A Strategy for Sustainable Development: Using Nanotechnology for Solar Energy in Buildings (Case Study Parand Town)

Jamal-e-Din Mahdi Nejad & Faezeh Asadpour*

Faculty of Architecture and Urban Engineering, Shahid Rajaee Teacher Training University, Tehran, Iran
*E-mail: faezeh.asadpour@yahoo.com

Abstract. Solar energy is a source of free and clean energy that has no harmful environmental effects. Simple applications of new technologies such as nanotechnology are a cost-effective way of using renewable energy, which has led many industries to invest in this area. In this descriptive-analytical study the utilization of solar energy in a hot and dry region of Iran was investigated as a useful and safe resource for supplying the energy needed for the construction of Parand town, considering the available climatic potentials. The statistical population in this study was a group of inhabitants of Parand town, employees of the Tehran Construction Engineering Organization and experts in the field, from which 384 participants were selected by simple random sampling. After collecting field information through a questionnaire, the relationships between the variables of the study were tested by SPSS. The result of the study showed that the most important achievements of using nanotechnology for solar energy in view of the sustainable development of building construction from the participants' perspective were photovoltaic coating on building roofs (58.7% of the participants' responses), nano solar water heaters (57.4% of responses) and active solar cell dryers (22.1% of responses) respectively.

Keywords: *energy saving; nanotechnology; Parand town; solar energy; sustainable development.*

1 Introduction

The transition towards an energy system characterized by a high share of renewable energy sources (RES) is necessary to drastically reduce carbon emissions and avoid climate-change related risks. Buildings have a great impact in terms of carbon emissions in the EU [1], the US, and globally [2]. Moreover, the issue of resource efficiency in the building sector [3] is becoming increasingly urgent, highlighting the need for a systemic view and adequate policies as well as adjustments in the energy market [4]. According to statistics, the building sector accounts for approximately 40% [5] of primary energy consumption and 32% [6] of total carbon emissions. Thus, effective utilization of locally available renewable energy sources is seen as an important measure to

Received August 19th, 2018, Revised January 10th, 2019, Accepted for publication January 11th, 2019.
 ISSN: 2337-5779, DOI: 10.5614/j.eng.technol.sci.2019.51.1.7

reduce fossil fuel consumption in buildings and cut associated carbon emissions [7].

Additionally, the global rapid urbanization trend determines the need for concentrating research and development efforts on subject of the built environment. From a practical standpoint, actions have to be prioritized, i.e. defining policies that are able to cope effectively with the underlying problems and realistically considering technical, economic, social and environmental constraints. The transition from the present environmental, economic and societal paradigm to a sustainable one is a great challenge that requires a multi-disciplinary approach to innovation in which civil society organizations, industry, governments and academia work together in a quadruple helix model [8,9] to share knowledge and data among each other [10].

The assessment of residential building energy consumptions is one of the key aspects of energy management in urban areas [11], considering the primary energy consumption (PEC) and the renewable energy fraction [12]. Among renewables, solar energy is usually the first energy source used in buildings to improve their energy sustainability and to reduce their consumption of fossil fuels [13].

Today, optimized exploitation of the potential possibilities and power resources of each nation in the framework of goals related to the human living environment is one of the main local, national and international concerns. This matter is especially important in arid and semi-arid regions of the world, for example the new cities around Tehran (Iran), including the new town of Parand. The reasons for this are the vulnerability of its biological resources and the fragility of the ecosystems in this region because of the creation of short-lived climatic pollutants, exacerbated landslide hazard, noise pollution, underground water pollution, solid waste pollution, and also pollution increase in the wider region, which threaten the natural environment of this town. Due to the fact that these forms of pollution will gradually affect the physical form and the norms and behaviors of these communities, the use of different technologies for the provision of welfare, cost savings and environmental pollution reduction is important.

Understanding and recognizing transformational technologies can structure and develop the national planning of many countries across the world [14]. Since the main energy resources used in Iran are fossil fuels, especially oil and gas, which will continue to be mined the next few years without coherent planning of resource use, the importance of using solar energy is felt more than ever before. Such resources are fundamentally consistent with nature, do not lead to contamination, are renewable and there is no end to them. Optimum utilization

of this enormous source of renewable energy can be provided by using new technologies, specifically the currently emerging field of nanotechnology [15].

'Nano' is a prefix that comes from the Greek word *nanos*, which means 'very small' or in a technical sense one billionth ($1 \times 10\text{-}9$) (see Figure 1). Nanoscience is the study of nanoscale phenomena, generally between 1 nm (the same size as a molecule consisting of 10 iron atoms, i.e. 100,000 times smaller than the diameter of a human hair) to 100 nm. In other words, it is the understanding of the fundamental structure of atomic and molecular particles (see Figure 2) [16,17].

