IYSC

INVESTIGA I+D+i 2015/2016

WORKING GUIDE ON "Nanotechnology for Urban Revolution: Smart Cities"

Text by D. Pedro Serena

October 2015

Introduction

Nanoscience, nanotechnology and new materials have been considered, together, one of the five strategic categories of previous editions of the Research Programme I+D+I (http://www.programainvestiga.org/). This was chosen because these issues have been shaped as key issues in research by the world's most developed countries. To give a couple of examples, in the US 15 years ago the National Nanotechnology Initiative (NNI http://www.nano.gov/) that was intended to ensure that that country was a world leader in the application of nanotechnology in various sectors was launched, while in the European Union, nanoscience and nanotechnology have been a strategic focus of research both for the seventh Framework Programme and for the European Union's Horizon 2020 program. We also mention that China has emerged with great force into the global research landscape and now leads scientific progress in the field. A feature of nanotechnology is its cross-cutting nature, i.e. that it has application in many sectors, which has allowed each edition of the Research Programme I+D+I to address a different aspect: nanotechnology in general, nanotechnology and its application in sports, the impact of nanotechnology in agriculture, food and cosmetics, nano-robots, the fascinating and versatile graphene, and finally wearable nanotechnology.

This paper presents an aspect of nanotechnology that will extend or supplement the topics that have been addressed in previous editions: "nanotechnology and smart cities". The choice of this topic is intended to allow participants to delve into the fascinating world of nanotechnology, identifying its characteristics, showing its enormous potential to create new materials and devices that will be useful in developing future cities, which will be inhabited by forthcoming generations of humanity. In addition, another equally important objective is to show participants the possible existence of risks to health and the environment arising from certain nanomaterials, and how it is addressing this problem to ensure that nanotechnology is not perceived as a threat to society, thus slowing their expected development.

In short, its purpose is to take advantage of our fascination of the miniscule to encourage curiosity about science, increase knowledge about the technologies that are going to surround us in the medium- to long-term, and foster critical spirit among participants, who will be the future citizens of our country, some as consumers and users, others as entrepreneurs and very few, as political leaders. In the second section of this paper we review the main features that characterize nanotechnology. The third section is devoted to outlining various ideas on the issue raised in this edition of the Research I+D+I Program. The fourth section raises a number of questions and specific topics that can be used for discussion in classrooms and to participate in the Open Forum Research Program I+D+I. The ideas exchanged among the participants will be the seed of the work that students will develop later. The fifth section provides some advice on the development of the work. The paper ends with a small set of references that may be useful to dive both the topic of nanoscience and nanotechnology, as found in smart cities.

Nanoscience and Nanotechnology: key ideas

What is "nanoscience"? Simply put, you can define "nanoscience" as the structured accumulation of interconnected knowledge that allow us to understand how nature works when observed on a tiny scale, the so-called "nanoscale", i.e., when objects of a few nanometres in size are observed and their properties are studied. By the way, a nanometre is a unit of miniscule length: 1 nanometre equals 0.001 micrometres or microns, or 0.000001 mm, or 0.000000001 metres. You can write the same chain of equivalences using scientific notation: 1 nm = 10^{-3} microns = 10^{-6} mm = 10^{-9} m. Clearly the prefix "nano" (from the Greek "nanos", tiny) is used to refer to things which are very, very, small.

Meanwhile, "nanotechnology" goes beyond nanoscience, and aims to convert the basic knowledge that it provides us with, regarding the new properties of materials and goods, to improve existing products or propose radically new ones. Thus it is clear that nanotechnology is essentially concerned with the application of knowledge arising from nanoscience. Knowledge generation requires large investments which can have beneficial return, if such knowledge is put in practice. Knowledge generation takes place fundamentally at universities and research centers, while the application of knowledge should be developed in technological centers or companies.

