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Civil Engineering Doctoral Programme

DOCTORAL THESIS

SUSTAINABLE DEVELOPMENT. A conceptual and operative approach to sustainability principles for the construction sector

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SUSTAINABLE DEVELOPMENT. A conceptual and operative approach to sustainability principles for the construction sector

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An English synopsis taken from the Spanish version of the Doctoral thesis

(a condition required for the award of the European Doctorate)

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SUSTAINABLE DEVELOPMENT. A conceptual and operative approach to sustainability principles for the construction sector.

ENGLISH SYNOPSIS

Contents

COMPREHENSIVE CONTENT OF THE ORIGINAL SPANISH VERSION OF THE THESIS

Contents

EXECUTIVE SUMMARY

In recent decades, the relationship between humankind and the environment has grown stronger. Indeed, over time the concern and active participation of citizens in ecological and environmental issues is becoming more frequent worldwise, and more recently the link from those issues to social and economic issues is leading to a new paradigm called sustainability.

Accordingly, through this doctoral thesis the origin, evolution, and feasibility to operativize sustainability in the construction sector is studied.

The meaning of sustainability is different among the earth´s nations; nevertheless, there are some important common themes such as a concern for the environment and its resource limits and sink limits, and a concern for both inter and intrageneration equity. Thus, those common aspects had brought about that most sustainability definitions appeal to the goodwill so sufficient resources for future generations be left, in order for they having a quality of life similar to ours.

In this academic work the criteria from the main United Nations documents about sustainability has been adopted. A benchmark may thus be established by setting out the sustainability principles in order to approach them to the construction sector, dealing with new buildings specifically.

To approach sustainability principles for the construction sector, conceptualization and pragmatic (quite different) aspects must to be addressed in order to join them in a common task, taking into account the number of theoretical and empirical themes to deal with. The research and the thesis writing were organized on five linked parts, which make up thirteen chapters.

The first part (chapters I, II, and III) is the core of the thesis, because the methodology and the bottom line are set out in those chapters, and also because the origin, evolution, and the sustainable development debate are exposed.

The second part (chapters IV and V) relates to the technical items for sustainability such as Thermodynamics, the entropy law and the environment; and then these concepts and their relationship with energy and matter. It is to be stressed that these last items are the main raw materials for the construction sector.

This second part also contains tools and techniques to support sustainability, e.g. life-cycle assessment, multtiatribute decision analysis, the environmental impact assessment, sustainability indicators, ISO 14 000 standards, and life-cycle costs for building materials.

The previous parts provide enough knowledge and information for conducting a proposal to a more socially responsible construction sector through, the so called, sustainable construction. That is the core subject of the thesis, for which in the third part (chapters VI, VII, VIII and IX) the fundamental premises for sustainable construction are established, those premises stress the adverse environmental impacts from buildings to be tackled by sustainability principles related to resources conservation, minimizing waste through re-use and recycling materials, construction quality, nature protection, and indoor air quality.

The approach of sustainability to the construction sector is proposed from the planning, design, construction, maintenance, and deconstruction building phases. Selection of building materials, life-cycle of materials, and major environmental impacts as a result of buildings are highlighted in that third part.

The sustainable aspiration requires a benchmark in order to set out the measures to be taken in approaching sustainability. To support that process, the fourth part (chapters X, XI and XII) is orientated to support sustainability, even though that concept is not something that can be gauged in most cases, and whenever possible not necessarily would it be in a quantitative way.

To carry out such assessment, a real region and building case study were chosen. Then, a set of sustainabilty indicators was developed and the building materials selection in the sustainability framework were made. That building material selection was done through an quasi-sustainable assessment method in order to assist the building designer who must be a sustainable aware designer.

The main outcome of the thesis are contained within the fifth part, and include findings, conclusions, recommendations, and an epilogue. That part also contains a proposal for synergy among some sectors of the society in order to attain some sustainable goals, mainly related to the construction sector.

Assuming that sustainability is more than just an act but a process, the main outcome from the thesis set out the benchmark for other studies and projects for the formulation of actions in achieving a transition to a desirable, feasible, and sustainable future.

