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NEW MATERIALS AND TECHNOLOGIES APPLIED TO SUSTAINABLE BUILDING CONSTRUCTION

TITULACIÓN: GRADO EN ARQUITECTURA TÉCNICA

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INTRODUCTION

The present Bachelor Final Project in Building Engineering Degree has the main objective of investigating about some of the most innovative/new materials that are being studied or have recently begun to be applied on construction projects with the goal of reducing the environmental impact created by the building and improving certain important qualities such as reduction of energy and water consumption.

In order to introduce the concept of sustainability, a first section “state of the art” has been created to give some examples on how to reduce the environmental impact produced by the different materials used in a construction process, from the raw materials’ extraction to their reuse once expired.

Following to the next section, a technology by which materials can get to obtain self-cleaning properties on their surface is explained, by using the semiconductor materials “Titanium Dioxide” as a photocatalyst. Other properties apart from self-cleaning are also obtained as for example air-purification, anti-bacterial effect...

Since insulation materials are some of the most important ones concerning the thermal performance and the conservation of energy of our buildings, in section three, a group of innovating insulation materials is shown by comparing some of their properties (thermal conductivity, thermal resistance, U-value, fire protection....).

Finally, the last section of the project is made up of a questionnaire on sustainability which has been delivered to different construction companies and studios from professionals of the construction sector in order to get a better idea of whether firms are incorporating sustainable construction practices to their day to day project or not.

INTRODUCCIÓN

El presente proyecto de Final de Grado de Arquitectura Técnica tiene por objeto la investigación de algunos de los materiales más innovadores, los cuales están siendo estudiados o se han empezado a aplicar desde hace poco, en proyectos de construcción, con el objetivo de reducir el impacto medioambiental creado por los edificios y mejorar algunas cualidades como la reducción del consumo de agua y energía.

Con el fin de presentar el concepto de sostenibilidad, una primera sección llamada “Estado de la Cuestión” se ha creado para dar algunos ejemplos e ideas de cómo reducir ese impacto medioambiental producido por los diferentes materiales usados en el proceso constructivo, desde la extracción de las materias primas hasta su posterior reutilización una vez expirado.

Continuando con la siguiente sección, se presenta una tecnología por la cual ciertos materiales pueden llegar a obtener propiedades auto-limpiables en sus superficies, con el uso de un material semiconductor como fotocatalizador “Dióxido de Titanio”. Otras propiedades aparte de la auto limpieza como la purificación del aire, o el efecto antibacteriano son demostradas.

Finalmente, la última sección del proyecto se compone de una encuesta sobre sostenibilidad la cual se ha entregado a diferentes compañías constructoras así como a estudios de arquitectura y arquitectura técnica con el fin de obtener una mejor idea de si las empresas están aplicando prácticas sostenibles en el desarrollo de sus proyectos o no.

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STATE OF THE ART

1. INTRODUCTION TO SUSTAINABILITY and SUSTAINABLE DEVELOPMENT

It is becoming increasingly difficult to ignore the elevated amount of energy and resources consumed by people as a consequence of a progressive population growth.

Over the past century, there has been a dramatic increase in energy/water consumption and waste production which, if not controlled, can be harmful not only for our present environment and health but also for those of the generations to come.

Although there is not a commonly international definition for the term “sustainability” , the term itself is directly linked to the first serious worldwide discourse on sustainable development (1987) when the United Nations published the well-known *Brundtland Report (Our common Future)*.

On this report, Gro Brundtland, prime minister of Norway, who chaired the UN World Commission on Environment and Development, first defined sustainable development as:

“...the development which meets the needs of the present without compromising the ability of future generations to meet their own needs.”

Since the publication of the Brundtland report, sustainability has become an all-encompassing discipline because truly sustainable development must include all facets of human activity-agriculture, manufacturing, transportation, buildings and infrastructure. [1]

According to Sage [2], sustainable development refers to the fulfillment of human needs through simultaneous socio-economic and technological progress and conservation of the earth's natural systems. Sustainable world progress is dependent upon continued economic, social, cultural, and technological progress. To achieve this, careful attention must also be paid to preservation of the earth's natural resources. Sustainable development is a term generally associated with the achievement of increased techno-economic growth coupled with preservation of the natural capital that is comprised of environmental and natural resources. It requires the development of enlightened institutions and infrastructure and appropriate management of risks, uncertainties, and information and knowledge imperfections to assure intergenerational equity, intra-generational equity, and conservation of the ability of earth's natural systems to serve humankind. [2]

To summarize the concept, three different areas can be directly linked to the achievement of sustainable development:

The Three Spheres of Sustainability

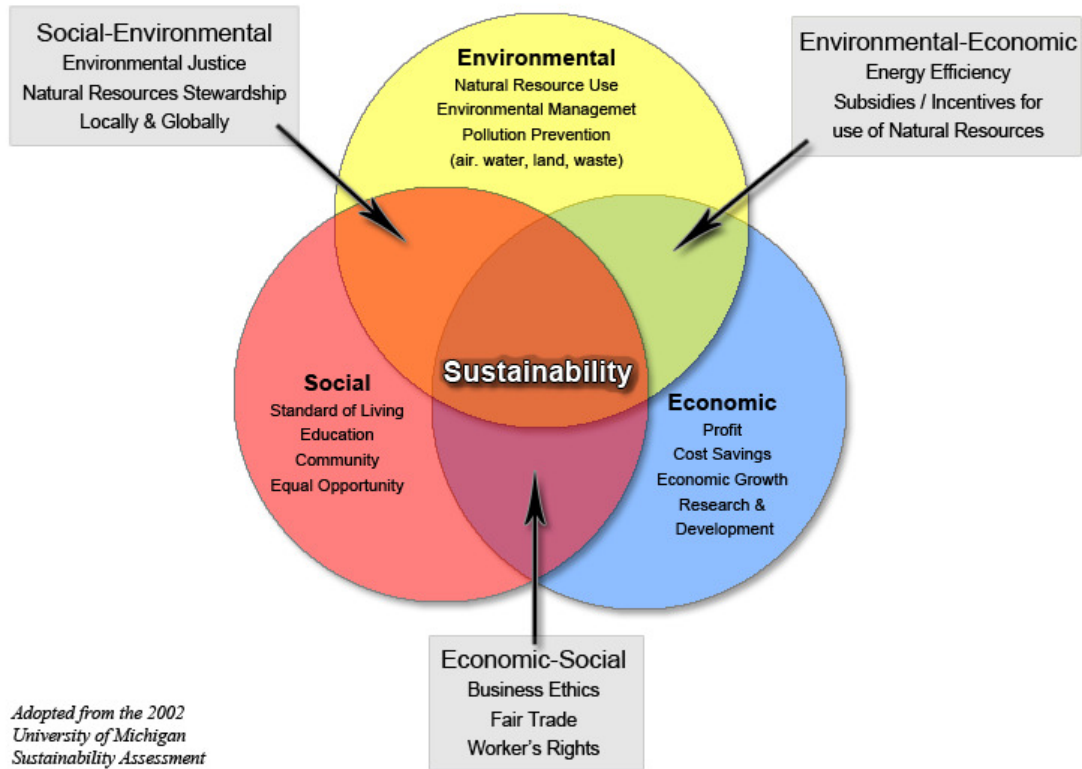


Figure 1. The three spheres of sustainability

[3] The scope of sustainability is frequently described as including three spheres – social, environmental and economic. To use an accounting metaphor, sustainability projects must be evaluated according to a “triple bottom line” of social, environmental and economic responsibility.

2. INTRODUCTION TO SUSTAINABLE CONSTRUCTION

While concepts such as green construction, ecological construction or sustainable architecture have now been used for a while, the term of Sustainable Construction was first introduced by Charles J. Kibert (1994) during the first international conference on sustainable construction held in Tampa;

“Sustainable construction is the creation and responsible management of a healthy built environment based on resource efficient and ecological principles” [4]

The International Council for Research and Innovation in Building and Construction (CIB) defined sustainable construction as:

“The sustainable production, use, maintenance, demolition, and reuse of buildings and constructions or their components”, while sustainable buildings and built environments are seen as “The contributions by buildings and the built environment to achieving components of sustainable development” (CIB, 2004, p. 02)

Other definitions that clarify the main objectives of this type of construction are the ones given by Huovila and Richter (1997) and by Lanting, 1998:

“Sustainable construction aims at minimizing the use of energy and emissions that are harmful for environment and health, and produces relevant information to customers for their decision making”

“...a way of building which aims at reducing (negative) health and environmental impacts caused by the construction process, by buildings or by the built environment”

2.1 PRINCIPLES OF SUSTAINABLE CONSTRUCTION

[5] Professor Charles J. Kibert of the University of Florida proposed 6 principles of sustainable construction:

1. Minimization of resource consumption
2. Maximization of resource reuse
3. Use of renewable and recyclable resources
4. Protection of the natural environment
5. Creation of a healthy and non-toxic environment

These principles will be individually explained within the following sections of how to assess the environmental impact of a product throughout its entire life-cycle.

There are three ways by which the civil engineering and construction industry can act to achieve sustainable construction [5]:

- Creating built environments
- Restoring damaged and/or polluted environments
- Improving arid environments

Miyatake [5] suggests that in order to achieve a sustainable construction, it is necessary for the construction industry to change its processes of creating the built environments. This could be coined as bringing change from linear processes to cyclic processes within the construction industry, meaning that the industry has to change the way in which all the construction activities are undertaken.

With the use of energy, materials and resources needed to create buildings and other civil engineering projects, a huge volume of discharge waste during and at the end of the facility's life is resulted.

Therefore, changing this linear process into cyclic process will bring increased use of recycle, renewed and reused resources, and decrease in significant use of energy and other natural resources.

On the other hand, in order to restore damaged and polluted environments, efforts have been done such as treatments of damaged and contaminated soils, water and air.

The idea behind improving arid environments is to improve large scale arid environments like deserts and introduce adaptive conditions for plants, animals and human beings.

When assessing construction sustainability the following components have to be evaluated (Anik et al, 1996):

- Prevention of unnecessary use of land and the avoidance of unnecessary construction.
- Restricting the brief of construction to the necessary minimum.
- Selection of the most efficient use of building materials
- Optimal exploitation of natural resources and the efficient use of energy in production and use of buildings, i.e. throughout the entire integrated life cycle of the building.
- Assurance of optimal new construction and sustainable refurbishment.

3. SUSTAINABLE CONSTRUCTION MATERIALS

Since building materials constitute a large part of the environmental burden created by a building, one of the easiest ways of beginning to incorporate sustainable design principles in our projects is by the careful selection of environmentally sustainable building materials.

[6] The assessment of environmental materials begins with establishing criteria for evaluating building materials. These criteria should complement the overall environmental project goals with often extensive research to evaluate prospective products.

Based on the environmental material criteria established for a green building project, selection of appropriate building products and systems can be accomplished.

[6] When selecting green building materials, environmental criteria and proper application of the materials should be considered. The following are the three phases of the environmental assessment process:

- Research
- Evaluation
- Selection

The research phase includes gathering information directly from manufacturers such as:

- Obtaining material safety data sheets (MSDs)
- IAQ test data (if available)
- Environmental Statements
- Recycled content data
- Durability information
- Product warranties.

Once the research and information gathering is complete, the evaluation phase begins including the confirmation of the information provided by the manufacturers and requests for missing or incomplete data. The evaluation and assessment can be accomplished by comparing similar types of building materials based on the environmental criteria.

The final phase of the environmental assessment process consists on the selection of sustainable materials which is based on the product that best meets the established environmental criteria and the most appropriate application for the project. [6]

3.1 ASSESSMENT AND SELECTION OF THE ENVIRONMENTAL IMPACT OF MATERIALS.

3.1.1 CONCEPT OF LYFE-CICLE DESIGN AND ITS PHASES

The environmental impact of materials is caused during their complete life time, from the gathering of raw materials, manufacturing, distribution and installation to their final reuse or disposal, a process known as “cradle-to-grave”.

That is why it is necessary to analyze each step of a material's life-cycle in order to evaluate the environmental impact of a product.

[7] The principles of Life Cycle Design provide important guidelines for the selection of building materials. A material's Life-Cycle can be organized into three different phases paralleling the life cycle phases of a building site:

- Pre-building Phase
- Building Phase
- Post-building Phase

3.1.1.1 THE PRE-BUILDING PHASE

It refers to the manufacturing process, describing the production and delivery of materials up to the point of their installation. This includes discovering raw materials in nature as well as extracting, manufacturing, packaging and the delivery/transportation to the construction site.

[7] This phase has the most potential for causing environmental damage because of the environmental consequences produced by:

- Raw material procurement methods
- Manufacturing Process
- Distance from the manufacturing location to the building site.

A material is only considered renewable if it can be grown at the same rate that meets or exceeds the rate of human consumption. So the extraction of raw materials from non-renewable sources has severe consequences causing ecological damage.

[7] This ecological damage includes the *loss of wildlife habitat*, due to the microclimate alteration and the damage of certain ecosystems which leads to the extinction of a high number of species. It also includes the *erosion of the top soil and runoff into streams and rivers*, resulting on a plant die-off and a decrease of the amount of oxygen to other life forms.

Not to forget the *water and air pollution* from waste and toxic by-products of mining and harvesting operations. The machinery needed, burns fossil fuels and the combustion engines emit several toxic gases such as:

- Carbon monoxide
- Carbon Dioxide
- Sulfur Dioxide and nitrous oxide.

3.1.1.2 THE BUILDING PHASE

This phase includes the On-site Construction Process from the moment materials are delivered to the site, including its installation, operation, maintenance and repairs.

From the perspective of the designer, multiple choices will have to be made in order to increase the material's useful life and its durability, such as reducing construction waste and selecting more durable materials.

3.1.1.3 THE POST-BUILDING PHASE

[7] This one could be the least considered and understood phase of the building life cycle, occurring when the building or material's life span has been expired.

From this point on, two main concepts should be differentiated depending on whether we are thinking of reusing or recycling some of the products or waste them:

- Deconstruction
- Demolition

[8] In the context of physical construction, "*deconstruction*" is the selective dismantlement of building components, specifically for re-use, recycling, and waste management. It has also been defined as "construction in reverse". It differs from "*demolition*", where a site is cleared of its building by the most expedient means.

The process of dismantling structures is an ancient activity that has been revived by the growing field of sustainable and green building. Buildings, like everything, have a life-cycle. Deconstruction focuses on giving the materials within a building a new life once the building as a whole can no longer continue.

When buildings reach the end of their useful life, they are typically demolished and hauled to landfills. Building implosions or 'wrecking-ball' style demolitions are relatively inexpensive and offer a quick method of clearing sites for new structures.

On the other hand, these methods create substantial amounts of waste. Components within old buildings may still be valuable, sometimes more valuable than at the time the building was constructed. [8]

To sum up, the demolition of buildings and disposal of the resulting waste has a high environmental cost because degradable materials may produce toxic waste, alone or in combination with other materials. So the energy embodied in the construction of the building itself and the production of these materials will be wasted if these “resources” are not properly utilized. [7]

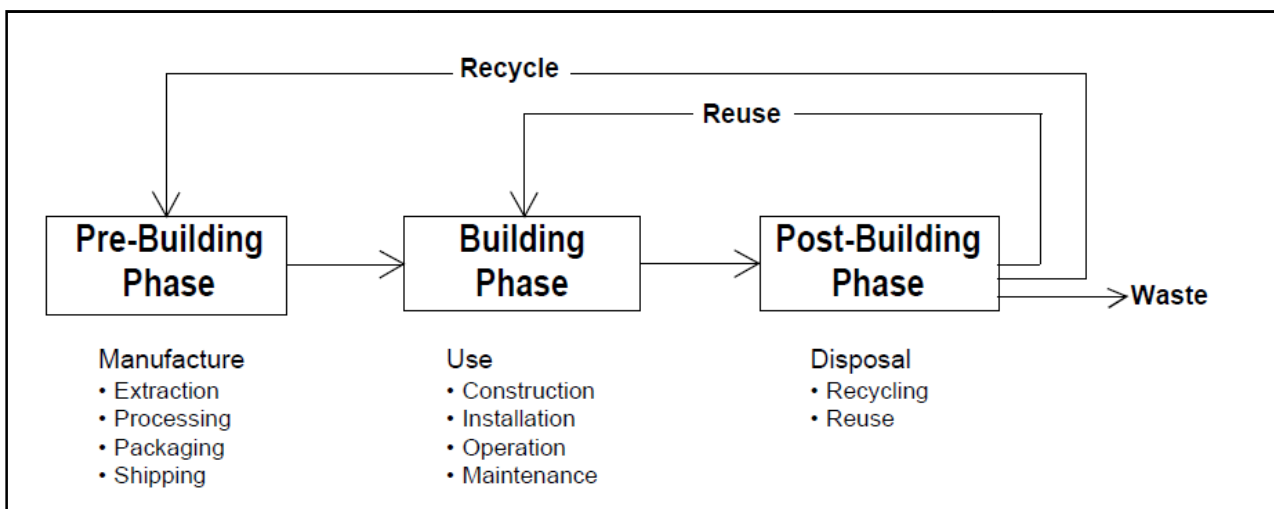


Figure 2. Phases of the building materials' life cycle

3.1.2 ASSESSMENT OF SUSTAINABLE BUILDING MATERIAL'S FEATURES.

The past thirty years have seen increasingly rapid advances in the field of the selection and incorporation of more environmentally building materials to the construction projects.

As mentioned before, it is not only important to focus on a single attribute of a material's life-cycle but, in order to understand the whole environmental impact of a product, it becomes necessary further research and a more complex study of the behavior of the material through the different phases.

On this section, these relationships are studied: the three main phases of a life-cycle design of a material with the different types of sustainable features that a product can accomplish through its entire life. The greater amount of these features a material has, the more sustainable it will be and the less environmental impact it will cause.