Nanotechnology literally means technology of the very small, but this definition cannot convey its true meaning, because it suggests that it only deals with very small objects. Very small objects have been made in the past but that process was not known as nanotechnology. Making devices consisting of several billions of smaller units is considered only one of the dimensions of nanotechnology. Nanotechnology is the world's movement towards the transformation of structures (everything based on atoms and molecules, including building objects). It is the development and use of structures and devices of 1 to 100 nm diameter, in other words, the use and control of nanoscale particles for specific purposes [18-19]. This technology is a comprehensive design science based on knowledge of nanoparticles, a science-technology that monitors physical manipulation at dimensions of one-billionth of a meter [20-21].

The 20-year development vision of the Islamic Republic of Iran places much emphasis on academic development in new areas, especially nanotechnology, biotechnology, information and communication technology, nuclear technology, environmental and aerospace technology so that Iran will be able to take first place in economic, scientific and technological fields in the Southwestern Asian region (including Central Asia, Caucasus, the Middle East and neighboring countries) [22]. Nanotechnology is a whole future, not a single part of it. It will play a major role in the development and completion of other sciences [23] and is currently one of the most advanced technologies. It has the potential to cause a revolution and achieve a high strategic position among all sciences and other fields, including economics, industry, security, military science, agriculture and medicine.

Solar energy is a source of free and clean energy that has no destructive environmental effects. In view of the energy crisis of recent years it is of great importance to reduce energy consumption, control the supply and demand for energy replace the use of fossil fuels with this renewable energy for sustainable development [15]. Thus, the use of radiation and temperature criteria plays a

more prominent role in the design of residential buildings. The new architecture in the cities of Iran, influenced by foreign examples with other climate standards than those of the country itself, is characterized by energy-wasting buildings.

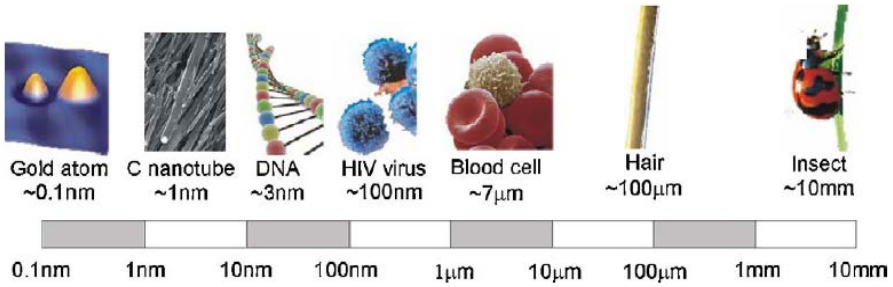

Figure 1 Length scale and some related examples [24].

Figure 2 The nanoscale [25].

Although solar radiation energy has always played a significant role in the architecture of buildings, no detailed information on climatic conditions and solar radiation within the country is available, in the absence of direct measurements. Thus, the introduction of related climate standards would meet urgent needs of engineers in the field [26]. Accordingly, it is important to identify the current environmental problems in relation to the fast construction process in the city of Parand. This study investigated the appropriate use of solar energy for providing the energy needed for the buildings by applying nanotechnology, considering its performance and efficiency, its application according to the local geographical and climate characteristics and its potential in terms of receiving solar energy in order to optimize fuel consumption and reduce environmental pollution in order to provide the inhabitants with maximum comfort and subsequently, from a more general perspective, to increase the quality of the urban environment [14].

2 Problem Statement

Increasing urbanization in Parand and the rapid extension of the city in response to the population surge has led to densely populated gathering places, high consumption of natural resources, high pollution rates and a high share in environmental destruction. Accordingly, urban problems are increased, so that urban land use and housing have become a challenge for the inhabitants [27]. This continuous retrogressive path results in a loss of urban environmental quality. Since urbanites place high demands on the city's physical capacity in terms of receiving services, this process can be considered a driving force of more instability of urban settlements. Therefore, problems such as pollution of air, water and soil, air heating escalation by human-made activities are observed and urban communities in the future will be faced with more and more serious problems. Therefore, direct attention to environmental management in urban areas is inevitable to improve this situation and create a favorable environment [28].

Negative effects of wrong planning, especially in the field of urban development, due to building intensity, high expansion rates in time and place can reduce environmental quality and destroy natural (rivers, wetlands, forests and meadows) and quasi-natural (agricultural lands and orchards) structures within and around cities, reducing the biological diversity and ecological stability of the region. Thus, it is necessary to pay attention to ecological and environment principles in the planning process for this type of development [29].

Using various different technologies with respect to the environmental and climate potentials of Parand is important to create wellbeing, comfort, cost-

savings and reduce environmental pollutants [30]. Since understanding the enormous capabilities of nanotechnology has led to structuring and developing national programs in many countries, the application of this revolutionary technology is expected to be very effective in the use of natural resources, such as energy and water. It would reduce the production of waste and pollution and provide the possibility of recycling and reusing materials, energy and water [31]. Using nanotechnology for solar energy in Iran is feasible due to the geographical and climatic characteristics of its hot and dry areas and the available potential of receiving solar energy [32].