INTRODUCTION

INTRODUCTION

The broad introduction to the theme that is developed in this Doctoral thesis is set out in Chapter 1. However, it is considered appropriate to define some matters of a general character more closely in order to contribute to the formation of a rapid initial idea concerning the conception, orientation and content of this academic work.

Structurally the subject lies within the lines of research of sustainable development, and in particular it interprets and proposes the application of the sustainability principles in the building construction sector. The objective is to bring forward operative criteria of this new paradigm for design and construction engineers working in industry, academia and government alike. As well as diffusing the concept in order to warn the wider public of the adverse impacts brought about by the construction sector.

The selection of the theme is justified by arguing that the construction and functioning of buildings are the causes of serious adverse impacts in today's world. Consideration is not taken of the underlying reasons, as, for example, the case of contamination arising from cars and factories, although paradoxically the problems brought about by buildings can be solved more easily than the aforementioned vehicular contamination.

The focus and extent of the work are inscribed in the most frequently cited and well-known definition of sustainable development, contained within the report dating from 1987 by the World Commission on Environment and Development (WCED) to the General Assembly of the United Nations, the so called Brundtland Report. This report contains a profound conceptualization of sustainability, establishing that human life could continue indefinitely on the planet if it were to sustain three fundamental dimensions: that people can progress (economic dimension), that cultures can develop (social dimension), but the effects of these activities must observe limits in order not to destroy the diversity and life systems (ecological dimension).

The foregoing reasoning explained in the cited text of sustainable development is..."ensure that it meets the needs of the present without compromising the ability of future generations to meet their own needs". This philosophy of development has an ethical intergenerational content, in the sense of future generations having the right to at least the same quality of life as that enjoyed by today's generations.

The detailed breakdown of this concept gave way to the proposals of action tending towards sustainable development, through the establishment of the obligations of the world's nations in the 21st Century, which were drawn together in the United Nations publication Agenda 21. This is the source document in which this thesis is based, from which its content is interpreted in order to propose the sustainability principles to be applied in the whole life cycle of buildings, which will be further explained in due course.

It is pertinent to comment that before the persistence of the debate concerning the concept of sustainable development, it is more easily understood and less controversial to use just one term. Once the difference is established with this dual expression, in the body of the thesis the noun *sustainability* and its adjective *sustainable* are used more frequently.

The anthropocentric essence of sustainability is not unknown in this case, however from the perspective of Construction Engineering the priority to be faced as soon as possible is the challenge represented by the antimony between economic development (which is the important component of the construction sector) and environmental deterioration (of which it is also responsible to a large degree). That's why giving greater attention to the other species with which the planet is shared require different methodological treatments to those set out here.

In the Engineering field, a number of proposals and projects which seek to apply the concept of Sustainability are known (CIB W82, 1998; MIYATAKE, 1996; SUSTAINABLE SEATTLE, 1998; and others). These can be interpreted as a formula of technical progress that begins to contribute to the equity, to gain time and to provide information on the moderation in the use and handling of materials and resources. Reference is made to equity because with sustainable proposals of these works, finite and scarce resources tend to be shared, at least with the most immediate generations. Time is gained by lengthening the existence of the reserves of natural resources and the capacity of the landfills, while one learns to resolve the substitution in a meditated and rational form. For its part, the anticipated moderation in the use of natural resources would be, together with other types of measures, a consequence of the consciousness raising inculcated in the population at large.

To place in context, the response from the building construction sector to sustainability must include, at least, the rational use of resources and energy efficiency, the consideration of environmental impacts, the minimization of residues, and the creation of healthy and comfortable environments.

For the treatment of these broad proposals, this work sets out from a conceptual exposition which contributes to form an awakening over the meaning of sustainability and subsequently through the use of the technical procedures that are more well known to Engineers. An applicability approach to the principles of sustainability in construction is sought, which implies embracing an extensive thematic space. This has suggested the convenience of grouping the different stuffs obtained in the investigation stage in five articulated parts, with the objective of inductively approaching from the general theoretical field to the specific pragmatic field of building construction.

The first of these five parts, entitled **Theoretical and Conceptual Framework,** is the axis upon which the thesis is developed, since it is in this ambit that the orientation of the work, the objectives and the conceptual bases of sustainability are established.