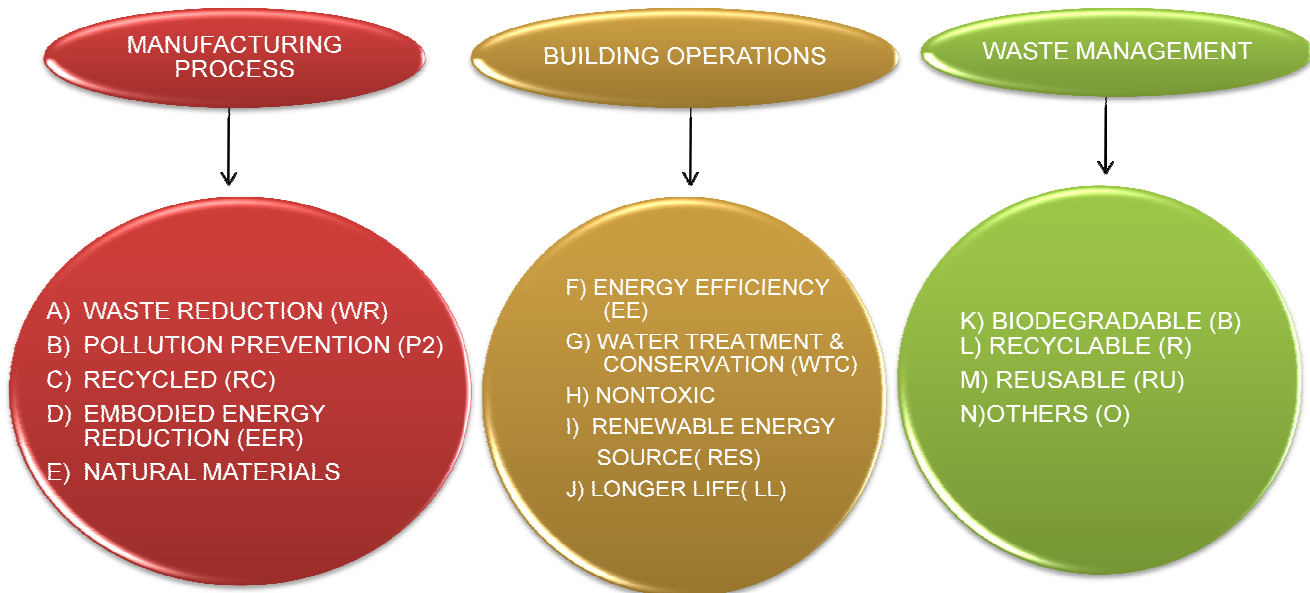


Figure 3. Green Features of Sustainable building materials

On the next pages, each one of these features and the way to achieve them will be explained.

The **Pre-Building Phase** of a material's life-cycle refers mainly to the manufacturing process where some of the next features can be improved with the finality of reducing the amount of green house gases emitted into the atmosphere.

A) WASTE REDUCTION

In industries, using more efficient manufacturing processes and better materials will generally reduce the production of waste. The application of waste minimization techniques has led to the development of innovative and commercially successful replacement products. Waste minimization has proven benefits to industry and the wider environment.

That is why; manufacturers have taken a few steps over the standard regulations to obtain a more efficient and environmentally sustainable production process.

On the one hand, this goal can be achieved by reducing the amount of scrap materials which can be immediately re-incorporated at the beginning of the manufacturing line so that they do not become a waste product.

On the other hand, industries can create power from the use of their own waste products such as reusing the water used for cooling equipment after being filtered instead of wasting it into the waste stream.

B) POLLUTION PREVENTION MEASURES

By reducing the amount of air, water and soil pollution during the manufacturing process, the indoor air quality improves not only for the building itself but for the workers as well.

[9] When we generate waste or pollution, we must safely and legally manage that waste or pollution. Here are some reasons to prevent pollution:

- Improved work environment and worker safety.
- Reduced liability.
- Increased efficiency.
- Fewer regulatory requirements.
- Better environmental protection.

C) RECYCLED

[7] A product featuring *recycled content* has been partially or entirely produced from post-industrial or post-consumer waste. The incorporation of waste materials from industrial processes into usable building products reduces the waste stream and the demand on virgin natural resources.

By recycling materials, the embodied energy they contain is preserved, so the energy used in the recycling process for most materials is far less than the energy used in the original manufacturing.

Key building materials that have potential for recycling include glass, plastics, metals, concrete, brick, and wood.

D) EMBODIED ENERGY REDUCTION

[10] The construction industry requires the extraction of vast quantities of materials and this, in turn, results in the consumption of energy resources and the release of deleterious pollutant emissions to the biosphere.

Each material has to be extracted, processed and finally transported to its place of use.

The energy consumed during these activities is critically important for human development, but also puts at risk the quality and longer term viability of the biosphere as a result of unwanted or “second” order effects.

Many of these side-effects of energy production and consumption give rise to resource uncertainties and potential environmental hazards on local, regional or national scales.

Energy and pollutant emissions such as carbon dioxide (CO₂) may be regarded as being “embodied” within materials. Thus, embodied energy can be viewed as:

“ The energy consumed by all of the processes associated with the production of a building, from the acquisition of natural resources to product delivery, including mining, manufacturing of materials and equipment, transport and administrative functions” (CSIRO 2008).

The next table shows the quantity of embodied energy and embodied carbon emissions of different material (bricks, mortar, concrete, glass...):

MATERIALS	Embodied Energy (MJ/Kg)	Carbon Energy (KgC/Kg)
BRICKS		
General	3	0,06
Limestone	0,85	-
CEMENT		
General	4,6	0,226
Portland cement, wet kiln	5,9	0,248
Portland cement, dry kiln	3,3	0,196
Fibre cement	10,9	0,575
Mortar (1:3)	1,4	0,058
Mortar (1:4)	1,21	0,048
Mortar (1:0,5:4,5 cement;lime;sand mix)	1,37	0,053
Mortar (1:1:6 cement;lime;sand mix)	1,18	0,039
Mortar (1:2:9 cement;lime;sand mix)	0,85	0,038
CONCRETE		
General	0,95	0,035
Precast Concrete, cement;sand;aggregate	2	0,059
1:1:2 (high strength)	1,39	0,057
1:1,5:3 (used in floor slabs,columns...)	1,11	0,043
Fibre-reinforced	7,75	0,123
Road and pavement	1,24	0,035
GLASS		
General	15	0,232
Fibreglass	28	0,417
Toughened	23,5	0,346
STEEL		
General	24,4	0,482
General, primary	35,3	0,749
General, secondary	9,5	0,117
Galvanised sheet primary	39	0,768
Stainless	56,7	1,676
TIMBER		
General	8,5	0,125
Glue laminated timber	12	-
Hardboard	16	0,234
MDF	11	0,161
Particle board	9,5	0,139
Plywood	15	0,221

Figure 4. Embodied and Carbon energy of different materials [10]

E) NATURAL MATERIALS

Natural materials are generally lower in embodied energy and toxicity than man-made materials because they require less processing and are less damaging to the environment. Many, like wood, are theoretically renewable and by incorporating low-embodied-energy materials into building products, these become more sustainable [7].

During the **Building Operation's Phase** certain aspects that contribute to the sustainability and to the energy and water reduction of our buildings must be studied and analyze during the design process of the project:

F) ENERGY EFFICIENCY

Investing in efficiency is critical to meeting future energy demand and mitigating climate change. It reduces greenhouse gas emissions and improves productivity. By reducing the energy demand, efficiency also makes renewable energy more affordable. [11]

Adopting cost-effective standards for a wider range of technologies could, by 2030, reduce global projected electricity consumption by buildings and industry by 14%, avoiding roughly 1,300 mid-size power plants. Between 1990 and 2006, increased energy efficiency in the manufacturing sectors of 21 member countries of the International Energy Agency resulted in a 21% reduction of energy use per unit of output. [11]

So in order to assess the energy efficiency, crucial factors must be evaluated during the design phase such as; the resistance to heat flow “R-value”, the rate of heat lost “U-value”, the shading coefficient, the illumination efficiency measured in “lux” or the control of the contribution of natural light into a building.

G) WATER TREATMENT AND CONSERVATION

In recent years, there have been an increasing amount of studies on improving new innovative waste water technologies with the objective of reducing the amount of potable water used for flushing fixtures, to minimize the quantity of water that must be treated by municipal septic systems as well as to increase the quality of the water.

According to Jon-Jin Kim [7], there are two ways to accomplish the water/treatment conservation feature:

A) By restricting the amount of water through the fixtures, using water-saving showerheads, faucets and vacuum-assisted or composting toilet.

B) By recycling the water that enters the site, separating the waste-water stream into “GREYWATER” (obtained from the cooking or hand-washing) from “BLACKWATER”. This can be achieved by installing a greywater treatment and disinfection system.

This way, greywater collected from kitchens and rain water collected from roofs or paved parking can be use for flushing toilets, for landscaping irrigation and for clothes washing.

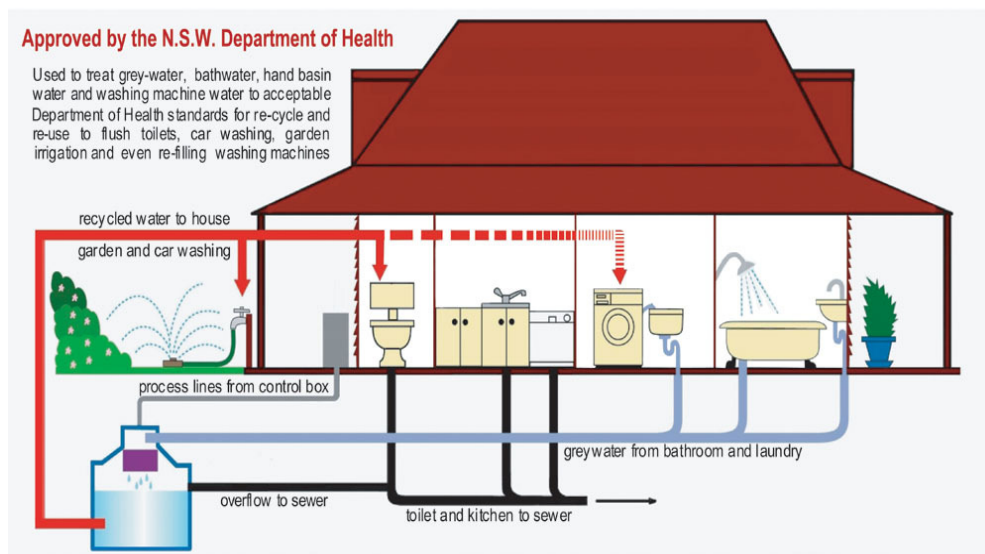


Figure5. Household greywater recycling diagram [12]

H) USE OF NON-TOXIC OR LESS-TOXIC MATERIALS.

The relative sustainability of materials is also a function of its impact on human health. A number of modern building materials, particularly adhesives used in wood products and floor finishes (carpets, linoleum and vinyl and rubber floorings), paints, sealers and sealants emit indoor air pollutants, which are harmful to human beyond a certain level of concentration.[1]

The most commonly discussed indoor air pollutants are [13]:

- Volatile organic compounds (VOCs),
- Microbial contaminants (fungi, bacteria, viruses),
- Non-viable particles,
- Inorganic chemicals (nitrogen oxides, carbon monoxide, carbon dioxide, ozone)

- Semi-volatile organic compounds (SVOC - including pesticides and fire retardants).

Major Health Effects of Indoor Pollutants [13]:

- Infectious disease: flu, cold, pneumonia.
- Cancer, other genetic toxicity, teratogenicity-(Ecotoxicity).
- Asthma and allergy.
- CNS, skin, GI, respiratory, circulatory, musculoskeletal, and other systemic effects.
- SBS (Sick Building Syndrome).

In addition to the impact of these materials on human health, it is also important to know their environmental impact because some materials will either release toxic materials during their use or degrade into harmful substances in landfills.

I) RENEWABLE ENERGY SOURCES

As the earth natural resources are finite, it becomes more and more necessary to adopt currently new renewable energy sources that supplement or eliminate the traditional cooling, heating and electrical system of our buildings in order to reduce the environmental impact.

Some of the main renewable technologies are:

- Solar power
- Wind power
- Hydropower
- Biomass
- Biofuel
- Geothermal energy

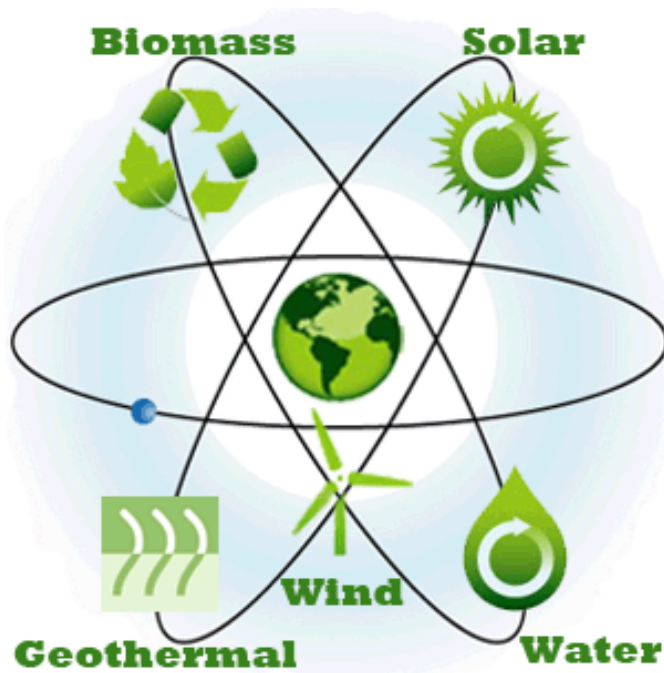


Figure6. Renewable sources of energy [14]

J) LONGER LIFE

From a sustainability perspective, a material, component or system may be considered durable when its useful service life is fairly comparable to the time required for related impacts on the environment to be absorbed by the ecosystem.

[7] Materials with a longer life relative to other materials designed for the same purpose need to be replaced less often.

Durable materials that require less frequent replacement will require fewer raw materials and will produce less landfill waste over the building's lifetime. Two important factors are related to the longer life of materials:

- Durability
- Low maintenance

Materials with longer life-cycling will be more cost-effective than some other materials that need to be replaced more often and on the other hand it should be considered that a short period in cleaning materials reduces the exposure of the building occupants to cleaning chemicals. [7]

Finally, during the last phase of a material's life-cycle design, **“the Post-Building Phase”**, concepts such as biodegradability, recyclability and reusability of the materials, have to be considered because once the building's materials lifespan has expired, three possible solutions can be given for those (from a waste management point of view) from the deconstruction or demolition process:

- Landfill (GRAVE)
- Recycle (Post-consumer waste as raw materials for manufacturing)
- Reuse (Post-consumer waste in refurbished/salvaged products)

K) BIODEGRADABILITY

An important green feature for sustainable materials is their biodegradability, which refers to the potential of the material to naturally decompose itself when its usefulness expires.

Organic materials can return to the earth rapidly, while others, like steel, take a long time reducing them to the natural condition. One consideration to take into account is whether the material in question will produce hazardous materials as it decomposes, either alone or in combination with other substances.

L & M) REUSABILITY AND RECYCLABILITY

Reusability of materials is a function of their age and durability. Very durable materials may have many useful years of service left once the building in which they are installed is decommissioned, and may be easily extracted and reinstalled in a new building site.[7]

So one of the ways of making a building more sustainable is by using materials that have been recovered from a demolition or deconstruction site because it reduces the amount of raw materials and the impact on landfills.

[14] Some entities such as the Building Materials Reuse Association (BMRA) are increasing opportunities for the recovery and reuse of building materials in an environmentally sound and financially sustainable way with the next objectives:

- Providing opportunities for Members and other interested parties to share information and increase knowledge and understanding of deconstruction and reuse of building materials.

- Educating the construction and demolition industry, the general public, institutional and governmental organizations about:
 - Benefits of deconstructing buildings for reuse and recycling ways that used building materials may stimulate economic activity via new markets and job creation while also promoting environmental benefits.
 - Certifications and standards that will increase the marketability, value and use of reclaimed building materials in new and renovation construction projects.
 - And conducting research and creating new knowledge.

Recycling is a process that uses waste materials into new products to achieve certain conditions such as:

- Preventing waste of potentially useful materials
- Reducing the consumption of fresh raw materials
- Reducing energy usage,
- Reducing air pollution (from incineration) and
- Reducing water pollution (from land filling)

With the application of these conditions, not only the need for “conventional” waste disposal is reduced but also the greenhouse gas emissions [16].

Recycling is a key component of modern waste reduction and is the third component of the "Reduce, Reuse, and Recycle" waste hierarchy.



Figure 7. The three “R”s

3.1.3 TOOLS FOR ASSESSING THE ENVIRONMENTAL IMPACT AND SUSTAINABILITY OF BUILDINGS.

As a result of the increased interest on the application of Sustainable Practices (green construction), a great number of organizations have developed codes and rating systems to study the environmental performance of buildings in the construction sector, establishing minimum requirements for constructive elements such as materials or energy efficiency systems.

The next table shows some of the diverse tools used by different countries to analyze and control the environmental impact of a construction:

BUILDING ENVIRONMENTAL ASSESSMENT TOOLS	
COUNTRY	TOOL
Australia	Nabers / Green Star /Basix
Brazil	Aqua / LEED Brasil
Canada	LEED Canada / Green Globes / Built Green Canada
China	GBAS
Finland	PromisE
France	HQE
Germany	DGNB / CEPHEUS
Hong Kong	BEAM Society Limited
India	Indian Green Building Council / GRIHA
Italy	Protocollo Itaca / Green Building Council Italia
Japan	CASBEE
Republic of Korea	Korea Green Building Council Certification
Malaysia	GBI Malaysia
Mexico	LEED Mexico
Netherlands	BREEAM Netherlands
New Zealand	Green Star NZ
Spain	VERDE
United States	LEED / Living Building Challenge / Green Globes /Build it Green / NAHB NGBS / International Green Construction Code / Energy Star
United Kingdom	BREEAM
United Arab Emirates	Estidama
Czech Republic	SBToolCZ

Figure 8. Building environmental assessment tools.

[17] Among some of the most known green building rating systems are BREEAM (United Kingdom), LEED (United States and Canada), DGNB (Germany) and CASBEE (Japan), in which they award credits (determining the level of achievement) for optional building features that support green design in categories such as:

- Location and maintenance of building site
- Conservation of water
- Energy Efficiency
- Building materials
- Occupant comfort and health

LEED (Leadership in Energy & Environmental design)

[18] Following the formation of the U.S. Green Building council (USGBC) in 1993, the organization's members quickly realized that the sustainable building industry needed a system to define and measure "green building". USGBC began to research existing green building metrics and rating systems.

The first LEED Pilot Project Program, also referred to as LEED Version 1.0 was launched at the USGBC Membership Summit in August 1998. After extensive modifications, LEED Green Building Rating System Version 2.0 was release in March 2000, with LEED Version 2.1 Following in 2002 and LEED Version 2.2 following in 2005 and the last in 2009 for new construction.

LEED certification involves five primary steps:

1. Choose which rating systems to use.
2. Register. The LEED process begins with registration. Once registration forms are submitted and payment is complete, your project will be accessible in LEED Online.
3. Submit your certification application and pay a certification review fee. Fees differ with project type and size.
4. Review. Await the application review.
5. Certify. Receive the certification decision, which you can either accept or appeal.