3 Geographical Location of Parand Town

Parand, the southernmost of the southern suburbs of Tehran, is located about 40 kilometer southwest of Tehran (Figure 3) and about 10 kilometer west of Robat Karim city. The population centers and agricultural lands are located in its northern part.

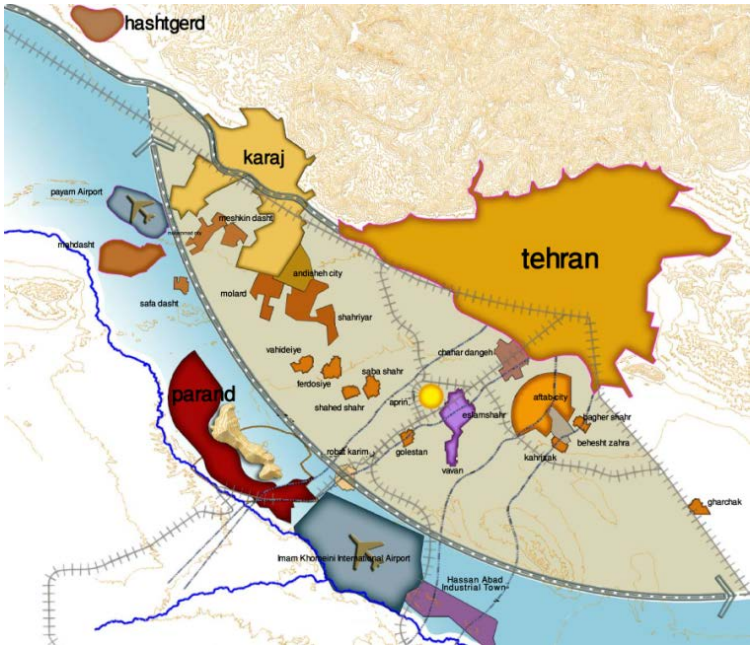

Figure 3 Location of Parand in relation to the metropolis of Tehran.

Parand has been constructed to accommodate part of the overflow population of the southwestern part of Tehran, while also establishing a number of transition industries from the industrial area of Tehran. It consists of two residential and industrial areas (Table 1).

Table 1 Geographical location of the town and its surroundings.

Geographical location of the town and its surroundings		**Southwest of Tehran and the southern slopes of Takht Rostam at 1200 meters above sea level**
Climate situation of the town		Semi-arid desert
Macro-regional land use		Lack of any agricultural activity or forests and grasslands
Restrictions on development	**Geographic**	Topographic and slope constraints in the north and in parts of the city Shoor (salty) River and its floodplain in the south
	Climate	Large fluctuations in temperature during the seasons of the year and increasing physical erosion
	Status of faults and earthquakes	Location of all lands of Parand in an area with high risk in zoning done by the International Institute of Seismology and location of the lands of Parand in the area with high and very high risk according to the research center's data
	Water resources	Lack of water resources
Development Facilities	**Geographic**	Diversity of topographical characteristics Appropriate slope to collect and direct surface water to the city Flat and low slope lands of Parand in the north-west for city development
	Soil	Lack of agriculture within the city range and land development
	Climate	Relatively good thermal bioclimatic conditions Appropriate wind blowing from the Shariyar
	Hydrology and Geohydrology	Shoor (salty) River with the possibility of beach buildings and beautification of the riverbank
	Water supply	Stepwise by Tehran regional water company from regional water resources

4 Materials

The first generation of solar cells was based on a single crystalline semiconductor wafer. The second generation utilizes an inorganic thin-film structure in cell assembly. They are cheaper to produce, but the efficiency of less than 14% of amorphous thin-film solar cells is lower than that of the single junction crystalline solar cells from the first generation, which can be as high as 27%. Theoretically, single junction cells should be able to exhibit a maximum efficiency of ±33% [33], a limit set by Shockley-Queisser thermodynamics. Thus, a new solar cell technology is required to achieve efficiencies greater than 33%, with lower production costs. This is made possible by the third generation of solar cells [34], which will deliver economic, highly efficient cells in the near future (Figure 4) [35].

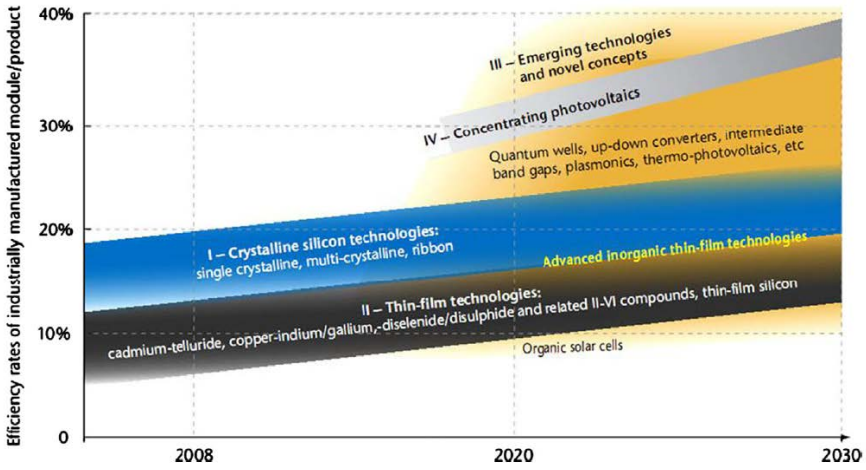

Figure 4 Solar cell technology status and prospects [36].