Moving on to another part, it is of note that neither the breadth and intensity of the Brundtland Report, nor the details of Agenda 21 which extend to offering the estimation of budgets, and methodological guidelines in order to put the principles of sustainability into practise. Therefore it was resolved to investigate and put forward a space of information with a sustainable implication of an engineering responsibility, in order to understand firstly the confluence of the technical aspects and of sustainability, and as a consequence bring forward ideas, studies and technical solutions with the incorporation of the mentioned principles. To this bridge of communication between scientific and conceptual aspects of the much cited theme, what is explained in the second part, called **Techniques and Tools for Supporting Sustainability** and comprises the technical-environmental foundations of the principal items used in construction (Matter and Energy), as well as management methods and tools to help sustainability principles to be operative.

It is in these types of supports that the transition or approach to **Sustainable Construction** is based, set out in the third part, through the incorporation of the notion of sustainability in the planning, architectural and structural design, selection of materials, construction per se, building operation, demolition and reuse of building materials.

The fourth part, **Towards Sustainability Measuring** leads the initiatives for the qualitative and quantitative valuation of sustainability in real cases of the construction sector. Sustainability indicators are developed in a specific region (Northwest of Mexico), as well as the economic-environmental valuation of a type of detached residential building project set in the same region.

The generality of this wide panorama of themes that are addressed is summarised in the fifth part, which is called **Compendium of the Approach to Sustainability Principles for the Construction Sector**, precisely in order to make the allusion to the stock of information, references, conclusions, recommendations and commentaries which can be of use to further research work on the theme in question.

The core themes tackled in this thesis cover construction design and procedures, environmental management techniques and methods, regional development and the sustainability philosophy itself. In view of the breadth involved it is not considered that it warrants going into greater depth to demonstrate the interrelation between the said themes, the objectives set out and the essence of the thesis.

The theme of sustainability is an emerging and evolving concept. Therefore some of the information presented is neither definitive nor conclusive. Nevertheless it provides a conceptual and operative guide of sustainability, which coincides with the objectives of the content of this doctoral work, which are intended to be of a disseminating and awakening character. In contrast, the aforementioned breadth of the themes tackled, (ranging from the origin and unfinished semantic debate of sustainable development, the methods of support which still require research, to the putting in practice of sustainability principles) will enable the research and development of subsequent projects starting out from the results of the thesis.

It is also important to stress that this academic work has been written in Spanish, the way is spoken in Mexico, resulting from the author's origins. Similarly it should be noted that some of the examples, proposals and ideas mentioned depend upon the experience, knowledge, idiosyncrasies and needs of the Latin American countries.

With respect to the format used, as previously mentioned the thesis is structured in various *parts*, according to the themes that are developed. These *parts* comprise *chapters*, which are in turn divided in and Finally, where necessary, subdivisions are made in order to include details that facilitate the corresponding documentation or explanation.

The Harvard bibliographical and information referencing system is used, with certain modifications for convenience. For example the last piece of information given refers to the place of publication, rather than placing this in the penultimate location, and the titles of books are not underlined, amongst other minor adaptations. Where the information source is the *Internet*, the exact date (year, month and day) of the consultation is stated and where it is provided, the updating reference is stated as well.

Finally, it is worth noting that in the conclusions of the Brundtland Report it was recognised that the path towards sustainability would not be easy and nor would it be devoid of obstacles. Rather hard decisions would have to be taken, requiring strong support in the political will of governments and in the consciousness-raising of different strata of the population. In the same way the elaboration of operative projects in the theme of sustainability is no straightforward task. That is they are not ready to be implemented in the same way as with other more conventional projects. This signifies therefore, that what has to be faced is a challenge of enormous dimensions.

FIRST PART

THEORETICAL AND CONCEPTUAL FRAMEWORK OF SUSTAINABILITY

CHAPTER I

FRAMEWORK OF THE THESIS

Justification

Objectives

Goals

Hypothesis

Methodology

State of the art

JUSTIFICATION

Nowadays the awareness of the immense planetary problems, causes mobilizations and debates between organizations, scientists, politicians and the public in general which transcends the local and immediate environment to become a matter of global interest. One of the global challenges is the interrelationship between the environment and the productive sectors, this has led to a progressive degradation of the environment with irreversible consequences in some cases and catastrophic in others.