There are several LEED Rating Systems, which are groups of requirements for projects that want to achieve LEED certification. Each group is geared towards the unique needs of a project or building type. Following, a list of the several rating systems LEED works with:

- LEED-NC for new construction and major renovations
- LEED-EB for existing buildings
- LEED-CI for commercial interiors
- LEED-CS for core and shell
- LEED-H for homes
- LEED-ND for neighborhood development
- LEED-S for schools

The next figures show the five major credit categories of LEED 2009 (Indoor Environmental quality, Materials and Resources, Energy and Atmosphere, Water Efficiency, Sustainable Sites), with a total of 100 possible base points, and 10 extra bonus points divided for Innovation and design and Regional Priority. Depending on the numbers of points that a building obtains, it will be given one of the four different levels of certification (certified, silver, gold, or platinum) [18]:

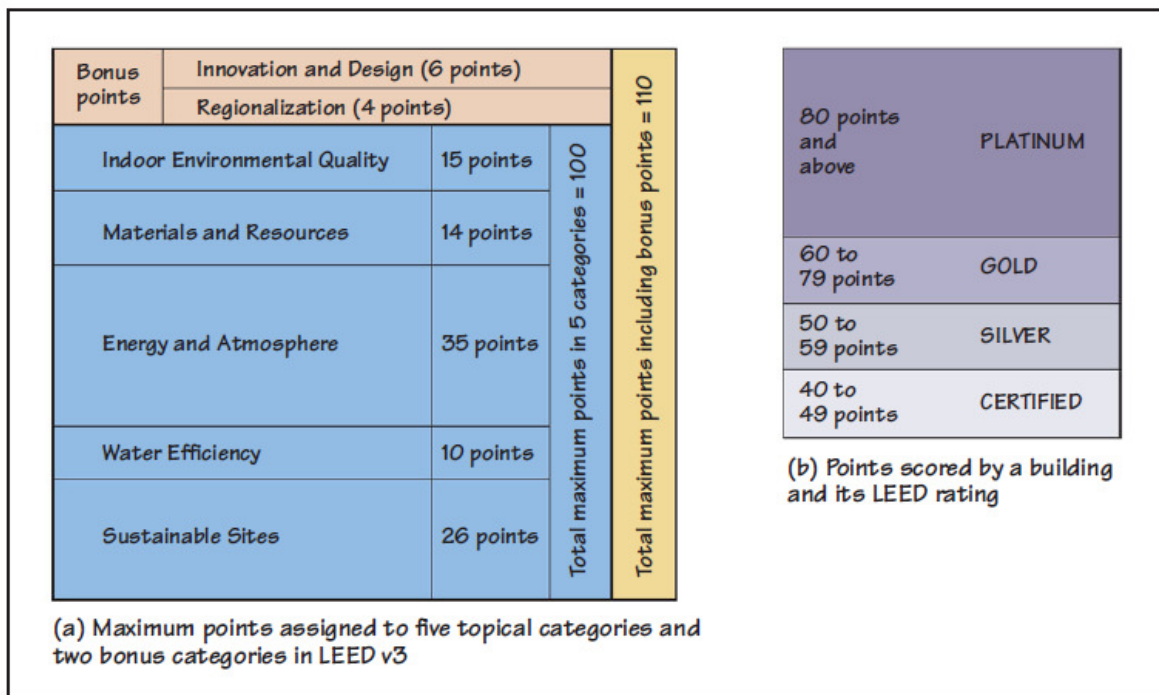


Figure 9. Leed Certification



APPLICATION OF TITANIUM DIOXIDE

4. INTRODUCTION TO PHOTOCATALYSIS

The concept of photocatalysis has recently attracted a great deal of attention among professionals within the construction industry sector and investigation laboratories due to its application for obtaining self-cleaning surfaces on building materials.

This particular property applied, for example, on external building walls can help us to reduce, not only the period time of cleaning or refurbishing these façades, but also the amount of pollutants nitrogen oxides in the atmosphere, while maintaining the best visual aspect as constant as possible.

That is why; the use of photocatalytic self-cleaning materials has a great importance nowadays because, first, a high fraction of the population lives in city buildings, and, second, air pollution provoked by traffic vehicles and industrial activities tends to increase so far, in spite of stricter regulations. Therefore façades soiling by solid deposits generated by combustions occurs more rapidly than ever before. [19]

The reduction on the amount of pollutants in the air and a longer materials lifespan, both contribute to an improvement and a decrease of the environmental impact of a building life-cycle.

5. PHOTOCATALYSIS AND TITANIUM DIOXIDE (HISTORICAL BACKGROUND)

Catalysis is a chemical phenomenon which alters the speed of a chemical reaction. Therefore, photocatalysis is a natural phenomenon in which a substance, referred to as photocatalyst, uses the action of light (natural or artificial) to modify the speed of a chemical reaction (often speeding it up and making it much more powerful). This phenomenon implies that in presence of air (and therefore humidity) and light a powerful oxidative process is triggered which will lead to decomposition of organic and inorganic pollutants that come into contact with photocatalytic surfaces. [20]

The beginning of photocatalyst was in the early seventies when Honda and Fujishima found water decomposition reaction by light on titanium dioxide (electrodes without using electricity. [21]

Before the Honda-Fujishima effect (1969), Titanium Dioxide powders had been commonly used as white pigments from ancient times. They are inexpensive, chemically stable and harmless, and have no absorption in the visible region, and thus, they have a white color. However, the chemical stability of holds only in the dark. Instead, it is active under UV light irradiation, inducing some chemical reaction. Such activity under sunlight was known from the flaking of paints and the degradation of fabrics incorporating .

In 1956, there were a series of reports by Mahio et al. (Japan), entitled “Autooxidation by as a photocatalyst” in which they dispersed powders into various organic solvents such as alcohols and hydrocarbons followed by the UV irradiation with an Hg lamp. They observed the autooxidation of solvents and the simultaneous formation of (strong oxidizer) under ambient conditions. [22]

It was in 1977 when Frank and Bard made reports on the research of the utilization of the strong photo-produced oxidation power of in which they described the decomposition of cyanide in the presence of aqueous suspensions and in the 1980s, detoxications of various harmful compounds in both water and air were demonstrated using powdered titanium dioxide actively as potential purification methods of waste water and polluted air. [22]

Around the 1990s, several investigations were made on the novel concept of titanium dioxide film photocatalysis under weak UV for coating materials. One of the first products to be commercialized using this particular effect was the self-cleaning cover glass in tunnel lighting in Japan.

Most tunnels in Japan use sodium lamps emitting yellow light and the decrease in light intensity due to filming with exhaust compounds is one of the most serious problems. So with the use of this technology (see picture on the right), glass covers on highway tunnel lighting which are darkened by automobile exhaust fumes can be maintained clean with the . However, it is important to mention that this function is only effective when the number of incident photons is much greater than that of filming molecules arriving on the surface per unit time. [22]

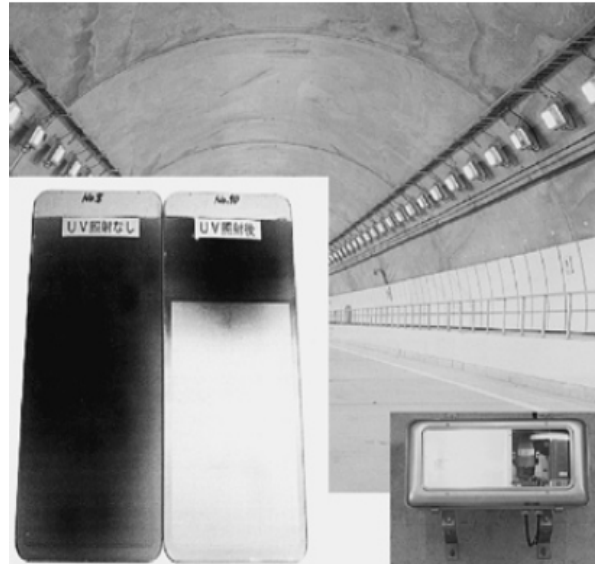


Figure 10. Tunnel lamps self-cleaning comparison

As previously mentioned, titanium dioxide has become a practical technology after the middle of the 1990s, and it is surprising the fact that many researches are still being carried out in order to find a way to develop both science and technology during and after the 21st century.

6. AS PHOTOCATALYST

Photocatalysts can facilitate the breakdown and removal of a variety of environmental pollutants at room temperature by oxidation, using either sunlight or artificial light as an energy source. That is why, it was so important for scientists and laboratories to find (among some semi-conductor photocatalysts such as CdS, ZnO,) the one that presents characteristics such as:

- High photocatalytic activity
- High biological and chemical inertness and stability
- High resistance to photocorrosion
- Low cost
- Non-toxicity
- Favorable band-gap energy

Indeed, experimental studies have demonstrated that is the most suitable photocatalyst, of all the compounds previously mentioned, for widespread environmental treatment and other applications. These applications include the destruction of microorganisms such as bacteria and viruses, odor control, the conversion on , the removal of mercury, the conversion of , and the decomposition of oil spills. Furthermore, a photocatalyst that exhibits high activity for the oxidation of volatile organic compounds (VOCs) under ultraviolet (UV) radiation offers economically and technically practical mean to clean air and water (Mehrabi 2008).

The photocatalytic activity of titania is strongly affected by physicochemical features of the particles, with respect to both structural and morphological characteristics. From a structural point of view can crystallize in three different polymorphic forms:

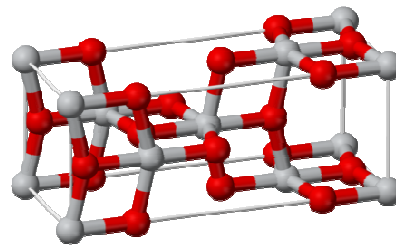
- ANATASE → Tetragonal
- RUTILE → Tetragonal
- BROOKITE → Orthorhombic

The anatase polymorph is generally reported to show the highest photoactivity compared to either brookite or rutile polymorphs because of the low recombination rate of its photogenerated electrons and holes. [23]

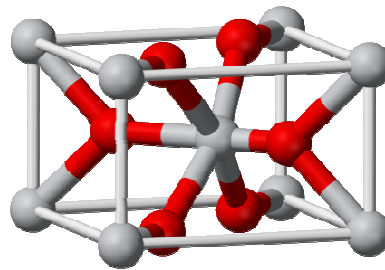
[21] To sum up, several materials are considered as photocatalyst, however titanium dioxide is described as the most superior materials at this time. Main reasons include that titanium oxide are:

- Stabilized without chemically dissolving acid and alkali
- Transparent without visible light absorption
- Oxidative with 3.2 eV of energy band
- Inexpensive when produced on a large scale as white pigment

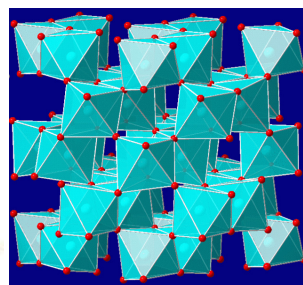
TITANIUM DIOXIDE STRUCTURAL POLYMORPHS [6]



ANATASE



RUTILE



BROOKITE

Figure 11. Titanium dioxide structural polymorphs

7. PRINCIPLES OF HETEROGENEOUS PHOTOCATALYSIS

A heterogeneous photocatalytic system consists of semiconductor particles (photocatalyst) which are in close contact with a liquid or gaseous reaction medium. Exposing the catalyst to light, excited states are generated which are able to initiate subsequent processes like redox reactions and molecular transformations. [25]

There are two types of photo-chemical reaction proceeding on a TiO₂ surface when irradiated with ultraviolet light:

- The photo-induced redox reactions of adsorbed substances
- The photo-induced hydrophilic conversion of TiO₂ itself [22]

[24] In the next figure a simplified reaction scheme of photocatalysis is shown. Due to their electronic structure, which is characterized by a filled valence band (VB) and an empty conduction band (CB), semiconductors (metal oxides or sulfides) can act as sensitizers for light-induced redox processes. The energy difference between the lowest energy level of the CB and the highest energy level of the VB is the so-called band gap energy E_g and it corresponds to the minimum energy of light required to make the material electrically conductive.

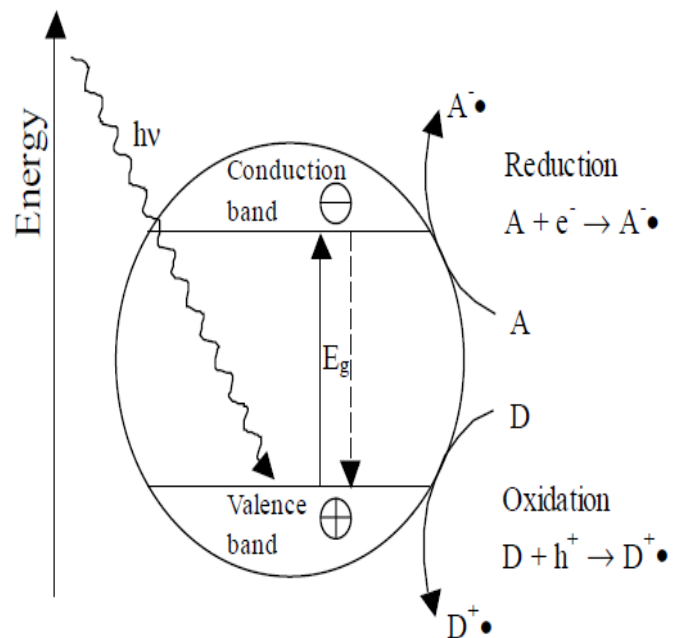
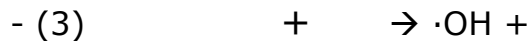


Figure 12. Photocatalysis process

[24] When a photon with an energy of $H\nu$ exceeds the energy of the band gap, a negative electron () is promoted from the valence band to the conduction band leaving a positive hole (). In electrically conductin materials, i.e. metals, the produced charge-carriers are immediately recombined. In semiconductors, a portion of this photo-excited electron-hole pairs diffuse to the surface of the catalytic particle (electron-hole pairs are trapped at the surface) and take part in the chemical reaction with the adsorbed donor (D) or acceptor (A) molecules. The holes can oxidize donor molecules (1) whereas the conduction band electrons can reduce appropriate electro acceptor molecules (2):



A characteristic feature of semiconducting metal oxides is the strong oxidation power of their holes . They can react in a one-electron oxidation step with water (3) to produce highly reactive hydroxyl radical ($\cdot\text{OH}$). Both the holes and hydroxyl radical are very powerful oxidants, which can be used to oxidize most organic contaminants.



In general, air oxygen acts as a electron acceptor (4) by forming super-oxide ion which are also highly reactive particles, being able to oxidize organic materials.



So the whole primary process of the charge-carrier generation (5) can be interpreted as:



[25] The heterogeneous photocatalytic oxidation with meets the following requirements what could make it competitive with respect to other processes oxidizing contaminants:

- A low-cost material is used as photocatalyst
- The reaction is quite fast at mild operating conditions
- A wide spectrum of organic contaminants can be converted to water and .
- No chemical reactants must be used and no side reactions are produced

8. NANO-SIZED VS MICRO-SIZED PARTICLES

[26] Man-made nanostructured materials such as fullerenes, nanoparticles, nanopowders, nanotubes, nanowires, nanorods, nanofibers, quantum dots, nanoclusters, nanocrystals and nanocomposites are globally produced in large quantities due to their wide potential applications, for example in skincare and consumer products, healthcare, electronics, photonics, biotechnology, engineering products, pharmaceuticals, drug delivery, and agriculture.

Human exposure to these nanostructured materials is inevitable, as they can enter the body through the lungs or other organs via food, drink, air, and medicine and affect different organs and tissues such as the brain, liver, kidney, heart, blood, and so forth and may cause cytotoxic effects, for example deformation and inhibition of cell growth leading to various diseases in both humans and animals.

Since a wide variety of nanostructured materials exists, their interactions with biological systems and possible toxicity largely depend upon their properties, such as particle size, concentration, solubility, chemical and biological properties, and stability. [26]

Titanium Dioxide nanoparticles are manufactured world-wide in large quantities for use in a wide range of applications including pigment and cosmetic manufacturing. Although is chemically inert, nanoparticles can cause negative health effects. [27]

According to [23], there appears to be no general agreement on the effect of the particle size on the photocatalytic activity of Titanium dioxide. Several authors report a peak efficiency, for the given reaction, in correspondence of an optimal particle size. A few examples are mentioned in the following:

[23] In the photocatalytic degradation of trichloroethylene in the gas phase with particles (in the 2.3-27nm range), Maira et al.(Maira 2000) found an optimum particle size of 7nm. Also, in the oxidation of trichloromethane, Zhang et al. (Zhang 1998) reported the best efficiency for an anatase size of 11 nm. On the contrary, Almquist and Biswas (Almquist 2002), in the photodegradation of phenol, instead report a much larger optimal particle size in the 25-40 nm range. Furthermore, other authors report a continuous increase in the photocatalytic activity with lowering of the particle size.

Both nano-sized and non-nano-sized exhibit almost the same photochemical performances, but the (pollution) degradation capability of nano- is much greater because of both large specific surface area and high density of surface coordination.

For that reason, certain companies have begun investigating in the possibility to prepare and use micro-sized particles instead of nano-sized particles in order to create safer materials than the traditional photocatalytic products for both workers and public safety. [23]

Following from this point and during the next chapter, in which a wide variety of functions and applications of will be explained, several experimental processes and some of the results will be compared to obtain a clearer idea of how the process of photocatalysis works.

[27] In the next two pictures a) and b), HR-TEM technique has been used to investigate the morphological features of two samples. The picture on the left is a low magnification image of a P25 nano-sized sample which is made up of highly crystalline closely packed particles and the picture on the right is a low magnification image of a pure anatase micro- (known as 1077 by Kronos).