Often it is felt that nanoscience and nanotechnology are modern and almost futuristic terms which we find in comics, movies, novels and television series. However, they are not so innovative, as research in nanoscience have been brewing in research laboratories for nearly fifty years. Already in 1959, the Nobel Prize winner in Physics Richard Feynman anticipated many of the concepts and tools that are currently used in this fascinating discipline. However, it is true that it has been for the last 15-20 years when nanoscience and nanotechnology have seen a dramatic boost from governments, institutions and companies that have realized its enormous potential. As an example I will mention that the first large initiative to promote nanotechnology was launched in the US and was named the National Nanotechnology Initiative (http://www.nano.gov/). This interest has resulted in huge investments which have launched new laboratories, new scientists and engineers that have been trained in the discipline, there have been prototypes and demonstrations, etc. Given that the term "nanotechnology" is the one that has more impact on the society & the media, from this time will be the one used in this document to refer to both the basic and more applied aspects.

Nanoscale, also often called the "nanoworld" is a country inhabited by different types of "nano-objects" and "nanostructures", among which we include atoms, molecules, nanoparticles, carbon nanotubes, graphene, metal nanowires and semiconductors, DNA strands, proteins, ribosomes, viruses, etc. This "nanofauna" is interesting because it shows a series of phenomena that would not manifest itself in its present for were its size much greater. This is what gives everything "nano" significant added value with respect to the "micro" or "macro", and hence it is said that "nano" is different. Why would we be interested in the miniscule, from a technological point of view, if it were not for a higher added value?

But why have these new properties appeared? There are several reasons. On the one hand it is known that atoms on surfaces behave differently to the atoms that are inside an object, since both have different environments. As an object becomes smaller we can observe that the proportion of surface atoms increases more and more. For example in a nanoparticle of 100 nm in diameter, 1-2% of its atoms are on the surface, while in a nanoparticle of 3nm this percentage increases to about 60%. One can say that the nanoparticle of 3 nm is more surface than volume. Therefore, as an object becomes smaller the power of its surface properties is becoming more and more important and the atoms in the interior are less relevant.

However it is not only the importance of the surfaces, but also, as the size of objects are made smaller and smaller, other phenomena that only intriguing quantum mechanics can explain are displayed. Quantum mechanics must be understood as the "manual of laws and rules" that scientists have written to understand the nature, rules and laws that explain how molecules and other more and more complex objects are formed, and how these objects react to mechanical deformations, electric fields, magnetic fields or light. But do not be alarmed, because the I+D+I Research Program participants will not have to study the basics of this exciting discipline. For now they should know that nano-objects in a series of "quantum" effects that cause the appearance of interesting properties. For example, quantum effects cause the electrons moving within a nanoparticle to only be able to have certain energies, which we call allowed energy levels. In addition, as the nanoobject becomes smaller, allowable values for these energies change. As a result many electrical, magnetic or optical properties, which depend on these energy levels, are also modified as you change the size of the object.

The effects mentioned above are called "quantum size effects" and are quite disturbing, because for each size and shape of a nanoobject it shows different properties. This, although it seems like we would lack control over it, really it is the great strength of nanotechnology: if the size and shape of a nanoobject is controlled, you can control its properties and then will be able to get more out of it. The idea is fascinating. Therefore, the ultimate aim of nanotechnology is to control, through physical and chemical methods, the shape, size and internal order of nano-objects and nanostructures to modify their properties at will. For example, by controlling the size and shape of nano-objects, electrical conductivity, its color, chemical reactivity, elasticity and other properties can be modified. It is said that we can manufacture "as materials" or we can "synchronise", or "tune the properties of materials to our will. This control of matter at the nanometre scale is continually improving thanks to powerful physical tools and novel chemical reactions that allow manufacturing nanodevices and nanomaterials. In addition, sophisticated tools allow us to observe what happens in the nanoworld. Among these instruments we can highlight new transmission electron microscopes, the scanning tunneling microscope (STM), atomic force microscope (AFM) or the next-generation powerful electron microscopes. These tools allow observation and even, in some cases, direct manipulation of atoms and molecules. For the last 25 years, human beings have already known how to manipulate atoms one by one, to produce small artificial structures. The nanotechnology has grown up before our very eyes and we can say that soon it will enter its maturity!