The environmental problem is so wide and complex that it transcends the purely ecological limits. The degradation of the natural capital has been caused by the global expansion of population growth and economic activities that generate planetary contamination and exhaustion of natural resources; this has been translated in to climatic change from the greenhouse effect, growth of waste, destruction of the of ozone layer, acid rain, pollution of water air and soil, losses of the biodiversity, deforestation, drought...

A possible solution is to reduce the impact and delay the negative effects. This is found within the framework of sustainable development, giving place to a wide movement that spreads to the creation of a new model for world society.

The so called Brundtland Report published in 1987, defined and popularised the term sustainable development. This has integrated the different fields of study in such a way that nowadays it is applicable to many human activities, particularly to those that have a direct impact on the environment like amongst others, the construction sector.

The future of the construction industry and sustainability was first discussed at the First Conference Sustainable Construction carried out in Tampa, Florida, in November 1994. It was then a relatively new topic in the field of Civil Engineering and like other fields there is still a lot of research to be carried out to make the concept of Sustainability completely operative.

In this context, the moral obligation or ethic of sustainable development is such that the current generation has to give to the future generations at least a world as diverse, clean and productive as the one that they themselves are in. This implies a search for a balance among human activities, socio-economic development and of course the protection of the environment.

The term " development " includes activities from industries of different productive sectors. In this arena the construction sector causes one of the most prominent impacts on the environment and in the Economy of any Nation. In both developed and developing countries, the construction sector is one of the biggest in investment terms, employment creation and contribution to the Gross Domestic Production, and is also a great consumer of natural resources. At a global level this sector consumes one sixth of the fresh water, one fourth of the wood consumption and two fifths of the flow of materials and energy (ROODMAN, 1995).

The wide influence that the construction sector has on the environment and on the Economy, and therefore on society, becomes a candidate for the application of the sustainability principles in its activities and materials used. Consequently, the Engineers teaching in Universities, working in the Industry and the government sector require to be familiarized with the topic of sustainability, so that they may participate in the debate of conceptualization and operativization of sustainable development, through development of their ideas, they may propose specific solutions through projects to contribute to and safeguard the natural environment for future generations.

Also, taking into account that the environment is a global concern, the work in this thesis serves to inform and to create awareness for all sectors of society. Governments, educators, investors, professionals and consumers when informed of the sustainable topic, could contribute to the formulation of better policies, projects and decisions. This can be illustrated in the construction industry, if it tried to modify its traditional way of operating regardless its impacts on the environment.

In this case, the construction concept is bounded to the buildings and the infrastructures that link them directly. The justification of this delimitation is based on the fact that, at the moment the construction and the operation of the buildings, are on the same level with factories and automobiles by the damage that they cause to the environment, without receiving the interest or the protests that the environmentalist movements have pay to these. For example, the demand of construction materials and energy and water flow contribute to the pollution of air and water, deforestation, reduction of ozone layer; propitious indirect liberation of carbon dioxide, nitrous oxids and sulfur dioxide; at least one third of the buildings suffers from what is called "sick building syndrome", and when they are demolished large quantity of solid waste is generated that surpasses the capacity of management of many of the city councils (RODDMAN, 1995).

It is in this vindicate that the elaboration of this Doctoral thesis, of the Civil Engineering programme of the Polytechnic University of Catalonia (UPC), Spain, is based.

OBJECTIVES

Integral objective:

To study the origin, the evolution, and the operability of the concept of sustainability as applied to the construction sector and its contribution to the search of the balance required among the human activities: the socio-economic development and the preservation and the disturbances correction of the environment.