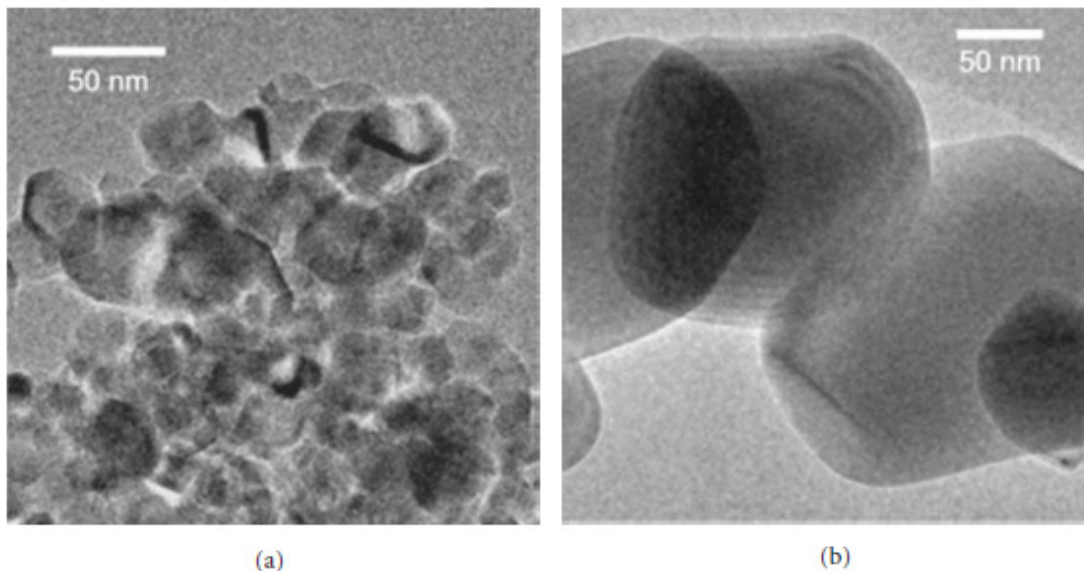


Figure 13. Nano and Micro-size titanium dioxide particles (source: BIANCHI, C.L., PIROLA, C., GATTO, S., NUCCI, S. and MINGUZZI, A., 2012. New Surface Properties in Porcelain Gres Tiles)

If both particle size and ultimate morphology of the plain Kronos sample are compared to the P25 features, it can be evidenced that:

- Particles are still packed, but to a limited extent if compared to the P25, and the edges of the particles are quite smooth;
- The size of the crystallites has enormously enlarged since the P25 particles present an average size of 20-50 nm range while the micro- present an average size of 50-200 nm range;

9. APPLICATIONS OF PHOTOCATALYSIS

In the next figure, the main field areas in which titanium dioxide photocatalysis can be applied to be shown, focusing mainly on the application on ceramic tiles:

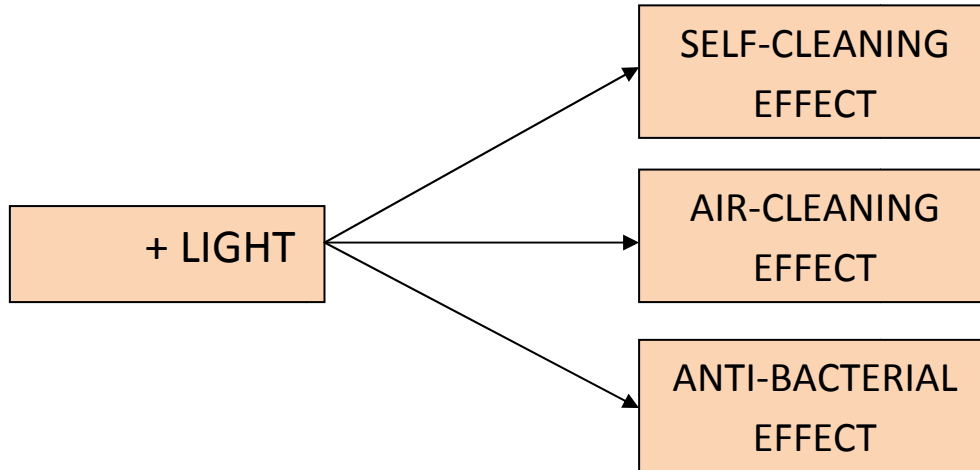
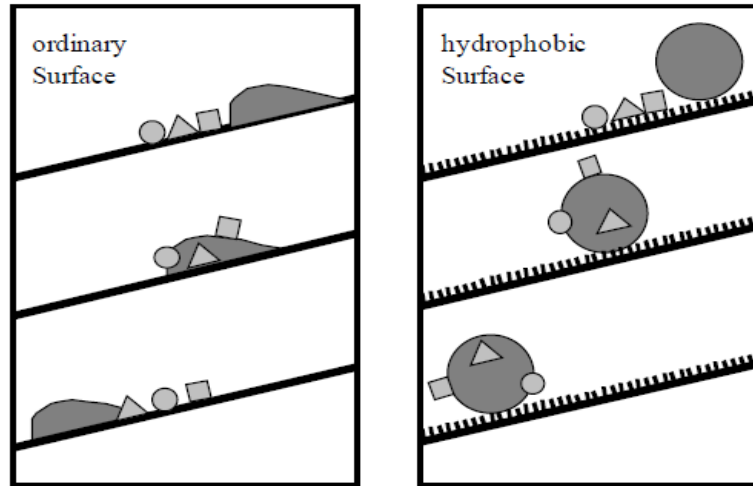


Figure 14. Applications of titanium dioxide

9.1 SELF-CLEANING FUNCTIONS

There are mainly two possible ways to obtain self-cleaning materials with efficient surfaces; i) creating and developing super-hydrophobic or ii) with super-hydrophilic surfaces.

Super-Hydrophobic surfaces are obtained by transferring the microstructure of selected plant surfaces to practical materials like tiles and façade paints, process known as the “Lotus Effect”; the water that enters into contact with such surfaces will be immediately contracted to droplets and the particles of contaminants will adhere to the droplet surfaces and will be removed from the rough surface when the droplets roll off (see image). [25]

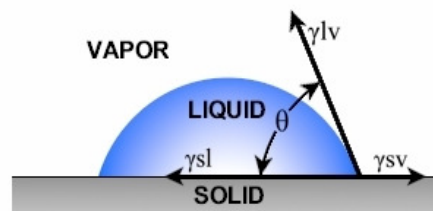


Lotus Effect

Figure 15. Lotus Effect

Young's Equation

$$\gamma^{sv} = \gamma^{sl} + \gamma^{lv} \cos \theta$$



- θ is the contact angle
- γ^{sl} is the solid/liquid interfacial free energy
- γ^{sv} is the solid surface free energy
- γ^{lv} is the liquid surface free energy

Figure 16. Young's equation for contact angle of water

Super-Hydrophilic surfaces have to do with the water wettability of the surface before and after UV light irradiation. With the discovery of this phenomenon, the application range of coating has been largely widened.

[22] The surface wettability is generally evaluated by the water contact angle (CA). The CA (θ) (which can be calculated by Young's Equation, see figure 16 [10]) is defined as the angle between the solid surface and the tangent line of the liquid phase at the interface of the solid-liquid-gas phases.

When the surface is exposed to UV light, water starts to exhibit a decreasing CA, that is, it tends to spread out flat instead of beading up. Finally, the CA reaches almost 0°, as shown in the next figure a). At this stage, the surface becomes completely non-water-repellant and is termed “highly hydrophilic”. The surface retains a CA of a few degrees for a day or two under the ambient condition without being exposed to UV light. Then, the CA slowly increases, and the surface becomes the initial less hydrophilic state again, as shown in the next figure b). [22]

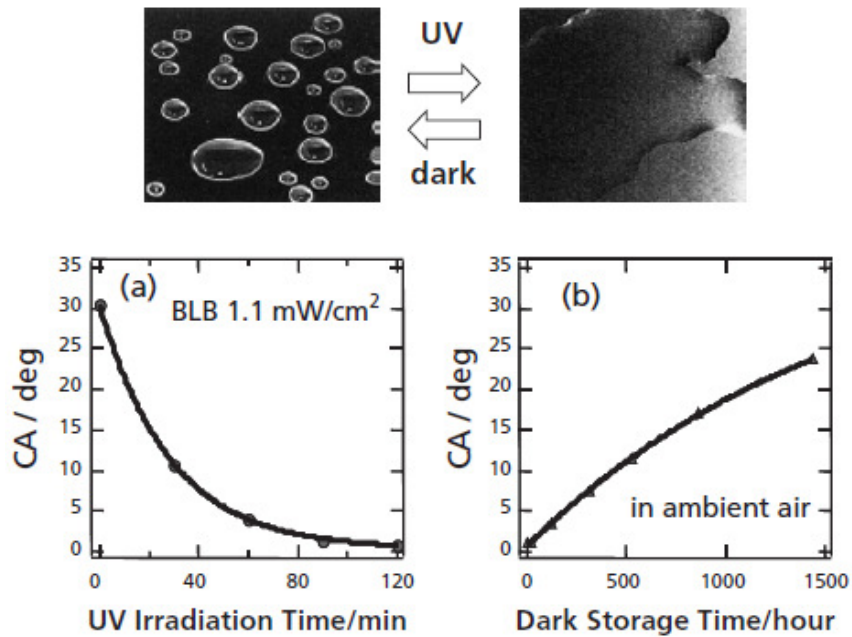


Figure 17. Contact angle variation

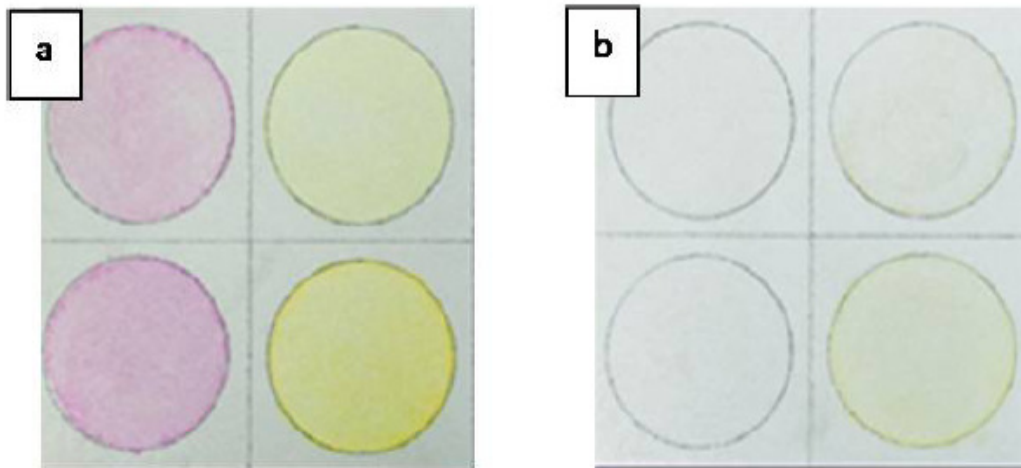
Another example of the decrease in the CA is the next image that shows an example of contact angle measurements for a) before and b) after irradiation with the UV lamp for 8 hours: [23]



Figure 18. Contact angle comparison

In order to prove the self-cleaning property and to verify that when is illuminated by light, grease, dirt and organic contaminants are decomposed and can easily be swept away by water (rain), several tiles were dirtied with two selected chemical dyes: Rhodamine B, often use a tracer dye within water, and Metanil yellow, a stuff dye once used also as food color.

The next image shows the colors disappearance after 10 days of exposure to the sunlight at an UVA mean power of 7.28 W/m^2 .



WGA tiles dirtied by Rhodamine B and Metanil yellow: (a) $t = 0$; (b) $t = 10$ days; solar irradiation (May 2012, UVA mean irradiation power: 7.28 W/m^2)

Figure 19. Self-cleaning tiles comparison

[29] To summarize, when it rains, exhaust fumes and particles dispersed in the air become incorporated in the raindrops and adhere to the surfaces of buildings, and so the buildings get dirty over time. The three main properties of the self-cleaning effect are:

- a) The reduction of adsorption of dust and particles
- b) It helps stop oily dirt from sticking
- c) It harnesses the power of the rain to wash the surfaces

a) When a building using photocatalytic coating is exposed to sunlight, a thin layer of water is formed on the exterior walls, which prevents the adsorption of dust and other particles by reducing static electricity, helping stop dirt from sticking.

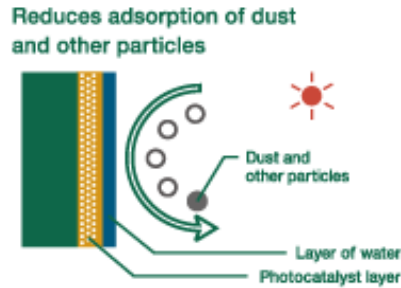


Figure 20. Self-cleaning application with water layer

b) When a building using photocatalytic coating is exposed to sunlight, activated oxygen is created on surfaces through the photocatalytic reaction. The active oxygen decomposes the dirt and reduces its adhesion.

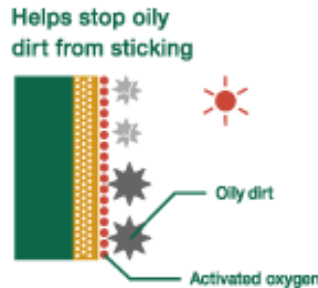


Figure 21. Self-cleaning application with oxygen layer

c) The super hydrophilicity makes the exterior walls easy to blend with water. When it rains, the rainwater spreads on the surface of the exterior wall by super hydrophilicity and it gets in between the dirt and the wall. Then it lifts the dirt off of the surfaces and washes it away. [29]



Figure 22. Self-cleaning application with rainwater

9.2 AIR PURIFICATION FUNCTIONS

[30] Nitrogen dioxide (NO_2) is one of a group of highly reactive gasses known as "oxides of nitrogen," or "nitrogen oxides (NO_x)." NO_2 forms quickly from emissions from cars, trucks and buses, power plants, and off-road equipment. In addition to contributing to the formation of ground-level ozone, and fine particle pollution, NO_2 is linked with a number of adverse effects on the respiratory system.

By using Titanium Dioxide in the surface of an exterior wall, air can be purified, harnessing the power of sunlight to achieve the REMOVAL OF NO_x in the .

As previously explained during the self-cleaning effect, when Titanium Dioxide is exposed to sunlight radiation, activated oxygen is created on the surface of the exterior wall (Figure a). Apart from decomposing the dirt reducing its adhesion, this activated oxygen oxidizes harmful NO_x in the air, converting them to Nitrate Ions NO_3^- . (Figure b)

When it rains, this Nitrate Ions adhere to exterior wall surface, seeping into rainwater and washing off. That is the way NO_x are removed from the air. (figure c) and d)

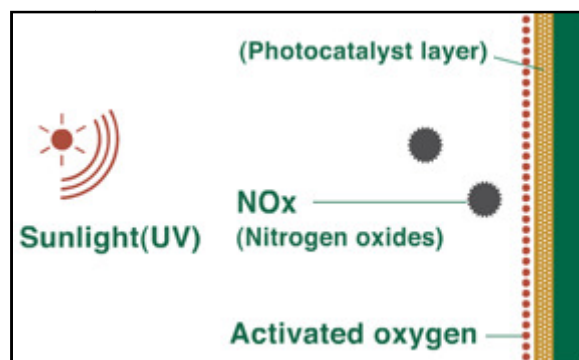


Figure 23. Air-purificating application destroying NO_x

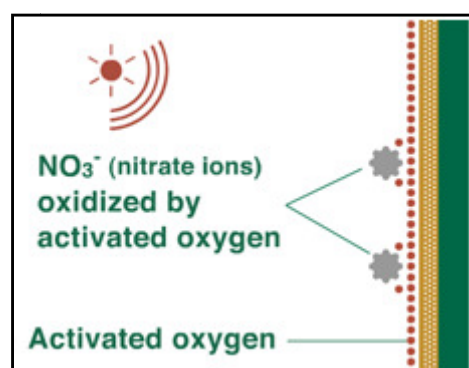


Figure 24. Air-purificating application destroying NO_x

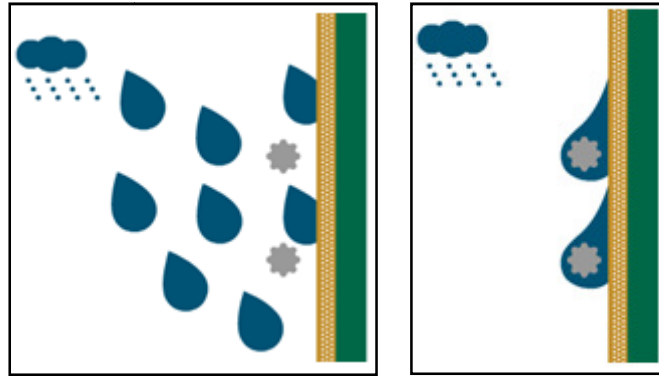


Figure 25. Air-purifying application destroying NOx

9.3 ANTIBACTERIAL EFFECT

Not only can titanium dioxide be applied to exterior surfaces but also to interior ones, since the photocatalysis is achieved through natural or artificial light. So, we can improve the indoor air quality by reducing the amount of bacteria, being the cause of odor and dirt.

[20] A number of species which are particularly hazardous to human health:

- Escherichia coli → can cause food poisoning with vomiting, diarrhea, abdominal cramps...
- Staphylococcus aureus → can cause infections of the skin, the respiratory system, the urinary apparatus...
- Klebsiella pneumoniae → can cause bacterial pneumonia as well as urinary tract infections.

The process of photocatalysis does not kill directly the bacteria, but damage their cell walls irreparably and irreversibly so that they die. [20]

Important it is then to install this type of technology in Bathrooms and Kitchen since those are the main areas in which bacteria is emerged (shower) and developed (toilet and kitchen).

The mechanism is very similar to the application on external wall surfaces:

When exposed to light (natural or artificial), activated oxygen is created in the surface where Titanium Dioxide has been applied. This layer of activated oxygen reduces the amount of bacteria and the amount of viruses, keeping the living environment hygienically.

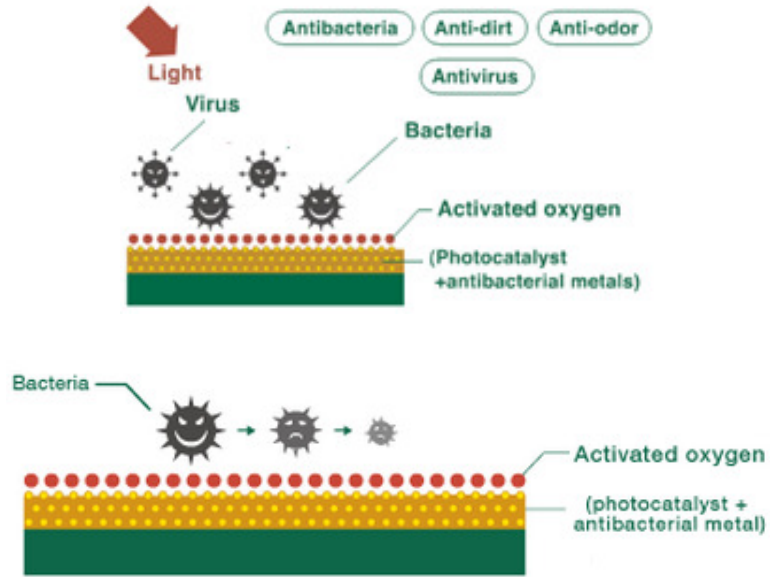


Figure 26. Anti bacterial application

INSULATING MATERIALS

10. - INTRODUCTION TO INSULATION MATERIALS

Materials are fundamental, not only to the economic, but also to the social and industrial development. They constitute the basis for the functionality of the built environment, products and technologies that are vital to modern society, which means that they can be the key innovative trigger in the development of many new products and technologies. [31]

The performance of insulation materials is the key to achieve any low energy homes strategy, whether designing, building a new house or refurbishing an existing dwelling. That is why, when installed correctly, insulation reduces the heat transfer through the envelope of a building.