Polymeric solar cells are a type of photovoltaic cells that are attractive because of their numerous potentialities, including low weight, flexibility, affordable construction and possible large-scale preparation. Some innovations, such as the use of nanostructures in the solar cell architecture as an active electrode or material, have been introduced to increase the efficiency of the photovoltaic cells. The use of nanostructures is much more effective because of their high surface area to volume ratio, which increases the amount light absorption and the number of transport carriers, thus improving efficiency.

The nanosolar industry has developed a technology for fast and easy printing of solar cells using nanoparticles and quantum dots. Since these cells can be easily printed on flexible metal foil at the desired size, they can be used to install the necessary circuits on the roofs of buildings to supply part of their energy [37].

Titanium dioxide is a common substance for photovoltaic coatings. It is a non-specific light transmitter and an ultraviolet light absorbent. The first feature makes titanium dioxide a very good material for the color white, while the second one is also self-cleaning and provides protection against ultraviolet properties. Thus, titanium dioxide applied on the roof of a building can be used to produce electrical energy by harvesting sunlight.

Many applications of nanotechnology contribute to its major importance in providing solutions to reduce energy consumption, especially with regard to advanced construction materials [23, 38-40], such as glass treated with a nanocoating, which helps to reduce heat transfer through the building envelope (Figure 5). The use of standard 6 mm clear glass in glazed facades leads to high

thermal loads in indoor spaces, increasing energy consumption inside the building for cooling [41,42]. Glass windows can be insulated using a nanocoating, optimizing heat exchange, and giving the glass low emission properties. Thus, the potential of nanotechnology in reducing energy consumption is undeniable [37]. Scientists have also succeeded in making windows that use ultracapacitors. These are embedded inside electronic windows capable of changing color to absorb and store light. The glass darkens and limits light transmission when the window's full capacity is reached. Thus, the amount of light entering the house and its temperature are controlled. The stored energy can be used by electronic devices, for example television displays. One of the advancements yet to be supplied to the market are anti-reflective coatings for flat glass for use in solar collectors or glass walls of buildings to increase the light transmission. Merck Co. is one of the industrial manufacturers of glass that provides anti-reflective properties using a type of nano-cavity coating. It is expected that the loss of reflected light will typically be reduced from 8% to 2% in the glass panels [43].

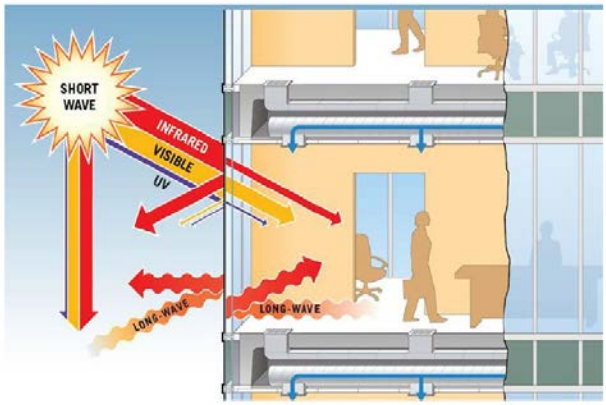

Figure 5 Glass treated with nanotechnology [42].

Students of MIT have created tiles that change color based on temperature change: when it is hot they become white and reflect much of the sun's heat and when it is cool they become black and absorb heat [37]. Self-cleaning nanocoatings that can be applied in the construction industry are able to absorb ultraviolet radiation through titanium dioxide. By absorbing ultraviolet radiation in the presence of water molecules, these nanoparticles can produce active oxygen components that can effectively eliminate bacterial films and break down organic molecules and pollutants attached to the surface [44].

Solar thermal energy can be used to provide hot water in homes and public places [15]. Tayefe, an electronics student, is one of the inventors that have succeeded in designing and producing a solar water heater using nanotechnology. His water heater design uses nanotechnology, magnetic waves and mineral rocks. The nanoproperties of the water heater allow for 30-40% faster heating [45]. Polymer nanocolors can be used for thermal and anti-corrosion insulation of walls, ceilings, installations, pipes, and tanks. This paint can be applied using very simple methods, such as spraying, rolling or brushing, and provides thermal insulation. Nanocolor insulation is used in the industrial and construction sectors in the form of a thin (micron size) layer of thermal insulation [46].

The use of solar forced convection dryers can accelerate the drying process three times the normal limit and decrease the required collector area by 50%. Therefore, the performance of these dryers is about six times that of previous ones. The drying system's fans can take their power from the electrical grid or, if electricity is not available, photovoltaic panels can supply the fans with the required power.