The ideas and tools used in nanotechnology evolve unstoppably thanks to the contributions made by chemists, physicists, engineers, mathematicians and medical biologists. Nanotechnology is a completely multidisciplinary field open on many fronts. This is because the components of matter, atoms and molecules, are the same for all these scientific fields. At a nanoscale, we use the same basic "building blocks": atoms and molecules. The aforementioned fusion of disciplines is called "technological convergence. Nanotechnology is a great process of convergence, which is currently still brewing. On the other hand we should not forget that biology plays a key role in nanotechnology, since life itself is pure nanotechnology. No more is needed to look inside a cell to realize that it performs all its functions thanks to "nanomachines" that work seamlessly thanks to extremely long evolutionary processes. In addition, biology presents before our eyes a large arsenal of solutions and strategies that allow us to solve specific problems. Biology is an inexhaustible source of "bio-inspiration" that can provide solutions to problems that arise in other areas such as materials science or chemistry.

To end this long introduction we should not forget to mention that the "nanoproducts" conceived from nanotechnology are encroaching gradually on all economic sectors: materials, electronics, information and communications, energy and environment, transport, construction, industry textiles, biotechnology, health, agriculture, food, etc. Nanotechnology is already becoming big business and we can say that the future will be "nano". In this new context, it is very important to consider the possible (usually negative) side effects that may have advances in nanotechnology. These potentially negative impacts are not unique to nanotechnology; all technologies have their friendly face and their dark side: nuclear power, thermal power plants, vehicles, aircraft, etc. It is very important to be aware of the pros and cons of each technology so that, as educated citizens and critics, we know the impact all kinds of nanoproducts may have, and so demand to have rules and appropriate regulation to ensure safe manufacturing, commercialization, consumption and recycling for both people and the environment.

Smart cities: the cities in which we live (or should live)

Having described what nanoscience and nanotechnology are, we must now describe what is meant by "smart cities", to then outline its connection with nanotechnology. The choice of this topic is due to a fact unknown to many citizens of this country. In Spain there are several cities that have developed programs in order to become “smart cities”. In particular, Santander and Malaga are two of the cities that have made more significant progress in their quest to be managed intelligently. What has been happening in these cities has inspired the question behind this edition: How will nanotechnology influence the implementation of smart cities? We have already said that nanotechnology is a cross-cutting issue, so smart cities will not escape its influence.

To start you have to know what a "smart city" is. There is really no consensus on what a smart city is, and the definition has evolved rapidly as more and more people, governments and companies are involved in its development. On the other hand, the term "smart city" has become a marketing term that is often used without referring to anything novel. The smart city sets sustainability and efficiency above other priotities. It would be the kind of city we need to have a sustainable economy. We are talking about energy efficient cities, with large-scale use of renewable energy sources, with lower emissions of CO2 and other pollutants, with lower environmental impact, designed to make life easier for citizens, which are equipped with much more participatory systems management and government.

Since Neolithic times, men have developed technologies which are applied in the design and construction of cities. Water distribution networks, sewage and water systems, waste collection systems, traffic lights networks, gas pipes, electrical distribution grids, telephone and fibre-optic installations and intercity transport are examples of all technological applications that have, so far, shaped cities, facilitating the social and economic activity of its inhabitants. Now these networks need, together with new applications, to work in a smart, efficient, and sustainable manner, and for this it is necessary to apply all the knowledge that mankind has developed until today.