Whenever there is a temperature difference, heat flows naturally from a warmer space to a cooler space. So, in order to maintain comfort in winter, the heat lost must be replaced by the heating system; and in the summer, the heat gained must be removed by the cooling system. Several studies have shown that at least 50% to 70% of the energy used in the average home in the US is for heating or cooling. Thus, it makes sense to use thermal insulation to reduce this energy consumption, while increasing comfort, saving money and reducing the environmental burden because of the less consumption of fossil fuels.

[32] The key benefits obtained by the insulating process of the external envelope of a building's conditioned space are:

- It provides a much more comfortable, productive and profitable structure. In addition, the effects of moisture condensation and air movement are minimized in well-insulated buildings. This results in lower maintenance costs and increased longevity of the building structure.
- It reduces energy requirements, which lowers the utility bills.
- It supports economic, environmental and energy conservation goals (being evidenced by the numerous studies sponsored by the Department of Energy).

Furthermore, thanks to the Action Plan For Energy Efficiency [3] adopted by the European Commission, it is expected an energy consumption reduction of 20% by 2020, by including measures; to improve the energy performance of products, building and services; to improve the yield of energy production and distribution; to reduce the impact of transport on energy consumption; to facilitate financing and investments in the sector and; to encourage and

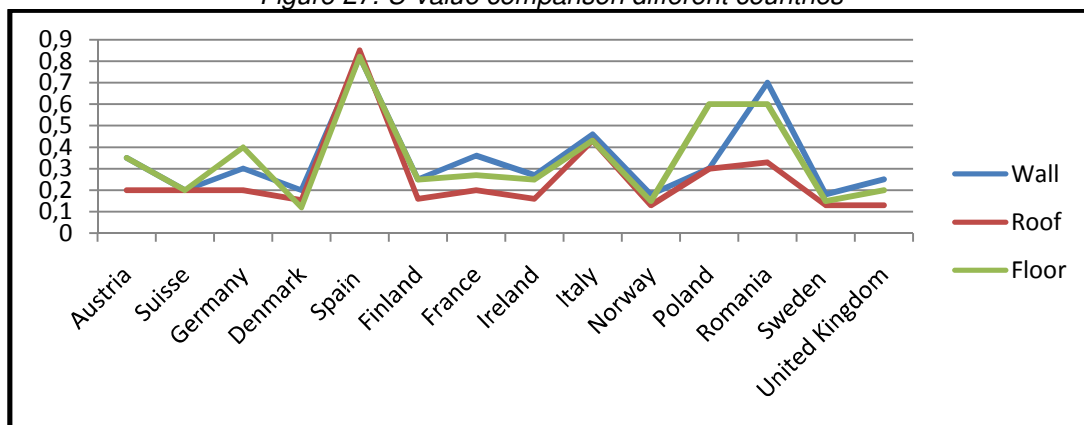
consolidate rational energy consumption behavior, stepping up international action on energy efficiency.

While existing building insulation materials can be very effective, improved or new high-performance materials are desirable because of an increasing emphasis on energy conservation and environmental concerns within the building industry. Improving building energy efficiency typically involves higher levels of thermal performance for envelope insulation; this requires either thicker insulation or higher-performance products. The main disadvantage of increasing the thickness of building components in adapting more insulation is the cost and sometimes it could be inconvenient. Insulations with greater R-value per unit thickness can thus avoid changing building techniques and improve energy efficiency. [34]

In the next table [35], there is a comparison of the different thermal transmittance "U-value" that must be achieved on some of the European countries/cities showed below for walls, roofs and floors. Depending on the climate situation of the country, lower U-values will be needed (for cooler countries) and higher U-value (for warmer countries):

U-Value (W/m ² K)				
Country	City	Wall	Roof	Floor
Austria	Wien	0,35	0,20	0,35
Suisse	Geneve	0,20	0,20	0,20
Germany	Berlin	0,30	0,20	0,40
Denmark	Copenhagen	0,20	0,15	0,12
Spain	Valencia	0,82	0,85	0,82
Finland	Oulu	0,25	0,16	0,25
France	Bordeaux	0,36	0,20	0,27
Ireland	Dublin	0,27	0,16	0,25
Italy	Milano	0,46	0,43	0,43
Norway	Oslo	0,18	0,13	0,15
Poland	Poznan	0,30	0,30	0,60
Romania	Bucharest	0,70	0,33	0,6
Sweden	Goteborg	0,18	0,13	0,15
United Kingdom	Manchester	0,25	0,13	0,2

Figure 27. U-value comparison different countries



As shown in the upper graphics, Spain's requirements for walls, roofs and floors differ in a big range from the other countries due to the mediterranean climate (Valencia), while cold countries like Norway, Denmark or Finland present values that are approximate to values required for the construction of Passivhaus ($U \approx 0.15 \text{ W/m}^2\text{K}$).

In fact, the best way to achieve lower U-values in the thermal performance of a building envelope is to choose, during the design phase, the insulation material/technology that better fits the constructive system and the thermal properties that we are expecting to obtain from it. This way, it is possible to replace certain traditional insulation materials, whose developments during the last decade hasn't advanced much, with more innovative and high-performance energy efficient materials that improve those thermal properties needed to obtain lower U-values.

In the next chapter, six of those "innovative high-performance materials", which have attracted a good deal of attention between professionals during the past years, will be explained from the point of view of their characteristics, thermal and fire protection properties, energy required to obtain the product and their actual market price.

11. - ANALYSIS AND COMPARISON OF SOME INNOVATIVE INSULATION MATERIALS

The European Union has decided to decrease the energy use for heating of building with 50% in 2050. In order to reach that target, the amount of insulation in the building envelope needs to be increased. With conventional insulation materials, such as mineral wool and expanded polystyrene (EPS), the required additional thickness of the building envelope leads to a larger share of the building volume dedicated for structural elements. That is why, it is necessary to introduce to the building market, more innovative insulation material that can give or improve the thermal resistance by using a thinner construction. [36]

[37-64] The main goal of this chapter is to describe and compare the next insulation materials, which have been recently studied for their applications on building envelopes or improved from its traditional system:

- A) Structural Insulated Panels (SIPs)
- B) Cellulose Insulation
- C) Silica Aerogel Insulation Blankets
- D) Gass-filled Panels (GFPs)
- E) Ultra-Light Cementitious Foam
- F) Vacuum Insulated Panels (VIPs)

11.1 DEFINITIONS

A) STRUCTURAL INSULATED PANELS (SIPS)

Structural Insulated Panels are high-performance building panels made by sandwiching a core of rigid foam insulation (Expanded Polystyrene EPS, Extruded Polystyrene XPS, Polyurethane PUR, or Polyisocyanurate) between two skins of wood structural panels, typically Oriented Strand Board. It has been demonstrated in SIP test homes that annual energy saving are reduce in a range of 50% to 60% and also saving builders a significant amount of onsite labour.

B) CELLULOSE INSULATION

Cellulose insulation is one of the greenest building materials since it is made from recycled paper products, primarily newsprint, and has a very high recycled material content, generally 75-85%. The remaining 15-25% is composed of natural fire retardants and anti-fungal agents such as boric acid and ammonium sulfate.

C) SILICA AEROGEL INSULATING BLANKETS

Aerogel is a synthetic porous ultra-light material derived from a gel, in which the liquid component of the gel has been replaced with a gas. Aerogel component can be presented in the form of blanket in a composition in which blanket sheets are laminated together to form a multilayer composite. This blanket is a new high-performance insulation material that has one of the lowest thermal conductivity of any known insulation material (0.013 W/mK), providing a high R-value and a low U-value for maximum energy efficiency.

D) GAS-FILLED PANELS

Innovative Gas-Filled Panels (GFPs), use thin polymer films (aluminum foil) and low-conductivity gas (Xenon, Krypton, Argon, or Air), to create a device with extraordinary thermal insulation properties, combining low-emissivity surfaces and multiple, low-conductivity gas-filled cavities to minimize radiation, convection and conduction. The three main components of a GFP are: a baffle, a barrier, and gas fills.

E) ULTRA-LIGHT CEMENTITIOUS FOAM

Cementitious foam is a form of insulation composed of organic magnesium oxide cement with air pockets from the blowing process, making it an especially safe and sustainable form of foam insulation. It absorbs echoes, and is one of the best foams for acoustic insulation. It contains no CFCs or other degrading chemical. It is non-toxic, insect and moisture resistant and non-flammable.

F) VACUUM INSULATED PANELS

Vacuum insulation is a material which has a volume filled with some kind of core material which is wrapped by a third material, functioning as a barrier. This barrier can be metal

sheeting, metal foil, polymer films or combinations of simple films. The most common core material used is precipitated or fumed silica.

All these types of insulations are very flexible and adaptable and present a wide range of applications on walls, roofs, floors ...

11.2 CHARACTERISTICS AND PROPERTIES

In this section, the next characteristics and properties will be explained and compared among the six different insulation materials:

- A) Thermal Conductivity ($\lambda=W/mK$)
- B) Thermal Resistance R-Value per inch
- C) Insulant thickness to achieve a U-value of 0'30 W/m²K
- D) Densities (Kg/m³)
- E) Fire Protection (Flame spread and Smoke Generation Rating)
- F) Embodied and Carbon Energy
- G) Market Price

A) THERMAL CONDUCTIVITY

In the next two tables, the different thermal conductivities of each one of the materials is shown:

INSULATION MATERIALS	THERMAL CONDUCTIVITY (W/mK)
SIP (PUR)	0,025
SIP (EPS)	0,038
SIP (XPS)	0,029
SIP (Polyiso)	0,022
Cellulose Insulation	0,035
Silica Aerogel Blanket	0,013
GFP (Xenon)	0,0074
GFP (Krypton)	0,0116
GFP (Argon)	0,0199
GFP (Air)	0,0281
Cementitious Foam	0,0371
VIP	0,005

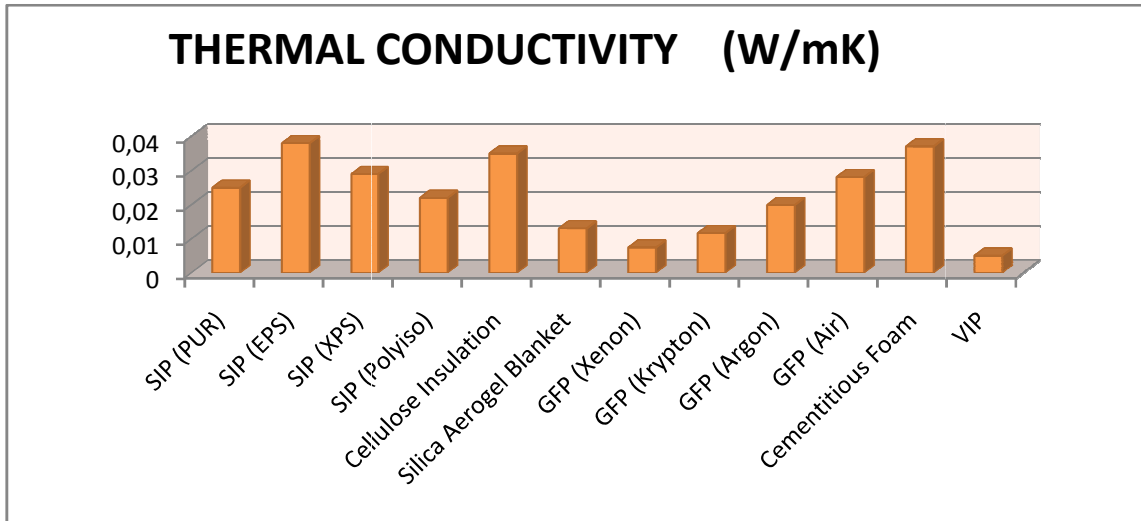


Figure 28. Thermal conductivity comparison of Insulation Materials

As shown in the previous graphic, the lower value for the thermal conductivity is the one obtained with the use of Vacuum Insulated Panels (0.004-0.01 W/mK) followed by the Silica Aerogel Insulation Blankets with a value of 0.013. It is also shown, how, depending on the type of gas used on Gas-filled Panels, we can achieve different values from 0.0074 (obtained with Xenon) to 0.0281 (with air), although the most common gases are krypton or argon. SIP (EPS) and Cementitious foam share almost the same value of conductivity.

B) THERMAL RESISTANCE R-VALUE PER INCH

In the next two tables, the different thermal resistance per inch, which can be achieved by using any of these materials, is shown:

INSULATION MATERIALS	R-VALUE per inch
SIP (PUR)	6,25
SIP (EPS)	4
SIP (XPS)	5
SIP (Polyiso)	7,6
Cellulose Insulation	3,8
Silica Aerogel Blanket	10
GFP (Xenon)	20
GFP (Krypton)	12,5
GFP (Argon)	7
GFP (Air)	5,1
Cementitious Foam	3,9
VIP	35

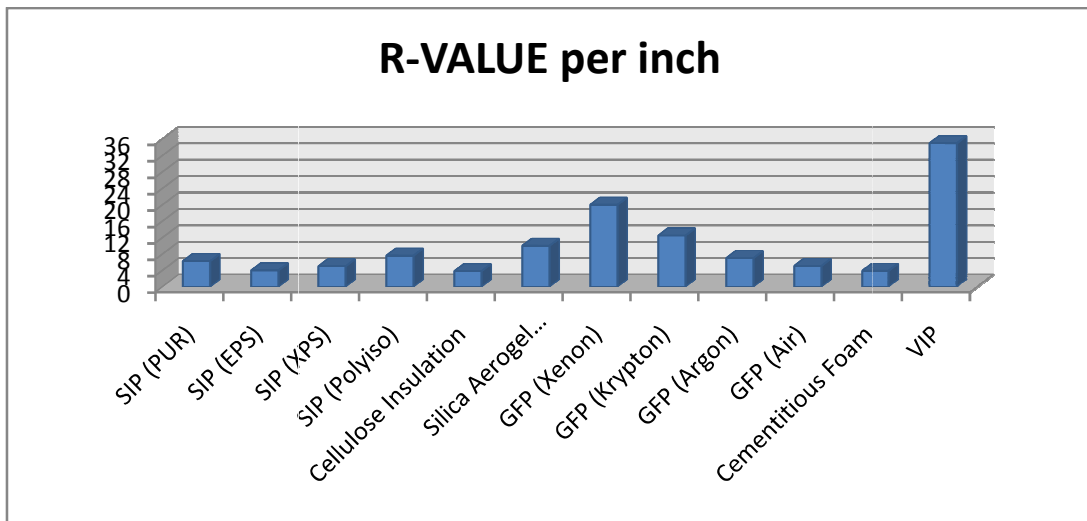


Figure 29. Thermal resistance comparison of Insulation Materials

Unexpected results were obtained when scientists analyzed and realized that R-values as big as R-35 per inch could be achieved by using Vacuum Insulated panels, thanks to its incredible thermal properties. Although, not such high values are obtained by applying the other materials, they also offer high resistance levels when compared to traditional insulation materials. Silica Aerogel Blankets can result on a higher value of R-15 and of course due to the thermal properties of the gas Xenon, this one can achieve values near R-20 per inch.

C) INSULANTING THICKNESS TO ACHIEVE A U-VALUE OF 0'30 W/M2K

As mentioned in the introduction, different U-values are required for building envelopes depending on the country and city in which we are located. In order to compare the effectiveness of these materials, the next tables show the necessary thickness (in cm) of every material in order to achieve a U-value of 0'30 W/m2K:

INSULATION MATERIALS	INSULANT THICKNESS (cm) TO ACHIEVE A VALUE OF U=30 W/m2K
SIP (PUR)	8,33
SIP (EPS)	12,66
SIP (XPS)	9,66
SIP (Polyiso)	7,30
Cellulose Insulation	11,66
Silica Aerogel Blanket	4,30
GFP (Xenon)	2,46
GFP (Krypton)	3,8
GFP (Argon)	6,6
GFP (Air)	9,3
Cementitious Foam	12,36
VIP	1,66

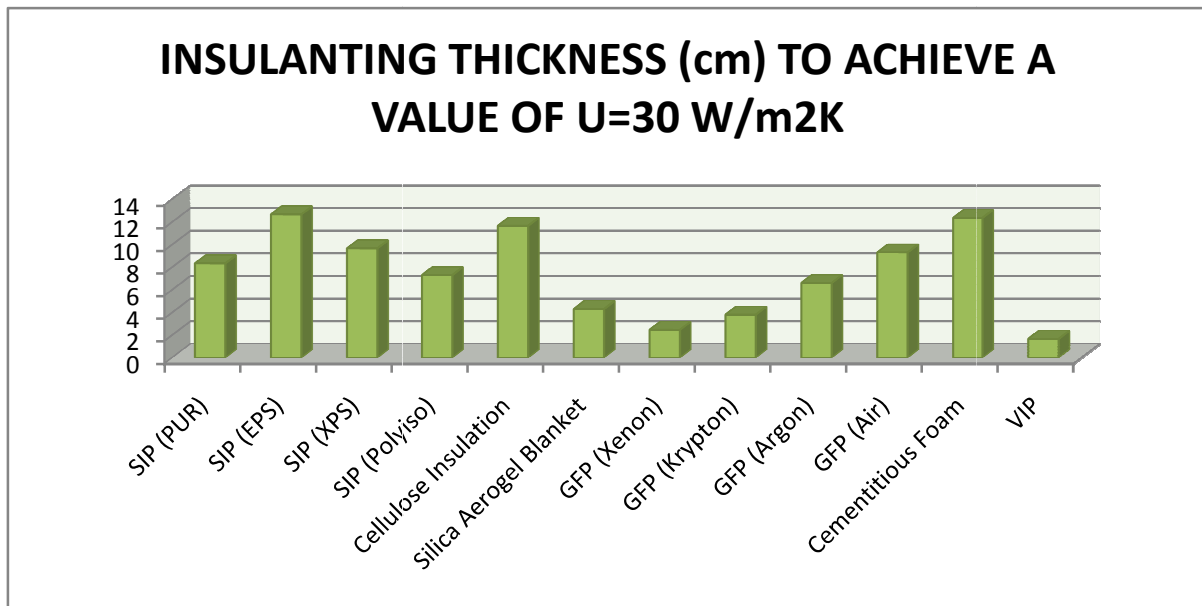


Figure 30. Insulant thickness to achieve a U-value of 0.30

The different values have been calculated by using the expressions $U = 1/R$ and $R = l / \lambda$. Where "l" is the thickness and "λ" the thermal conductivity. Clear it is then, that with lower values of "λ", higher R-values are obtained and so less thickness of insulation is needed. One good comparison is the thickness needed on SIP expanded polystyrene (whose conductivity is the lowest) = 12.66cm and the thickness needed with Gas-filled Panels (Krypton) = 3.8 cm.