5 Methods

This paper reports an applied descriptive-analytical study that used a questionnaire and interviews to collect data. Data were also gathered by library documentation and field study. The statistical population of this study was a group of inhabitants of Parand town and employees of the Tehran Construction Engineering Organization and experts in the field, from which 384 participants were selected by Cochran formula and simple random sampling. The study investigated the following variables: nanosolar water heaters, self-cleaning covers, smart windows (polyaniline nanowire arrays), anti-reflective coatings, polymer nanocolors for thermal and anti-corrosion insulation, nanostructures in polymer solar cells, low emission nanoglass, active solar cabinet dryers, photovoltaic coatings on the building ceilings, and nano color-changing tiles for preventing energy loss. The objective was to understand the extent of the use of solar energy through nanotechnology in designing and constructing residential complexes in Parand and its most essential achievements for increasing environmental quality, decreasing destructive and harmful impacts, and reducing energy use in view of sustainable development. The data were analyzed by statistical analysis software and by comparing the relative importance of the variables.

6 Discussion and Findings

Today, various technologies are used to provide more comfort and better environmental effects and save costs, especially in the use of energy resources. The use of nanotechnology to provide appropriate materials with specific features in different parts of the building will have direct and indirect effects on the reduction of energy use and environmental hazards. Hence, nano building design combines the form, function, control and main facilities of a shelter in order to waste no energy. It can save millions of dollars a year. This new design approach aims to present a new type of building that is very compatible with its environment.

Hypothesis 1 of this study states that using solar energy through nanotechnology in the construction of residential complexes is impossible for developing environmental sustainability and decreasing energy use. The participants were asked 10 questions about nanotechnology applications for sustainable development in order to test hypothesis 1 of this study:

1. Nanosolar water heating in home-heating systems.
2. Self-cleaning covers for reducing absorption of environmental dirt and pollution.
3. Smart windows (polyaniline nanowire arrays) for adjusting the amount of light entering the house and controlling its temperature.
4. Anti-reflective coatings for decreasing reflective radiation loss.
5. Polymer nanocolors for thermal and anti-corrosion insulation.
6. Nanostructures in polymer solar cells.
7. Low emission nanoglass for reducing energy use.
8. Active solar cabinet dryers.
9. Photovoltaic coatings on the building ceilings to produce electricity and reduce energy loss.
10. Nano color-changing tiles for preventing energy loss.

The results extracted from 384 questionnaires (Table 2 shows the data) indicate that the most important achievement of the use of solar energy using nanotechnology to develop residential complexes is related to photovoltaic coatings on the roofs buildings (58% of the responses) and nanosolar water heaters (57.4% of the responses). The weakest achievement was found to be active solar cabinet dryers (1/22 % of the responses).

The results showed that the effect of these applications was slightly higher than the average expected level, so that among the 10 factors mentioned in this study, all factors were slightly higher than three (Table 3).

Table 2 Percentage of participants' responses to the research variables.

Question	Very Little	Little	Average	Much	Very Much
Question1	15.7	13.4	13.5	34.3	23.1
Question2	17.6	9.8	29.1	25.9	18.5
Question3	20.6	27.4	19.3	16.8	15.9
Question4	13.3	15.8	19.8	30.5	20.6
Question5	22.7	29.5	10.7	15.7	21.4
Question6	19.4	28.7	22.6	15.5	13.8
Question7	26.2	32.7	20.3	7.3	13.5
Question8	14.3	7.8	31.5	27.9	18.5
Question9	17.3	11.3	12.7	37.5	21.2
Question10	15.2	9.6	25.2	29.2	20.8

Table 3 Comparison analysis of average participants' comments on achievements of nanotechnology use in the development of residential complex in Parand.

Variables of the research	Test Value (expected means)	Mean (observed means)	T	Sig.
Nano solar water heater	3	3.30	4.634	0.000
Self-cleaning covers	3	3.32	4.648	0.000
Smart windows (polyaniline nanowire arrays)	3	3.43	8.536	0.000
Anti-reflective coatings	3	3.15	0.717	0.000
Polymer nanocolors for thermal and anti-corrosion insulation	3	3.41	5.476	0.000
Nanostructures in polymer solar cells architecture	3	3.25	4.278	0.000
Low-emission nano-glass	3	3.32	5.942	0.000
Active solar cabinet dryers	3	3.65	12.409	0.000
Photovoltaic coatings on the roofs of buildings	3	3.16	4.083	0.000
Nano color-changing tiles to prevent energy loss	3	3.32	8.727	0.000

This means that – in spite of the relatively proper scientific and educational activities that have been performed to develop knowledge in the field of nanotechnology in Iran in recent years – practitioners, authorities and users have not yet addressed the effect of the application of nanomaterials in parts of the

building and architectural elements to achieve maximum comfort and energy savings, reduce environmental pollutants and solve construction industry problems. Thus, attempts to inform, train and achieve high efficiency in the use of nanotechnology for sustainable development in the construction industry should be enhanced.

