material, generating electricity by the nanosolar panel utility, and ameliorating the existing PV performance by the antireflective coating, the existing building envelope is upgraded to establish an aggressive energy efficiency target that enables us to produce the amount of on-site renewable energy required to reach a net zero carbon emissions footprint of the building.

4. Conclusion:

The proposed nanotechnology material can be practical to insure a new Zero carbon architecture; it employs an ecological envelope that is responsive to the site and environment forces; it reduces or eliminates dependence on fossil fuels; it is renewable, and strives for little or no carbon based energy consumption. Referring to our study case, the paper proposes several architectural solutions depending on nanotechnology and nanomaterial. The integrated design of Q-cells solar system is treated with anti-reflective AMD AR Nano-coating, to confront the derivation of the cells orientation and increase the cellsefficiency 2%. To provide the rest clean energy required to reach zero carbon emissions, the research identified on-site renewable energy systems that include 10 Nanosolar panel covered the South and West pitched roof. The new solar system is characterized by a low initial cost comparing with the existing one. Nanoseal wet look is a Nano-product proposed to prevent thewater penetration through the external stone cladding (Figure 16). The external layer of the double clear glass used in the windows and doors, can be replaced by SOLARBAN 60 Solar Control Low-e Glassto block 60% of the solar heat gain through the envelope opening with a high penetration of daylight. The project created a design solution for affordable zero carbon emissions residential building by generating 135% of the energy needed depending on Nano renewable sources (Table 6).

Wider, several recommendations are stated to the private sector, local authorities and Government to reduce the threat of carbon emissions. First and foremost, for the private sector, strategies of raising the level of knowledge and awareness about climate change danger and the new buildings materials technology should be set forward. The local authorities can also take steps forward in this domain. The guidelines for sustainable developments should be integrated in the Lebanese construction law. Nonetheless, they should ensure that, at least, public projects ought to use energy efficient and environmentally sustainable components and construction practices. Creating a new green and amenities area in the urban fabric can enhance the community engagement in the Decarbonisation plan. Furthermore, the discounts on new environment friendly materials and green construction technologies such as nanotechnologies can promote importing and using such materials locally, and encourage the scientific research focusing on nanotechnologies.

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