Specific objectives:

- To contribute to diffuse the sustainability concept among Engineers working in the industry, the academia and the government sector, so that in reciprocity they contribute ideas, studies, projects and works that help to safeguard the environmental common patrimony of the current and future generations.
- To provide information on sustainability to the academic area, with option that it is included in the activities of teaching Engineering.
- To make aware to the colleagues of Engineering that the productive activities from the construction sector and environmental care are compatible, if measures are adopted for to balance construction and the environment.
- To link the theoretical-philosophical content of sustainability with the activities that the construction sector develops.
- To contribute criteria and procedures to the construction sector, so as to be able to moderate the consumption of natural resources and diminish the deterioration of the environment.
- To disclose the notion of sustainability in an accessible form, in such a way that allows the broad public to understand the environmental impacts that the constructive industry causes.

GOALS

- To develop the topic of sustainability integration into the construction sector of, to obtain the Doctoral degree in Civil Engineering.

- To translate into English the most relevant areas in the thesis.

- To opt for the award of the *European Doctorate*, according to the rules set down by the normative of registration and authentications of the studies of doctorate at Catalonian Polytechnic University (UPC).

HYPOTHESIS

The concept of sustainable development will acquire bigger connotations if the concept of sustainability is to be understood better in meaning in the each field of expertise, e.g. in academia and in the diverse productive and services sectors (LEWIS, 1998; MIYATAKE, 1998; WELFORD, 1998). Of this tendency they are derived the following hypotheses:

1. The insight into the interpretation is leading to disintegration of the dual concept (develop and sustainable), which is allowing to emerge the meaning and application of the sustainable term gradually and covering a broad dimension, contributing to overcome in certain ways the confusion of the semantic-ideological debate that addresses the presumed ambiguity and contradiction of the expression, sustainable development.

2. The operability of sustainability should not wait until sustainable development is understood in context by the different thought currents (mainly economists), so that it can be applied later in the global and national scales. Rather the sustainability principles implicit in the Brundtland Report of the World Commission of the Environment and Development (CMMAD, 1992), and also in the Agenda 21 (UNCED, 1992), should be adapted to each necessity to be applied on regional and local scales, on projects, and even on personal attitudes. This proposal is coincident with the concept of thinking globally and acting locally.

3. Thus, the operatively of the concept will promote more supporters to sustainability than a possible consensus on the definition will do it.

METHODOLOGY

For methodological purposes, the levels of interest in the topic are, on one hand, sustainable development as a research line, and on the other hand, the conceptual and operative approach of Sustainability to the activities and the human and natural resources that integrate the construction sector. The main element for the implementation of methodology are information and data, which are frequently restricted just as chapter 40 of the Agenda 21 sets out

The subject to be developed is based on having enunciates and definitions close to the experience, and empirical data from traditional practice of construction, for which the approach treatment to sustainable construction is on an inductive type. Even when one is dealing with Engineering, and this is a discipline that generally approaches the solution of problems in a deductive form. The process of research of the topic in question is of hybrid character, because it combines the methodological phases and logic of the classic research process, also denominated scientific method (SIERRA, 1995); that is to say, conceptual elements of sustainability and pragmatic practice are proposed simultaneously.

Once these considerations are set out, the model to be developed consists of a feed back cycle for which can be continuously up dated, since the sustainability approach to construction is an emergent topic that still requires a lot of research and experimentation, and requires to be refined gradually. The figure 1 represents a methodological approach for the conception and search for Sustainability in the construction sector, through the stages of a research process considered as typical.

Hence, the practical interpretation of the methodological proposal is mapped out as shown in figure 1.