The comparison results of a sample t-test showed that the observed means (33.30) was higher than the expected means (30) (Table 4). Therefore, hypothesis 1 ('the use of solar energy through nanotechnology for sustainable development of buildings in Parand is impossible') was confirmed at an error level of 0.01.

Table 4 Comparative one sample T-test.

One-Sample Statistics				
Calculated average of the research hypothesis based on 10 questions	N 3.84	Mean 33.3301	Standard deviation 6.54072	Standard error of mean 0.33164

One-sample Test						
	Test value = 30					
Analysis of variance of 10 research questions	T	df	Sig. (2-tailed)	Mean Difference	95% Confidence interval of the difference	
					Lower	Upper
	10.533	382.0	0.000	3.44010	2.6779	4.2101

Therefore, the following suggestions are presented based on changing the current approaches to construction in Parand, which does not yet benefit from nanotechnology, as well as promoting and expanding the use of nanotechnology for sustainability in the construction of future buildings in Iran:

1. Incorporating theoretical and practical discussions related to different technology frameworks in academic courses to promote the use and exploitation of nanotechnology in the construction industry and learning the benefits of using nanotechnology for solar energy in future projects.
2. International cooperation to facilitate and accelerate research and development activities and support new small and medium nano companies to develop this technology for the construction industry.
3. Paying attention to the use of nanotechnology for solar energy and modeling the application of nanotechnology in developed countries.
4. Improving awareness of authorities, practitioners and users of the benefits of using nanotechnology for solar energy, especially in the areas of control

of supply and demand for energy, reducing energy consumption and environmental effects.
5. Increasing public confidence in using nanotechnology in private and public constructions to save energy and reduce environmental hazards.
6. Holding workshops and promoting the achievements of the use of nanotechnology for solar energy in construction in the entire country.
7. Inviting engineers and specialists in nanotechnology from developed countries to Iran and providing practical training to local engineers in order to institutionalize and increase the motivation to use nanotechnology in future construction.
8. Taking into account appropriate government funding and large investments to implement studies and research on the application of nanotechnology in the use of solar energy in the construction industry.

7 Conclusion

Every city is the manifestation of environmental, economic, social, cultural and physical requirements ruling on them. The current rapid expansion of Parand, its increasing residential population, the lack of using proper construction technologies in creating the environmental and structural elements in urban space, the lack of sustainable planning that pays attention to the importance and potential limitations of the natural environment given that gaining more economic profit only increases the speed of construction, will cause a great deal of irreparable environmental damage. On the one hand, all these factors will increase the cost of municipal services and utilities and lead to urban infrastructure not being provided. On the other hand, the surrounding farm lands will be destroyed due to the development of the city.

Solar energy is a source of free and clean energy that has no destructive environmental effects. It is of high importance to replace fossil fuels with this renewable energy source. Iran's geography makes it possible to use the maximum amount of solar energy in different parts of the country throughout the year, such as the hot and dry area of the new town of Parand.

Solar energy can be optimally utilized by appropriate application of nanotechnology, such as polymer solar cells, photovoltaic coatings, low emission glass with a nanocoating, smart windows (polyaniline nanowire arrays), nano color-changing tiles, self-cleaning covers, polymer nanocolors for thermal and anti-corrosion insulation, nanosolar water heaters, active solar cabinet dryers and anti-reflective coatings in residential complexes. The contribution of nanotechnology innovations to different types of construction materials and products is an important factor in support of the choice for such technological solutions in building design from an eco-efficient perspective.

It is already possible to identify in certain types of nanostructured materials a significant response to the need of reducing the environmental impacts of industrial processes in the construction field. An increased ability to control and manipulate different types of materials at the nano scale will primarily result from a strengthening of the instruments through which the mechanisms that determine their chemical-physical characteristics and final properties are investigated and understood. This will make it possible to significantly modify conventional construction methods as well as building performance and appearance. This energy source, which has no harmful environmental effects, should be used optimally as an investment in a better future, because it is essentially compatible with nature, does not pollute, is renewable and there is no end to it.

References

[1] BPIE, *Europe's Buildings under the Microscope. Brussels*, Belgium: Buildings Performance Institute Europe (BPIE), 2011.

[2] IEA, *Technology Roadmap Energy-Efficient Buildings: Heating and Cooling Equipment*. Paris, France: International Energy Agency (IEA), 2011.

[3] Dodd, N., *Gama-Caldas M. Identifying Macro-Objectives for the Life Cycle Environmental Performance and Resource Efficiency of EU Buildings*. Luxembourg: JRC EU Commission, 2015.

[4] Newbery, D. & Strielkowski, W., *Market Design for a High-Renewables European Electricity System*, Renewable and Sustainable Energy Reviews, **91**, pp. 695-707, 2018. DOI: 10.1016/j.rser.2018.04.025.

[5] Roaf, S., *Counting the Costs of Comfort*, Building Research and Information, **43**(3), pp. 269-273, 2015. DOI: 10.1080/09613218.2014. 998948.