D) DENSITIES (KG/M3)

The effect of density on product properties varies from one insulation material to another and this is as well valid even within the group of different mineral wool insulation materials (glass wool, stone wool, ULTIMATE). Therefore it is not useful to compare different materials just by their density. Although, just for a brief knowledge of the density of these materials, a graphic is shown with the approximate density values:

INSULATING MATERIALS	DENSITY (Kg/m3)
SIP	33
Cellulose Insulation	43
Silica Aerogel Blanket	150
GFP	12
Cementitious Foam	33
VIP	180

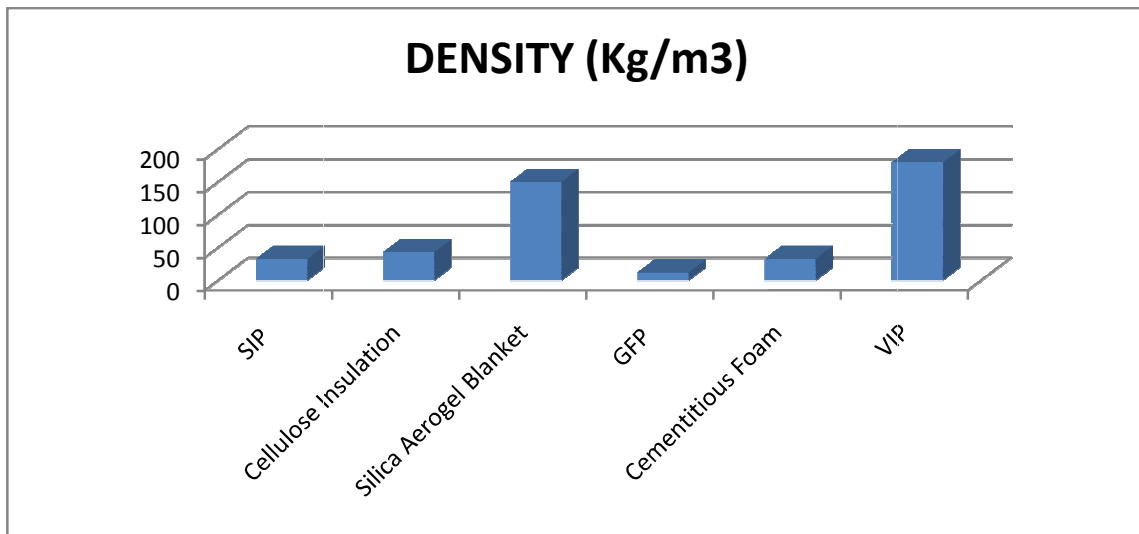


Figure 31. Density comparison of insulation materials

In this case, the two materials that present the best thermal performance (Silica Aerogel Blanket and Vacuum Insulated Panels) are the ones with the higher density, 150 and 180 respectively.

E) FIRE PROTECTION (FLAME SPREAD AND SMOKE GENERATION RATING)

Building code for fire protection ASTM E84-81 A establishes a maximum flame spread rating of 25 and a maximum smoke generation rating of 450 for wall applications. The next table and graphic show the different values presented by the six materials:

INSULATION MATERIALS	FLAME SPREAD	SMOKE GENERATION
Code Requirement(walls)	25	450
SIP	20	300
Cellulose Insulation	5	25
Silica Aerogel Blanket	0	0
GFP	20	65
Cementitious Foam	0	0
VIP	25	20

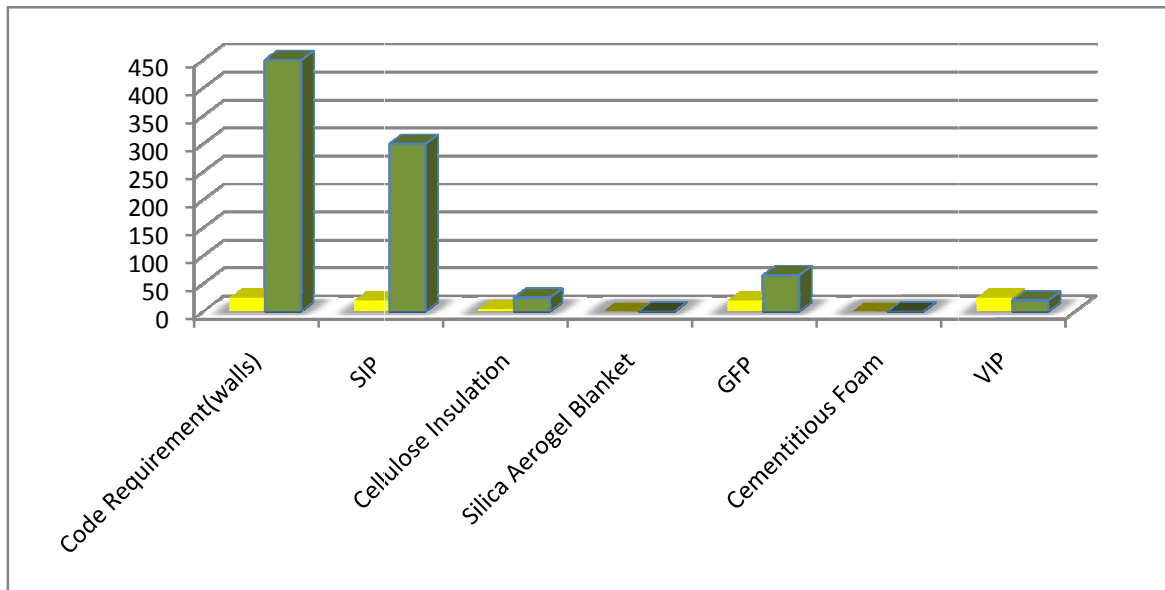


Figure 32. Flame spread and Smoke Generation of the insulation materials

Amazing “Surface Burning Characteristics” are shown by the Silica Aerogel Blanket and the Cementitious foam, which after being investigated and produced, have obtained a flame spread and smoke generation rating of 0. Also, thanks to the fire retardant treatment, cellulose insulation provides extremely effective fire protection capabilities with a flame spread of 5 and a smoke generation of 25. Not as effective as Cellulose insulation in flame spread is the VIP with a value of 25, which also obtains an excellent value for smoke generation of 20.

E) EMBODIED ENERGY AND CARBON ENERGY

Embodied energy is defined as the total energy inputs consumed throughout a product’s life-cycle. Initial embodied energy represents energy used for the extraction of raw materials, transportation to factory, processing and manufacturing, transportation to site, and construction. Once the material is installed, recurring embodied energy represents the energy used to maintain, replace, and recycle materials and components of a building throughout its life. Academic studies have illustrated that embodied energy accounts for the majority of a building’s energy footprint for approximately the first 15-20 years of a building’s life-cycle. [7]

In the next table/graphic the embodied energy in (MJ/Kg) of the different insulation materials is shown, except for that one of the Vacuum Insulation Panels, which information hasn’t been able to be obtained:

INSULATION MATERIALS	EMBODIED ENERGY (MJ/Kg)
SIP (PUR)	72
SIP (EPS)	89
SIP (XPS)	89
SIP (Polyiso)	69,80
Cellulose Insulation	3,3
Silica Aerogel Blanket	53,00
GFP - Barrier Virgin aluminum	218
GFP - Recycled Aluminum	29
Cementitious Foam	27,9
VIP	-

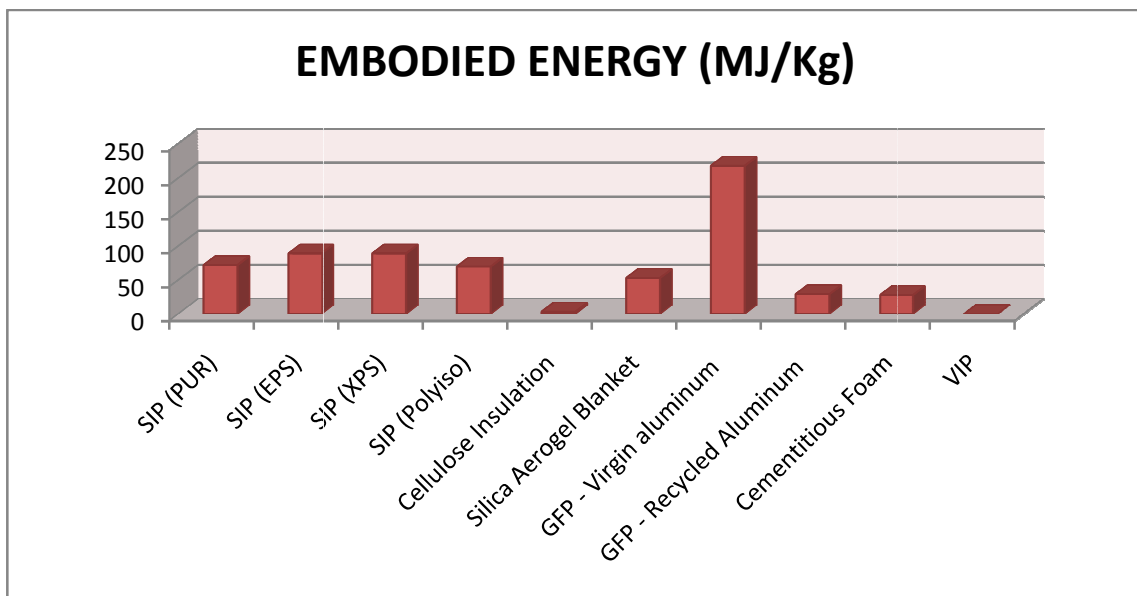


Figure 33. Embodied Energy Comparison

It is evident how low the embodied energy of the Cellulose insulation is, due to its 75% recycled content (3.3 MJ/Kg) while others like Gas-filled panels that use virgin aluminum for the barrier components show a value of 218 MJ/Kg. Noticing that if instead of virgin aluminum, recycled aluminum is used, the embodied energy is reduced in more than a 70% (29 MJ/Kg) being similar to that one of the Cementitious foam (27.9 MJ/Kg).

Carbon energy is defined as the amount of Kg of CO₂ emitted to produce 1 kg of the desirable product. The next table show the different value of carbon energy for each of the materials, except for values of the cementitious foam and VIPs which could not be found:

INSULATION MATERIALS	CARBON ENERGY (Kg of CO2/Kg)
SIP (PUR)	3
SIP (EPS)	2,5
SIP (XPS)	2,5
SIP (Polyiso)	5,5
Cellulose Insulation	0,106
Silica Aerogel Blanket	4,2
GFP - Barrier Virgin aluminum	11,46
GFP - Recycled Aluminum	1,69
Cementitious Foam	-
VIP	-

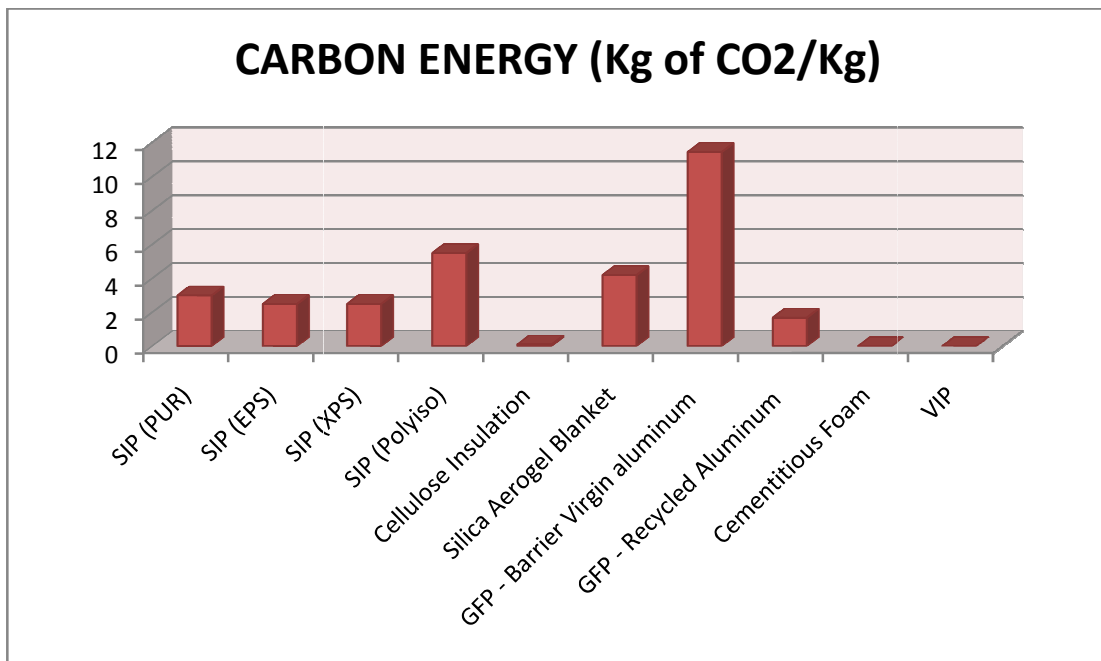


Figure 34. Carbon Energy Comparison

According to the embodied energy and their high content in recycled material, cellulose insulation is the insulating material with the lowest environmental impact during its fabrication, only emitting 0.106 Kg of CO2/Kg if compared to the others. Followed by GFP with recycled aluminum foils and the polystyrene insulation for SIPs.

G) APPROXIMATE MARKET PRICE

Next figures have been obtained from different commercial companies that offer this type of insulation materials, for the gas-filled panels, no prices for the whole material were obtained although in the table the different prices of each gas is shown in order to compare them:

INSULATION MATERIALS	MARKET PRICE (\$/m²)
SIP (PUR)	6 to 55
Cellulose Insulation	4 to 10
Silica Aerogel Blanket	45 to 255
GFP (Xenon)	4 \$ / l
GFP (Krypton)	0,35 \$ / l
GFP (Argon)	0,002 \$ / l
Cementitious Foam	15 to 22
VIP	32 to 54

Figure 35. Insulation material approximate price

As shown in the upper table, Silica Aerogel Blankets are the ones with the highest price since it costs from 45 to 255 \$/m² depending on the thickness of the blanket (from 10 to 40mm). Vacuum insulated panels “which are likely to become one of the most popular insulation material for buildings in the near future” show a lower price than silica Aerogel, although its cost is still quite considerable. If gas-filled panels using different gases are compared, it is obvious why the Argon and Krypton gas are most common used due to its low price compared to that one of Xenon (even if this one presents better thermal conductivity). Finally, we can consider Cellulose insulation to be cheapest of all, followed by Cementitious foam and structural insulated panels. [37-64]

12. - FINDINGS

As previously seen, it is of vital importance to take into account several parameters when deciding which type of insulating material better fits to our projects. Depending on the climate area, the type and orientation of the building, the application on which the insulation is to be used and some properties such as fire resistance, water behavior or mechanical stability, we will decide to use one type of insulation or another. The thermal performance of the insulation materials is one of the most important properties to take into consideration since we can reduce the energy consumption of the building by selecting materials that can achieve a high R-value per inch due to their low thermal conductivity.

By studying, investigating and applying new insulation materials, we can reduce the total fossil fuel consumed by buildings (40% in the European Union) and thus, the amount of greenhouse gases, closing the gap every time more, to achieve net-zero energy buildings.

QUESTIONNAIRE

13. - OBJECTIVE OF THE RESEARCH

The main goal of this study is to get a better understanding of how professionals within the construction sector (in Spain), perceive and applied sustainable practices into their day-to-day projects and to find out what is their opinion on the actual and future situation of Spain in the field of sustainable construction.

14. – RESEARCH METHODOLOGY

Most of the information needed to create the questionnaire was achieved through primary and secondary sources like textbooks, journal, thesis, conference papers and the use of internet. Some of the questions were obtained from other sustainability questionnaires, created by the government and from different thesis related to sustainable principles.

15. – DATA COLLECTION AND QUESTIONNAIRE

The process of data collection is one of the main phases to achieve the objective of the research. Questionnaires were mainly delivered personally in the different offices of several architects, building engineers, contractors... although, in order to obtain as many responses as possible, the questionnaire was also sent via email to companies around Spain.

This data collection process began with the creation of the questionnaire. This one is divided in three different sections depending on the information needed in each one:

SECTION A

This section is focused on obtaining personal information of the respondents and of the company he/she works with. This way, a clear idea on the age, gender, position in the company and type of projects the firm deals with, is obtained.

SECTION B

The second section is being created in order to know how much the respondent knows on the sustainability field, concerning definitions, sustainable codes, sustainable certifications, and also to find out how they qualify the education they had on sustainability.

SECTION C

The last section of the questionnaire focuses on the application of sustainable construction practices in projects. In this part, respondents reply with some of the sustainable materials and practices and also are asked to give their opinion on the present and possible future situation of sustainability in Spain.

QUESTIONNAIRE SAMPLE

• NAME OF SURVEYOR: SANTAMANS LÓPEZ, CARLOS

• NAME OF SURVEY SURVEY NUMBER: _____

RESPONDENT: _____

SECTION A. GENERAL INFORMATION ABOUT YOU AND YOUR FIRM.

QUESTION 1.

GENDER:

- MALE
- FEMALE

QUESTION 2.

AGE:

- 22 – 25 years
- 26 – 32 years
- 33 – 40 years
- 41 – 47 years
- +47 years

QUESTION 3.

WHAT SORT OF POSITION DO YOU CURRENTLY SERVE WITHIN YOUR FIRM/ORGANISATION?

- ARCHITECT
- BUILDING ENGINEERING
- CIVIL ENGINEERING
- CONTRACTOR
- OTHER: _____

SECTION A. GENERAL INFORMATION ABOUT YOU AND YOUR FIRM.

QUESTION 4.

WHAT TYPE OF PROJECTS DOES YOUR FIRM USUALLY DEAL WITH?

- PRIVATE PROJECTS
- GOVERNMENTAL PROJECTS
- BOTH

QUESTION 5.

WHICH OF THE FOLLOWING BEST DESCRIBES THE TYPE OF WORK YOUR COMPANY UNDERTAKES?

- HOUSING BUILDING
- HOUSE REPAIRMENTS, MAINTENANCE AND IMPROVEMENTS
- COMMERCIAL PROPERTY BUILDING
- COMMERCIAL REPAIRMENTS, MAINTENANCE AND IMPROVEMENTS
- OTHER (please specify): _____

QUESTION 6.

HOW MANY YEARS HAS YOUR COMPANY BEEN INVOLVED IN THE CONSTRUCTION INDUSTRY?

- 3 years
- 4 – 9 years
- 10 - 15 years
- 16 – 20 years
- +20 years

SECTION B. INFORMATION ON SUSTAINABILITY

QUESTION 7.

IS THERE AN ENVIRONMENTAL DEPARTMENT OR ANY ENVIRONMENTALLY RESPONSIBLE PERSON/S FOR THE PROJECTS?

- YES
- NO
- DON'T KNOW

IF YES, WHICH POSITION DOES HE/SHE SERVE? : _____

QUESTION 8.

HAVE YOU HEARD ABOUT THE TERMS "SUSTAINABLE DEVELOPMENT" AND "SUSTAINABLE CONSTRUCTION"?