Therefore it seems that the development of smart cities requires more efficient and less polluting transport systems, more habitable residential buildings that require less energy to operate, establishment of better managed public services of all kinds, etc. This involves developing and using technologies on several fronts. Some of the challenges are: (i) the development of lighter and more resilient materials whose manufacture requires less energy, for use in transportation or building; (ii) develop the electric car by designing new batteries or development of hydrogen technologies; (iii) design and manufacture more resistant construction materials, capable of self-repair that remove air pollution, helping to purify the air we breathe in cities, (iv) develop new building materials, capable of photovoltaic energy generation, or able to filter light based on brightness; (v) develop low-power lighting and signaling systems; (vi) establish extensive networks of sensors that allow to know the traffic situation, car parks, filling of containers of waste, air pollution, the presence of pollen, the temperature, the number of pedestrians, the moisture content of the gardens, etc. in real time and scale of tens of meters; (vii) develop devices that allow contact between themselves to make decisions automatically; (viii) develop systems for storage and processing of the huge amount of data collected in order to improve information systems, decision-making, power grid and water network management, the participation of citizens in city government, etc.; (ix) design vehicles and systems that allow automatic driving; (X) support of control and observation tasks by system drones… From this it follows that the development of smart cities is linked to the development of new materials and devices, the use of sensor networks, the handling of huge amounts of data (Big

Data), the development of communication systems between objects ("Internet of things"), decision-making ("artificial intelligence"), etc. It's amazing to see how all these concepts just mentioned are interrelated.

Smart cities are slowly becoming a reality, developing pilot projects in many parts of the world (Amsterdam, Dubai, Helsinki, San Diego, San Francisco, etc.). In Spain, the Spanish Network of Smart Cities (RECI) is formed by 62 cities and in all of them, projects of varying scope are being carried out to develop and test technologies that will gradually implanted in other cities. By mid-century, many of our cities will have reached reasonable levels of "intelligence".

Potential topics for discussion

Nanotechnology, transversal and multidisciplinary, provides solutions in virtually all economic sectors: health, energy, automotive, space, food, cosmetics, security, agriculture, etc. Nanotechnology, which is seen as the instigator of a new revolution, will be further enhanced when it starts to converge with biotechnology, information technology and communications (ICT), along with advances in neuroscience. It is clear that the scope of applications of the “nano” is very broad and we must focus on specific applications or in certain nanomaterials that are protagonists of nanotechnology. The topic of nanotechnology, applied in the field of intelligent cities, has been chosen for this edition of Research Program I+D+I. In view of what was discussed in the previous section, it is clear that nanotechnology has a key role in the field. However, nanotechnology has no direct application, besides its application in the materials and devices to be used, in turn, for sectors such as electronics, communications, construction, energy, etc. As mentioned before, nanotechnology is a transversal technology that is applied in many sectors and will be "hidden" in many materials and devices, which will have amazing applications.

The work carried out by participants of this edition of Research Program I+D+I should be based on inquiry and consultation of hundreds of web pages and other documents dealing with the aspects mentioned in the previous section. Their work should address issues that allow us to answer some of the questions raised in this list:

- Which types of nanomaterials are to be used in construction to develop smart buildings?
- Which energy efficient lighting systems, are used in information panels? Are they based on nanotechnology?
- Electric cars will need high storage capacity batteries with faster loading times. How does nanotechnology influence this issue?
- Are there nanomaterials that allow savings in the transport of energy to cities?
- Which nanomaterials allow us to lighten the weight of vehicles?
- Are there intelligent windows whose color changes depending on external light levels?
- Can we use nanotechnology to improve water purification in cities?
- Can we deploy tiny sensors into objects of all kinds and managed to get these objects to communicate with one another?
- How will our processors handling massive amounts of data work? How can we increase their speed? How can we increase the capacity of data storage systems? What nanotechnology will be used in hard drives or processors of the future?
- What function can mobile phones or similar systems serve in a smart city? How can we improve mobile phones with nanotechnology? What new features will they have?

There is great challenge for participants, because we have to make an effort to connect seemingly distant subjects and ideas, but that science and technology are fast-approaching. Obviously, in addition to the previous themes, participants will ask new questions and find new answers, which will provide significant added value to the work they produce.

Information sources

Before moving on to list some potentially useful references, one must mention that search engines find tens of millions of nanotechnology-related sites. In this topic, as in others, what is left is information and therefore students should be cautious when selecting the most appropriate sources of information, this phase being of great importance for the successful completion of research. The references shown are related to nanotechnology in general and some related to smart cities have been added. The search for more specific references on the issues raised is part of the work to be carried out by each participating student. These references are only the starting point of a long journey that will last several months. Good luck!