[6] European Communities: Brussels, *Proposal for a Recast of the EPBD, Impact Assessment*, . COM(2008)755, SEC(2008)2821, Belgium, 2008.

[7] Ren, G., Zhao, X., Zhan, Ch., Jin, H. & Zhou, A., *Investigation of the Energy Performance of a Novel Modular Solar Building Envelope*, Energies, **10**(7), pp. 2-17, 2017. DOI: 10.3390/en10070880.

[8] Carayannis, E G. & Campbell, DFJ., *Mode 3 Knowledge Production in Quadruple Helix Innovation Systems: 21st-Century Democracy*, Springer New York: Innovation, and Entrepreneurship for Development, 2011.

[9] Kolehmainen, J., Irvine, J., Stewart, L., Karacsonyi, Z., Szabó, T. & Alarinta, J., *Quadruple Helix, Innovation and the Knowledge-Based Development: Lessons from Remote, Rural and Less-Favoured Regions*, Journal of the Knowledge Economy, **7**, pp. 23-42, 2016. DOI: 10.1007/s1 3132-015-0289-9.

[10] Tronchin, L., Manfren, M. & Nastasi, B., Energy Efficiency, *Demand Side Management and Energy Storage Technologies - A Critical Analysis of Possible Paths of Integration in the Built Environment*, Renewable and Sustainable Energy Reviews, **95**, pp. 341-353, 2018. DOI: 10.1016/j. rser.2018.06.060.

[11] Mattoni, B., Pagliaro, F, Gugliermetti, L. & Bisegna, F., *A Territorial Based Strategy for the Distribution of Sensor Networks in Smart Cities*, 2015 IEEE 15th International Conference on Environment and Electrical Engineering (EEEIC), pp. 653-658, 2015. DOI: 10.1109/EEEIC.2015. 7165242.

[12] Noussan, M. & Nastasi, B., *Data Analysis of Heating Systems for Buildings - A Tool for Energy Planning, Policies and Systems Simulation*, Energies, **11**(1), Article No. 233, 2018. DOI:10.3390/en11010233

[13] Groppi, D., Santoli, L.D., Cumo, F. & Garcia, D.A., *A GIS-Based Model to Assess Buildings Energy Consumption and Usable Solar Energy Potential in Urban Areas*, Sustainable Cities and Society, **40**, pp. 546-558, 2018. DOI:10.1016/j.scs.2018.12.041.

[14] Asadpour, F. & Jamshidi, H.A., *Biological Collections; Their Necessities and Needs for Nanotechnology in The New City of Parand*, Bulletin of Environment, Pharmacology and Life Sciences, **4**(Special Issue 1), pp. 67-72, 2015.

[15] Ramezan Nejad Kutani, A., Mohamadi Nia, S. & Lotfi Nejad, A., *Solar Energy and The Application of Nanotechnology in Solar Energy*, the 1st International Oil, Gas, Petrochemical and Power Plant Conference, Tehran, Iran, 2012.

[16] Abedi Firooz Jah, H., *Study of Interdisciplinary Relationships of the Iranian Science and Nanotechnology Papaers*, indexed at ISI by the end of 2007: Documentary Study, Master's Thesis, Alzahra University, Iran, 2008.

[17] Mohammadi, E., *Drawing A Scientific Map of Nanotechnology in Iran. Master's Thesis Ending*, Islamic Azad University, Science and Research Branch, Iran, 2008.

[18] Jamshidi, H. & Asadpour, F., *The application of Nanotechnology to Reduce the Environmental Effects in New City of Parand*, First Conference on the Development of Civil Engineering, Architecture, Electricity and Mechanic in Iran, Gorgan, Iran, 17 December, 2014.

[19] Najafi Moti'ei, M. & Doroudi, Z., *The role of Nanotechnology in Energy Optimization in Buildings (Nanotechnology in the Construction Industry)*, the Fourth International Conference on Energy Conservation in Buildings, Iran, 2005.

[20] Paya, A. & Kalantari Nejad, R., *Philosophical Assessment and Policy Implications of the Impact of Convergent Sciences & Technologies on Culture and Society: A Study from the Viewpoint of Critical Rationalism*,

Journal of Science & Technology Policy, **2**(4), pp. 33-51, 2010. DOI:10.22034/jstp.2011.2.4.535129

[21] Chamani, J.Kh. & Neshati, Z., *Nanotechnology: The Core of the Future Sciences*. Rahyaft, **14**(32), pp. 105-111, 2004. DOI:10.22034/Rahyaft. 2004.14.32.537888.

[22] Azadi Naghsh, F., *Strategic Information and Communication Interception Referred to in The Islamic Republic of Iran Vision Document On the Horizon of 202*, Master's Thesis, Tarbiat Modares University, Iran, 2008.

[23] Jahanshahi, Z., *Nanotechnology is All About the Future, not Part of It*. Scientific Information, **25**(2), 48-53, 2010.