- YES
- NO

IF YES, WHERE:

- INTERNET
- COURSES/SEMINARS
- BOOK/ARTICLES
- RADIO/TV
- OTHERS: _____

QUESTION 9.

GIVE A PERSONAL DEFINITION OF WHAT YOU PERCEIVE AS "SUSTAINABLE CONSTRUCTION".

SECTION B. INFORMATION ON SUSTAINABILITY

QUESTION 10.

HOW WOULD YOU QUALIFY THE EDUCATION YOU RECEIVED ON SUSTAINABLE CONSTRUCTION AND DEVELOPMENT DURING YOUR DAYS OF PROFESSIONAL SCHOOLING OR TRAINING PROGRAMS?

- VERY POOR
- POOR
- FAIR
- GOOD
- VERY GOOD
- EXCELLENT

QUESTION 11.

DO YOU THINK SUSTAINABILITY WITHIN THE CONSTRUCTION INDUSTRY IS BEING ENOUGH PROMOTED BY THE GOVERNMENT?

- YES
- NO

IF NO, WHY: _____

QUESTION 12.

WHAT TYPES OF NATIONAL OR INTERNATIONAL SUSTAINABILITY CODES ARE YOU AWARE OF? (IF ANY)

QUESTION 13.

WHAT KIND OF NATIONAL OR INTERNATIONAL SUSTAINABLE BUILDING CERTIFICATIONS ARE YOU AWARE OF?

SECTION C. SUSTAINABLE PRACTICES ON PROJECTS**QUESTION 14.**

DO YOU THINK THE FINAL COST OF A SUSTAINABLE CONSTRUCTION IS HIGHER THAN ANOTHER ONE WHICH DOESN'T INVOLVE/INCLUDE SUSTAINABLE SPECIFICATIONS?

- NO
- YES, 5% HIGHER
- YES, 5-10% HIGHER
- YES, 10-20% HIGHER
- YES, +20%

QUESTION 15.

THE ENVIRONMENT AND SUSTAINABILITY ARE MORE IMPORTANT THAN SAVING COSTS ON CONSTRUCTING HOMES TO DEVELOPERS. "IMPLEMENTATION OF STRATEGIES CAN BE COSTLY AND THE REALITY IS THAT IT CAN PUT DEVELOPERS OFF BEING SUSTAINABLE".

- STRONGLY AGREE
- AGREE
- NO CHANGE
- DISAGREE
- STRONGLY DISAGREE

QUESTION 16.

WHICH 3 OF THE FOLLOWING TOPICS COULD BE CONSIDERED THE MOST IMPORTANT FROM YOUR POINT OF VIEW DURING THE DESIGN PHASE OF A PROJECT?

- ENERGY EFFICIENCY & CO2 EMISSION REDUCTION
- WATER CONSUMPTION REDUCTION
- APPLICATION OF NEW SUSTAINABLE MATERIALS
- CONSTRUCTION WASTE REDUCTION
- POLLUTION PREVENTION MEASURES
- HEALTH AND INDOOR AIR QUALITY
- REUSABILITY AND RECYCLABILITY OF MATERIALS
- EMBODIED ENERGY REDUCTION OF MATERIALS
- USE OF RENEWABLE ENERGY SOURCES

SECTION C. SUSTAINABLE PRACTICES ON PROJECTS

QUESTION 17.

LIST ANY SUSTAINABLE CONSTRUCTION PRACTICES YOU HAVE USED IN YOUR MOST ENVIRONMENTALLY-SENSITIVE PROJECT (If you have done work involving sustainable design or construction strategies).

QUESTION 18.

LIST ANY SUSTAINABLE CONSTRUCTION MATERIALS YOU HAVE USED IN YOUR MOST ENVIRONMENTALLY-SENSITIVE PROJECT (If you have done work involving sustainable design or construction strategies).

QUESTION 19.

DO YOU THINK FUTURE TECHNOLOGICAL ADVANCES WILL ALLOW FOR THE CONSTRUCTION COSTS TO BE REDUCED AND MEET PROJECTED TARGETS?

- STRONGLY AGREE
- AGREE
- NO CHANGE
- DISAGREE
- STRONGLY DISAGREE

SECTION C. SUSTAINABLE PRACTICES ON PROJECTS

QUESTION 20.

WHAT SORTS OF NEW POLICIES OR PROGRAMS WOULD MAKE IT EASIER FOR YOU TO BECOME MORE INVOLVED IN INCORPORATING SUSTAINABLE BUILDING STRATEGIES INTO YOUR PROJECTS IN THE FUTURE? (Mark any that apply).

- ECONOMIC INCENTIVES
- EDUCATIONAL PROGRAMS
- STRICTER STATE BUILDING CODE REQUIREMENTS
- SUSTAINABLE DESIGN GUIDELINES AND CONSTRUCTION STANDARDS (VOLUNTARY)

QUESTION 21.

WHICH WOULD YOU STATE IS THE MAJOR OBSTACLE WITHIN SPAIN SUSTAINABLE CONSTRUCTION?

- THE CURRENT ECONOMICAL CRISIS
- THE SOCIAL LACK OF AWARENESS OF ITS ADVANTAGES
- THE LACK ON PROFESSIONAL'S FORMATION IN THE SECTOR
- COMPLEXITY OF THE WORK COMPARED TO TRADITIONAL CONSTRUCTION

QUESTION 22

IN A PERIOD OF TIME OF TEN YEARS, DO YOU SEE THE SUSTAINABLE CONSTRUCTION PRACTICES INCREASING OR DECREASING IN SPAIN?

- INCREASING
- DECREASING

WHY?: _____

16. – RESULTS AND FINDINGS

This research focuses on delivering the questionnaire, shown in section 3, to construction firms, architectural offices and professionals of the construction sector who have a direct implication on the different phases of a construction project (designing, planning...).

As previously mentioned, in order to obtain as many responses as possible in the time given, there have been two main ways to contact with professionals; by personally delivering the questionnaire in their office (attracting more their attention) and by sending emails with the enclosed questionnaire to companies within Spain. Unfortunately, not as many “email” respondents, as first thought, replied. Although, most of these “online” respondents were working on companies that were somehow related to application of some sustainable practices, providing good answers to the different questions.

For the study, a total of 103 questionnaires were delivered, from these, 31 were personally delivered and 72 were sent via online. Finally obtaining 21 for the face-to-face interviews and 14 for those replied by the companies emails.

As it will be explained while analyzing some of the questions, there were people who did not fill in some of these because whether they did not know the answer or they had no knowledge of it.

SECTION A) GENERAL INFORMATION ABOUT THE RESPONDENT AND THE FIRM

Next figure shows the percentage of the people who did not respond the survey, as well as those who responded the full questionnaire and a few who replied with an incomplete survey.

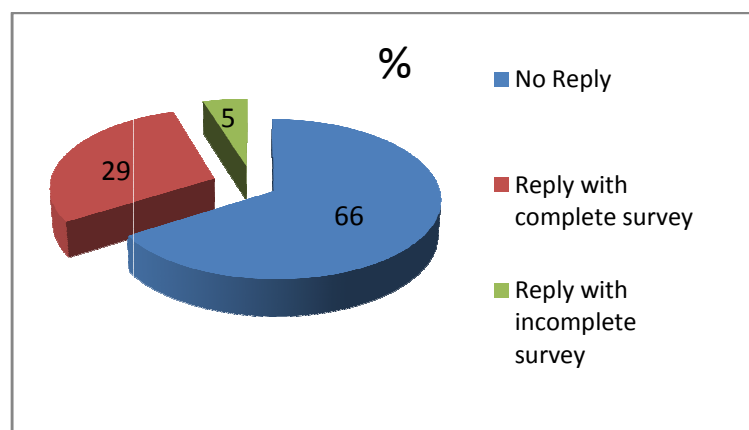


Figure 36. Feedback of the respondents

All the surveys delivered personally took place in Valencia while those obtained via email are from different cities of Spain such as Madrid, Barcelona, Seville, Granada, Malaga, and Mallorca ...

In the next two graphics (**questions 1 and 2**), the amount of men and women and the % of the age of the respondents are shown:

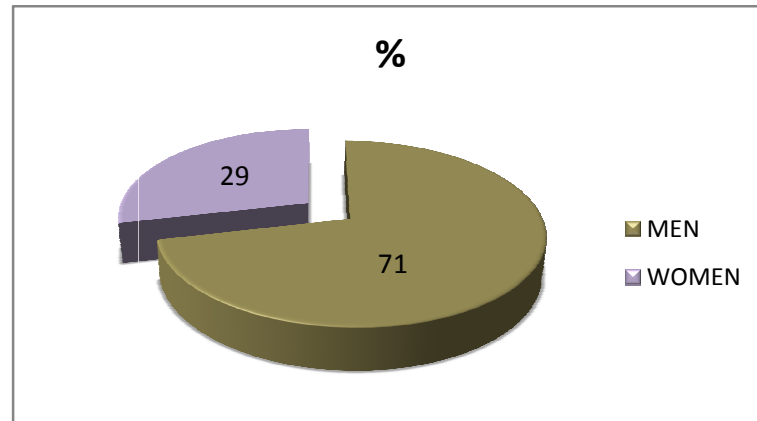


Figure 37. Men/Women respondents

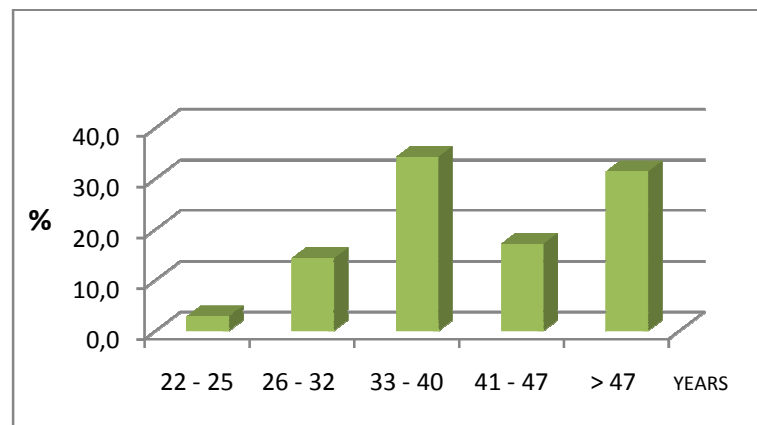


Figure 38. Age comparison of the respondents

As can be seen in the upper figures, the number of women that answered to the survey is significantly lower than those answered by men. Although as shown in recent studies, the role of women in the construction sector has been and is increasing exponentially during the past few years.

From a point of view of trying to understand how professionals perceive the concept of sustainability, it was important to obtain a high number of respondents with an age higher than 47, due to their experience and sometimes their lack of knowledge on the sustainable field.

Some of the better answered questions were made by people with a range of age of 33-40 and 26-32 since as it will later be shown, they are closely related to sustainable practices due to courses or seminars. Also, even if experience is not a quality of those who just finished their studies, it is important to listen to them since they can add a new perspective from the ideas they obtain in their recent sustainable studies.

In the next figures (**question 3 and 4**), the position of the people in their firm and the type of projects they are used to working with are shown:

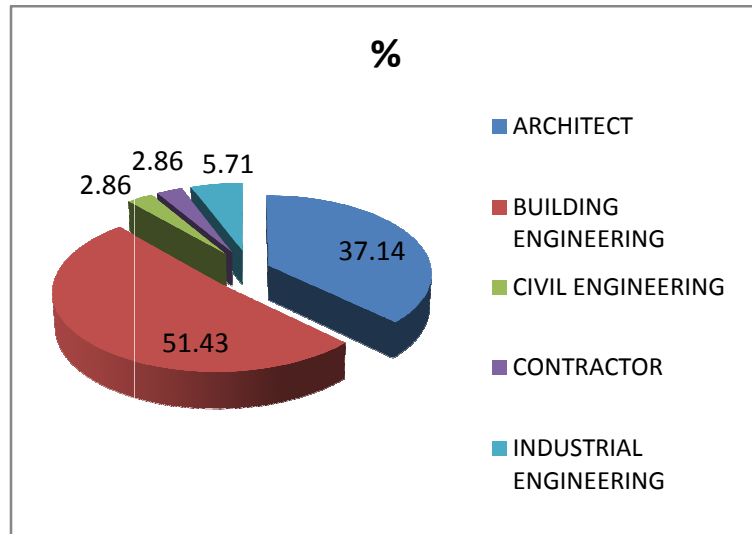


Figure 39. Position in the companies of each professional

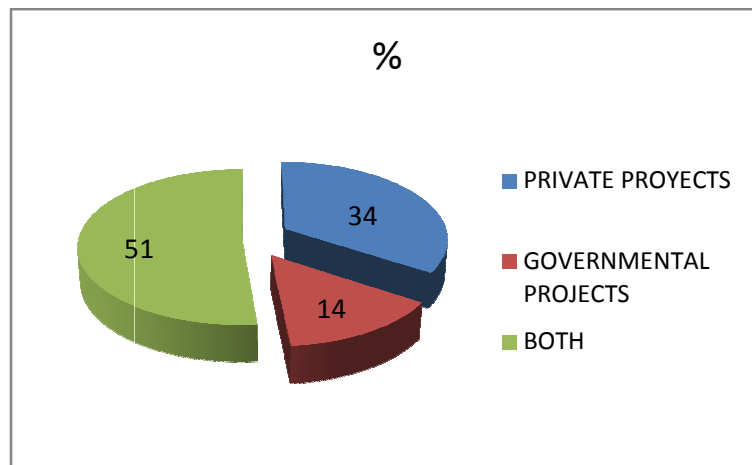


Figure 40. Projects the companies work on

To remark it all, the important presence of building engineers and architects because of their huge responsibility regarding the selection of materials, technologies and systems which play an important role in the reduction of water and energy use as well as the increase on the energy efficiency of the projects. As shown, in the second figure, 51 % of the respondents deal with both, private and governmental projects, so they have a high influence concerning the application of sustainable practices.

With some more details on the type of projects the respondents work with (**question 5**), the next figure shows what kind of construction they achieve:

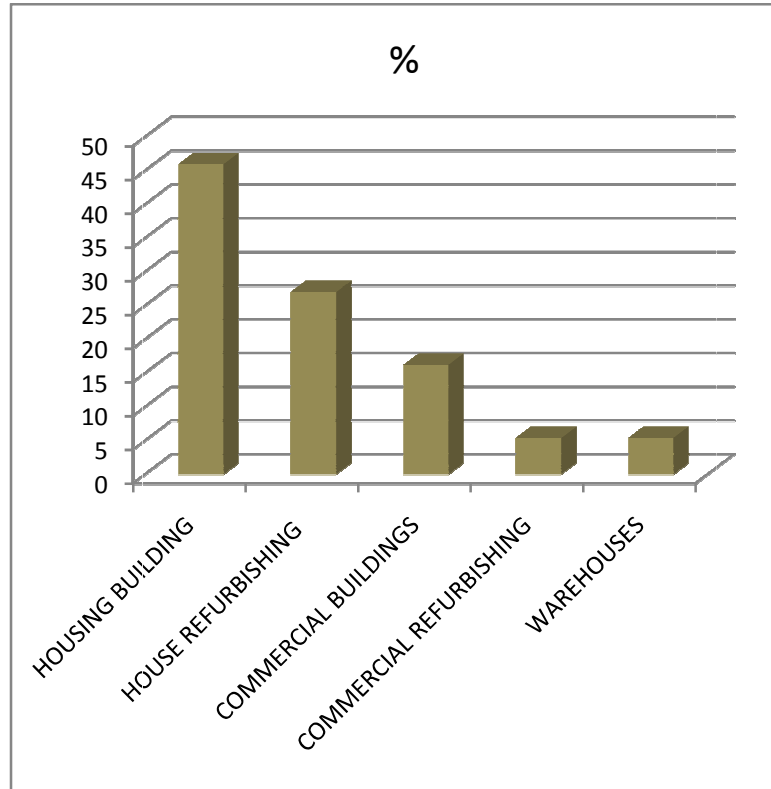


Figure 41. Type of projects developed by the firms

It is a good thing that 46 % of the respondents were to work on housing building because that led in providing some more exact details on the sustainable practices that they are used to use.

To finish with the results of section A) of the questionnaire (**question 6**), it is necessary to mention (question 6) that a 43% of the respondents work in a company that has been involved in the construction industry for more than 20 years, which shows their experience. A 26% is obtained in those who work in companies involved between 10 to 15 years. 17% for companies between 4 to 9 years and a final 11% for companies between 16 to 20 years.

SECTION B) INFORMATION ON SUSTAINABILITY

In this section of the questionnaire, questions related to the knowledge on sustainability of the respondents were asked.

The next figure (**question 7**) shows, the percentage of people who dispose of an environmental department or any environmentally responsible person for the projects.

Surprisingly, 69% of the respondents claimed that their company does not have an environmental department, which is something to worry about since some of them described they would support the creation of one to analyze better the environmental impact of their projects.

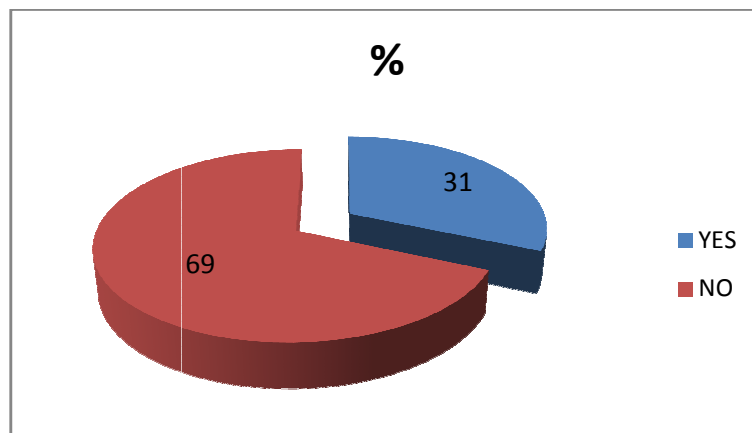


Figure 42. % of people who have an environmental department in the company

In **questions 8 and 9** the respondents were asked if they had ever heard about the terms “sustainable development” and “sustainable construction”, where they had heard about it and also they were asked to give a personal definition for the term “sustainable construction”.

Everyone who replied to the questionnaire confirmed they had heard about those terms except for one of them who did not. Mainly, nearly everyone agreed on the sources, which are courses and seminars and the internet. Although books and articles are also some common sources of information on sustainability matters.

Following, some of the most repeated definitions the respondents gave to question number 9, defining sustainable construction:

1. Energy self-sufficiency / not consuming energy/ no waste
2. Use and management of natural resources
3. Constructing with materials and efficient systems that respect the environment
4. Sustainable for humans in its process, reducing products environmental impacts.