[24] Serrano, E., Rus, G. & García-Martínez, J., *Nanotechnology for Sustainable Energy*, Renewable and Sustainable Energy Reviews, **13**(9), pp. 2373-2384, 2009. DOI:10.1016/j.rser.2009.06.003.

[25] Ibrahim, M.A., *Nano Architecture and Global Warming*, Doctoral Dissertation, Alexandria University, 2010 .

[26] Hosseinian, Gh. & Darkhall, A.A., *Climatology and Solar Energy Use in Reducing Fuel Consumption in Building*, The 3rd Conference on Optimizing Fuel Consumption in Building, p.3, Tehran, 2003.

[27] Fereydoon, K., Hosseini, A. & Zabihi Nia, K., *Study the Apartment Socio-Cultural Problems in Parandnew City*, Journal of Social Research, **2**(5), pp. 21-40, 2010.

[28] Moloudi, J. & Fani, Z., *Evaluation of the Urban Environment in Terms of Laws and Regulations with an Emphasis on Air Pollution*, Journal of Urban Management, **24**, pp. 51-64, 2009.

[29] Botequilha Leitão, A. & Ahern, J., *Applying Landscape Ecological Concepts and Metrics in Landscape Planning*, *Landscape and Urban Planning*, **59**(2), pp. 65-93, 2002. DOI:10.1016/S0169-2046(02)00005-1.

[30] Asadpour, F., *The Necessity of Using Nanotechnology to Reduce Environmental Risks in The New City of Parand*, International Journal of Advanced Biotechnology and Research (IJBR), **7**(2S), pp. 270-281, 2016.

[31] Abbaspoor, S., *Nano-Houses*, *Future Houses*, Journal of Honar-Ha-Ye-Ziba, **30**(30), pp. 83-90, 2007.

[32] Asadpour, A. & Asadpour, F., *Optimization of Energy Consumption Using Solar Bath in the Hot and Dry Climate of Iran*, European Online Journal of Natural and Social Sciences, **3**(3), pp. 40-49, 2014.

[33] Shockley W. & Queisser, H.J., *Detailed Balance Limit of Efficiency of P-N Junction Solar Cells*, Journal of Applied Physics 1961, **32**, pp. 510-519. DOI:10.1063/1.1736034.

[34] Green M.A., *Prospects for Photovoltaic Efficiency Enhancement Using Low-Dimensional Structures*, Nanotechnology, **11**, pp. 401, 2000.

[35] Frankl, P. & Nowak S., *Technology Roadmap: Solar Photovoltaic Energy*, OECD/ IEA, Paris, France, 2010.

[36] IEA PVPS, *Trends in Photovoltaic Applications – Survey Report of Selected IEA Countries between 1992 and 2008 (Reports Published 1999 to 2009)*, 2009.

[37] Asadpour, F. & Jamshidi, H.A., *The Use of Solar Energy Using Nanotechnology to Reduce Energy Consumption in Biological Buildings of Parand*, Journal of Applied Environmental and Biological Sciences, **5**(12S), pp. 430-436, 2010.

[38] Ashby, M., Ferreira, P. & Schodek, D., *Nanomaterials Nanotechnologies and Design: An Introduction for Engineers and Architects*, Butterworth-Heinemann, Elsevier, 2009.

[39] Bhushan, B., *Introduction to Nanotechnology. In: Springer Handbook of Nanotechnology*, Berlin Heidelberg, Springer, p. 1-13, 2010.

[40] Mohamed, A.M.M., *Zero Carbon Architecture*, Doctoral Dissertation, University of Alexandria, Alexandria, Egypt, 2010.

[41] Sev, A. & Ezel, M., *Nanotechnology Innovations for The Sustainable Buildings of the Future*, International Journal of Architectural and Environmental Engineering, **8**(8), pp. 886-896, 2014.

[42] Carbary, L. D., Hayez, V., Wolf, A. & Bhandari, M., *Comparisons of Thermal Performance and Energy Consumption of Facades Used in Commercial Buildings*, Finland, Glass Performance Days, 2009.

[43] Hosseini, F.S. & Mohammadi Y.S., *Applications of nanotechnology in the construction industry (in Germany)*, Iran Nanotechnology Initiative Council (INIC), Iran, **24**, 2012.

[44] Asadpour, F. & Jamshidi, H.A., *Use of Solar Energy through Nanotechnology to Reduce Energy Use in Buildings of Parand Town*, International Conference on New Achievements in Civil Engineering, Architecture, Environment and Urban Management, Tehran, Iran, 2015.

[45] Khodabakhshi, Z., *An Assessment of the Hot and Dry and Hot and Humid Environment of Iran (Considering the Use of Renewable Energy)*, The 2nd International Conference on Optimizing Fuel Consumption in Buildings, Tehran, Iran, 2002.

[46] Iran Nanotechnology Initiative Council (INIC), *Nanotechnology Comprehensive Training System with Subject: Antibacterial Surfaces and Their Application in the Building*, http://edu.nano.ir/paper/294, Accessed date: (January 10th, 2019).