5. Resource and energy optimization
6. Utilization of resources for energy savings
7. Type of construction that has in consideration; health and ecology of the place; energy savings; the use of renewable energies and natural materials
8. Construction which uses non harmful materials for the environment
9. Construction in which the energy consumed is equal or lower to the generated energy
10. A way of constructing in which a “cradle to grave” analysis of the products’ life cycle is needed (from raw materials extraction, transportation, fabrication, installation and its reutilization)
11. Construction that tries to reduce water and energy consumption as well as waste reduction
12. Sustainable construction does not imply the use of specific materials, but the good utilization of the available resources, transport savings, construction phase time reduction, use of pre-cast elements.....

To achieve a better understanding on how well qualified the respondents were on the sustainability field, **question 10** asked them how they would qualify the education they received on sustainability during their early studies. And as it can be seen in the next figure, most of them qualified their education on very poor or poor level:

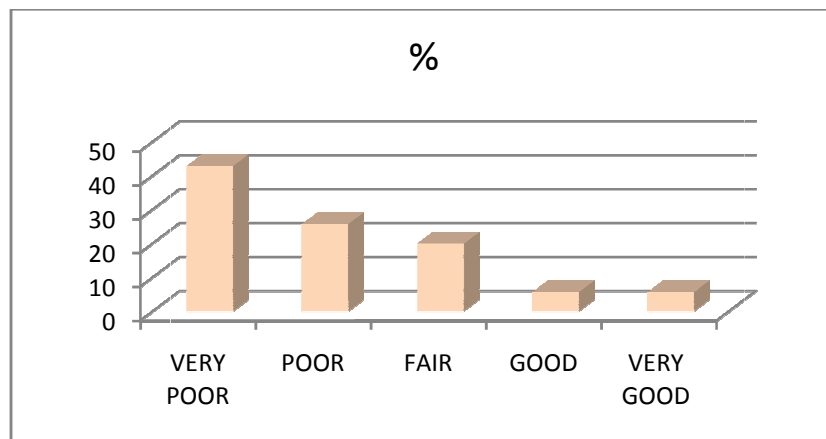


Figure 43. Education qualification of each respondent on sustainability

Since most of the respondents are at an age > 41 years old, and the whole sustainable practices began to gain attention like a decade ago, it is quite obvious that they did not dispose the same kind of education that is imparted nowadays; therefore most of them qualify it as very poor. When the respondents were asked to answer **question 11**, they were asked whether they thought sustainability within the construction industry is being enough promoted by the government. Only one person from all responded YES while everyone else said NO.

Following, some of the reasons why people think sustainability is not being enough promoted:

1. - Lack of funding to support the sector.
2. - The construction of sustainable buildings/homes should be more encouraged.
3. - It is more expensive so investors do not justify the investments.
4. - Not enough awareness campaigns.
5. - Government is more preoccupied making money than worrying for the environment
6. - Not encouragement enough to compensate the additional effort that can require sustainable constructions.
7. - There are limited tools offered by the Administration for the technicians and they do not work properly (Lider). Indeed, there are some others and better such as Ecotec, Design Builder...

In **questions 12 and 13**, the respondents were asked to write the different sustainability codes and sustainable building certification they were aware of. Necessary to mention that 25 % of the respondents either left the filling space blank or they wrote they did not know any. Here are the most mentioned ones:

- ISO 14001 / 14040 (Environmental Management/Life cycle)
- ISO 50001 (Energy Management Systems)
- EMAS (Eco-Management and Audit Scheme)
- CTE DB-HE Energy Savings
- UE Plan for Energy Efficiency
- Law 2/2011 Sustainable Economy
- ENSLIC (Energy Saving through promotion of Life Cycle assessment in buildings)
- Pellet Standard EN14961-1
- Territorial Strategy of Valencia Community
- RD 47/2007 Energy efficiency certificates for new construction
- RD 235/2013 Energy efficiency certificates for existing buildings

And some of the certifications described:

- BREEAM (Building Research Establishment Environmental Assessment Methodology)
- LEED (Leadership in Energy & Environmental Design)
- GREEN BUILDING INSTITUTE
- PASSIVEHAUS
- CE3X (for energy efficient certificates)
- CALENER VYP
- QUALITY PROFILE – ENERGY CERTIFICATE
- CERTIFICATE FOR SUSTAINABLE FOREST WOOD

SECTION C) SUSTAINABLE PRACTICES ON PROJECTS

The first two questions of section C are related to the cost of sustainable constructions. In **question 14**, respondents were asked if they think that the final cost of a sustainable construction is higher than another one which does not include sustainable specifications; next figure shows the results gathered:

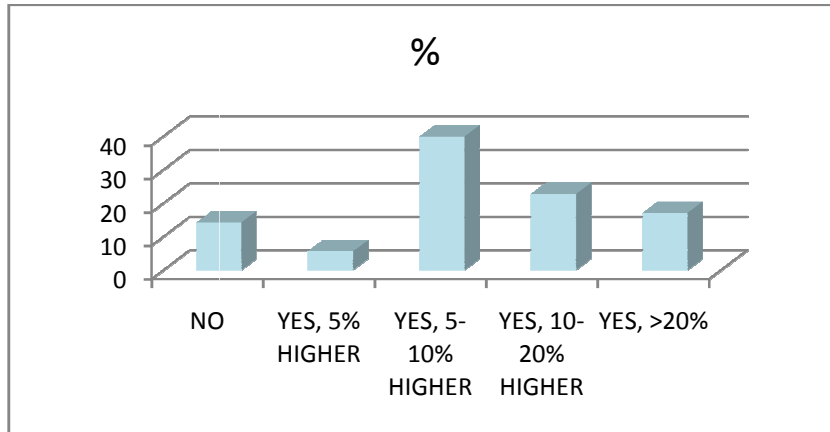


Figure 44. Cost of a sustainable construction compared to a traditional one

According to the results, 40% of the respondents think the cost of a sustainable construction is from 5 to 10% higher than a traditional construction without sustainable requirements. 17% opine it is more than a 20% higher and 14% think it does not increase the cost. While only 6% says it is 5% higher and a 23% says it is 10 to 20% more expensive.

Question 15 asked whether the respondents agreed or not to the next sentence:

“The environment and sustainability are more important than saving costs on constructing homes to developers”

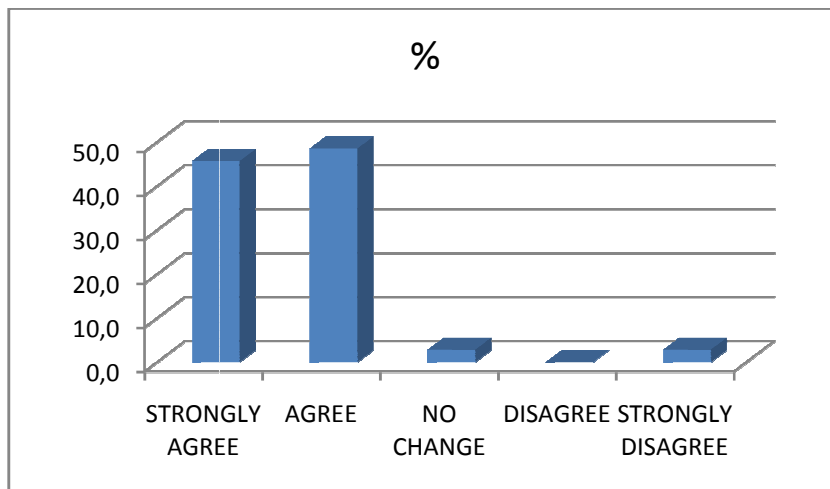


Figure 45. % on the importance of environment and sustainability compared to saving costs

As seen in the upper figure, most people responded agreeing to the statement that it is important to focus a little bit more of attention on the efficiency and sustainability of the projects instead of trying to cut prices to every phase to obtain the maximum profit.

In question 16, some of the most important “green features” that a building can accomplish are mentioned and respondents are asked to pick up the three they think are the most important to have in consideration during the design phase of a project. The different features are:

1. - ENERGY EFFICIENCY & CO2 EMISSION REDUCTION
2. - WATER CONSUMPTION REDUCTION
3. - APPLICATION OF NEW SUSTAINABLE MATERIALS
4. - CONSTRUCTION WASTE REDUCTION
5. - POLLUTION PREVENTION MEASURES
6. - HEALTH AND INDOOR AIR QUALITY
7. - REUSABILITY AND RECYCLABILITY OF MATERIALS
8. - EMBODIED ENERGY REDUCTION OF MATERIALS
9. - USE OF RENEWABLE ENERGY SOURCES

And here are the results:

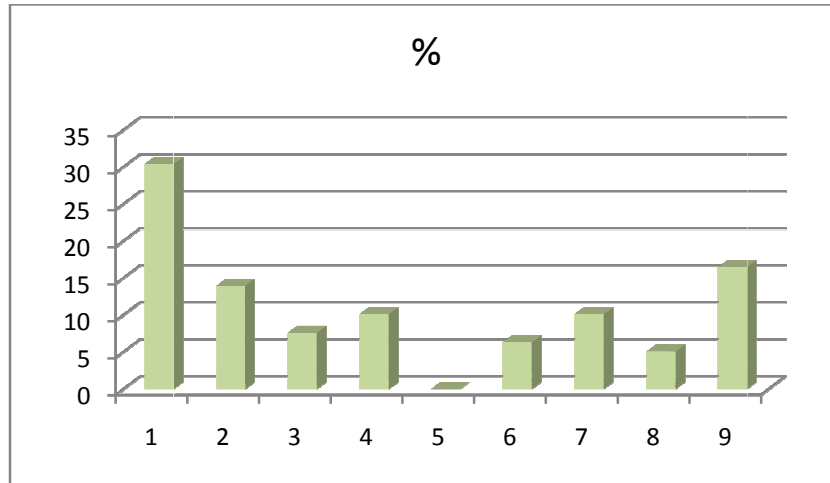


Figure 46. The three most important “green features”

The three features which respondents opine are the most important are the energy efficiency and CO2 emission reduction (30%), the use of renewable energy sources (16%) and water consumption (14%) and, followed by construction waste reductions (10%). Confirming with other sustainable questionnaires done by governments, those four are the ones who are being studied the most.

For **questions 17 and 18**, the intention was to obtain a main idea of what kind of sustainable construction practices and materials, the different companies have been using in their projects. Also, to mention that 6 of the respondents did not fill in these questions because they had not applied any of what it was asked.

Following, a list of the contribution practices and materials answered:

Sustainable Practices

- Water consumption reduction
- CO2 emissions reduction
- Solar panels for domestic hot water “DHW” and heating
- Use of Biomass boilers (used by a 20% of the respondents)
- Trombe wall
- Cross ventilation
- Rainwater harvesting systems (deposit storage for future use)
- Passive design (sunlight irradiation analysis, wind analysis...)
- Energy efficiency analysis of the interior illumination
- Use of renewable energies (Aerothermia, Biomass...)
- Reutilization of demolition materials
- Analysis of the orientation of the house, sunlight control, cross ventilation...
- Use and design of constructive elements according to its posterior disassembly and reutilization.

Sustainable Materials

- Cellular Concrete “Ytong”
- Natural cork
- Concrete with recycled aggregates
- Treated wood
- Cellulose Insulation
- Natural coatings
- Exterior pavement “Bio-Innova” (Use of photocatalysis to transform Nitrogen Oxide particles and organic volatile compounds in harmless nitrates and inert salts)
- Release agent (formwork) with non-toxic particles
- Soil bags as a grand mass envelope insulation
- Not using PVC in a whole building
- Green roofs

As shown in the upper practices and materials, there are some of them who contribute a lot to improve the quality and environmental impact of a building as can be the Trombe wall, the use of Biomass or the passive design as well as using cellulose insulation or “bio-materials” that help increase the air quality.

The last four questions are related to how sustainability can be improved in Spain and which are the main reasons for our present situation respect to it.

Question 19 asks the respondents if they think future technological advances will allow for the construction costs to be reduced. As expressed in the next graphic, most of the people questioned have a positive opinion on this statement while 11% think there will not be a difference and 9% opine the cost will increase instead of being reduced.

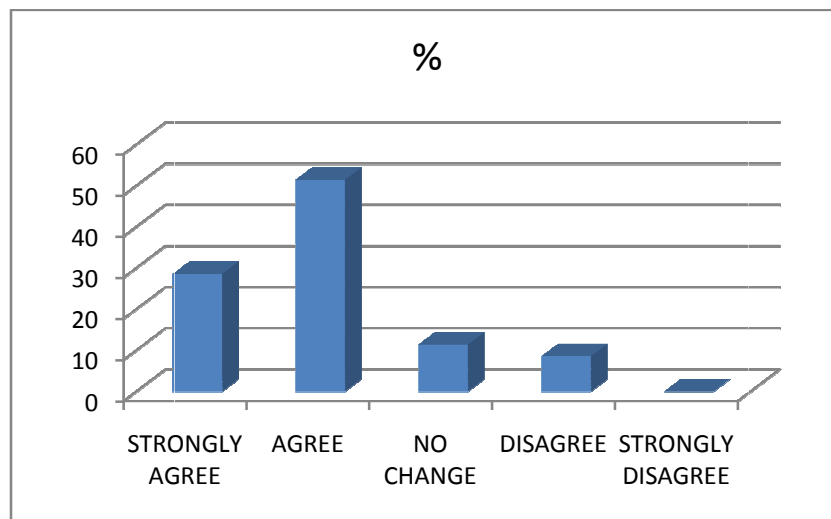


Figure 47. % of agreement on future technological advances

In order to know what would make it easier for people to become more involved in incorporating sustainable strategies into their project , **question 20** was elaborated, and according to the results, people would change their attitude towards sustainability if economic incentives and more educational programs were organized and also a fifth part thinks stricter code requirements could also be helpful.

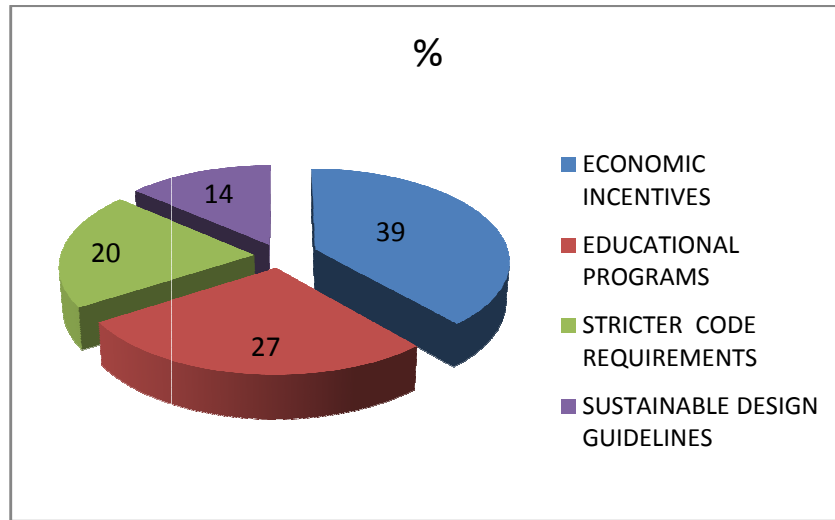


Figure 48. Strategies of involvement on sustainability

At the end of the questionnaire, (**question 21**) people are asked to say what is for them major obstacle within Spain sustainable construction (out of four options). The percentages are shown in the next figure:

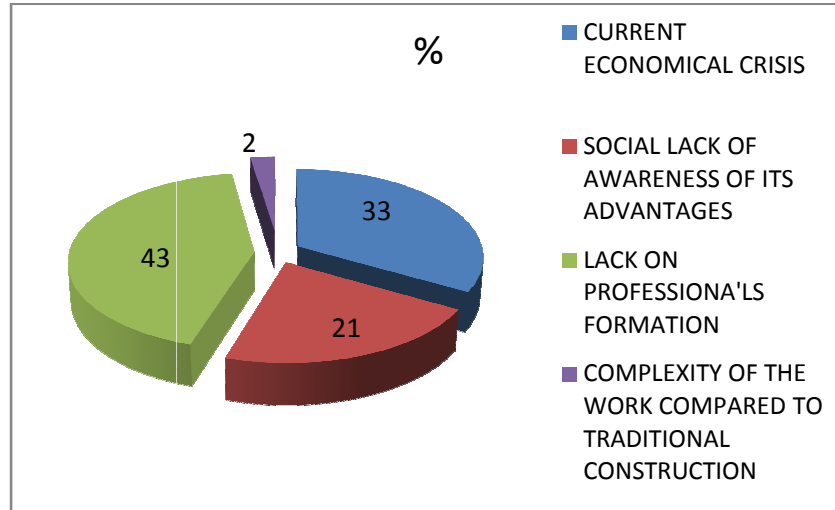


Figure 49. Major obstacle within Spain sustainability progress

According to the general sense of the current situation, the crisis would be the main obstacle (in second position with a 33%), there is a 43% of the respondents who opine that professional are not properly formed on the sustainability field.

Finally, ending up the questionnaire, (*question22*) people were asked if they thought sustainable construction practices will increase or decrease in a period of time of ten years from now. Indeed, everyone who took the survey answered that it will increase, giving some of the next reasons:

- Because of the increase of the population and the reduction of renewable energies.
- We will take more into account the environmental impact of projects.
- Social awareness is increasing (little by little).
- We have no other exit than to support sustainable practices.
- Because in a future dwelling buyers will ask for dwellings with less energy costs.
- There will exist a better professional formation.
- Improvement of the actual economical situation.
- Improvement on the high initial cost of sustainable constructions.
- Because non renewable energies will increase its costs due to its depletion.

5. - FINDINGS

After having compared and analyzed the results and the answers to the questionnaire by several companies and professionals of the construction sector, the next conclusions were obtained.

On the one hand, it has been shown how people who have finished their studies more recently, compared to those who finished them more than 20 years ago, have a better understanding/knowledge of what kind of applications and designs of sustainable practices could be applied to construction projects. Although, some of the most experienced respondents, who have lately participated on sustainable courses or masters, have also contributed with positive answers.

Indeed, the majority of people agreed that in order to better promote the sustainability in construction projects, a higher number of courses and seminars should be imparted, as well as the development of new and stricter design standards.

Concerning the sustainable construction practices mentioned by the respondents, it is worth to claim that some of them are very acceptable within the sustainable and efficient field, such as the use of trombe wall as a bioclimatic strategy for passive solar design, the utilization of exterior pavement with self-cleaning properties or the application of recyclable insulation with a very low embodied and carbon energy like cellulose.

As for the approximate cost of a sustainable construction, since most of the respondents opine that the economic price is higher than a traditional construction, that is probably the reason why the majority would take more into consideration the application of sustainable practices if more economic incentives were granted for it.

Even though the current situation of Spain concerning the application of sustainable practices is pretty deficient in comparison with some European countries, there is a positive attitude to the implementation of new strategies and models which will somehow lead Spain towards a more sustainable future.

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