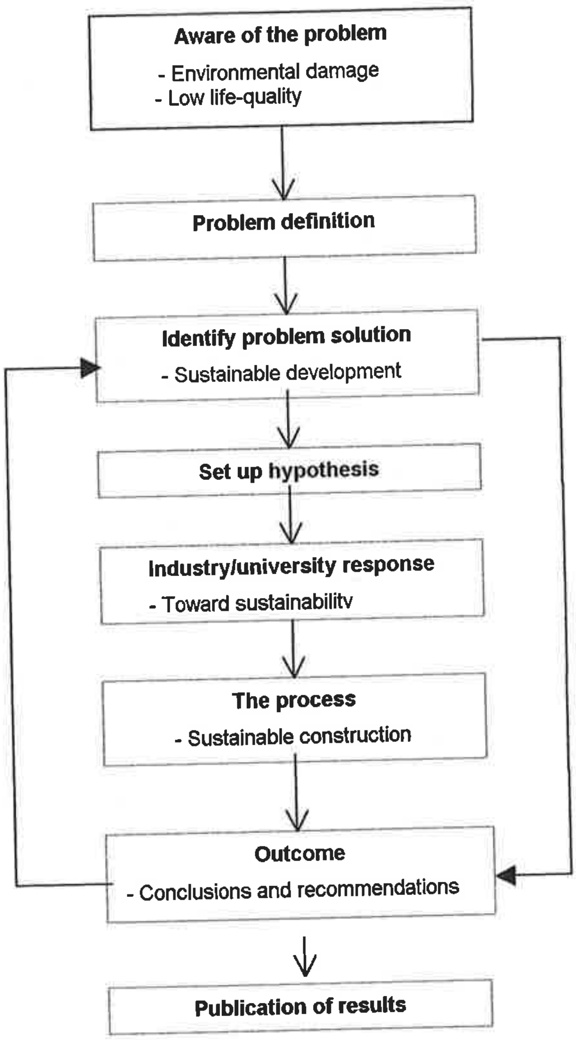


Figura 1. Methodological flow

The awareness about the problem constitutes the origin of the solution that is sought to achieve with the research (GARCIA, 1995; SIERRA, 1995). The progressive degradation of the environments quality, is largely propitiated by productive activities, among those that are highlighted is the construction sector, for the case, comparable to the initial stage of the process.

Since sustainability is a relative new topic, it bears as was already commented, scarcity of information. The requirements from the beginning and during the realisation of the current work involved the implementation of an exhaustive process of informative and documental investigation, collected from Catalonia, Spain, but that it also implied the visit to other countries of interest (Germany, Belgium, Ireland and Mexico), as well as the continuous communication by conventional mail and electronic mail. Briefly, the activities undertaken to obtain information were carried out as following:

Libraries, specialized centers in environmental information, bookstores, databases, government agencies and universities, non governmental organizations, specialized, journals, Internet, international information suppliers were consulted, as well as interviews with experts.

At the same time, exchanges of opinions and information were made by means of participation in international events, such as congresses and meetings with groups that work in the field of sustainability. The appendix C contains the details of people, agencies and other consulted informative sources.

As a result of the information attained and the linkage with the objectives set out, the theoretical conceptual framework for sustainable development was established, taking the term of sustainability as a benchmark, since it is a universal concept. From this process emerged some chapters that contain the basic conceptualization of sustainability.

Established a common area of the multidisciplinary character, then a link between the sustainability principles and the construction activities was set out, taking into account the interrelation of the matter and the energy, since they are the main row materials of the construction activities. This was analized in the frame of the Thermodynamics, since many environmental problems are explained through this discipline.

In order to apply the sustainable principles to the construction sector, it was necessary to agglutinate and to adapt methods and tools that had already proved their viability in other fields, in order to do the proposal for sustainable construction.

There is no universal definition for sustainable construction (CIB W82, 1998), however some of the principles that can contain such a concept are common nowadays in every country, for example those that refer to environmental protection. As a consequence, starting from the proposal of the First International Conference for the Sustainable Construction (KIBERT, 1994a), and analyzing the proposal made by representatives of diverse countries it was possible to achieve a definition of sustainable construction according with to the objectives of this academic work.

The last stage of the methodology is to set up conclusions and recommendations, and a final reflection, which is a product of the whole development of the topic of sustainable construction. This stage implies the extension of the conclusions and recommendations that are the output of the project, what should be interpreted as the diffusion and socialization of the information contained in the thesis.

STATE OF THE ART

Taking into account the hybrid characteristic of the subject to be developed, it is pertinent to make emphasise two features, on one hand the existence of a bulk of conceptual knowledge about sustainability, from its origins and evolution to the current state of the world movement on sustainable development and on the other hand, there is a need for the application of the sustainability principles to activities and projects.

The conceptual part of the thesis was examined within two chapters, dealing mainly with the Brundtland Report, the commitments emanated from the Rio de Janeiro´s Summit and Agenda 21, and lastly for contributions from researchers and authors that continue working on the subject in question.

With the operability of the concept in question, the following quotes are some examples of sustainability implementation that show the state of the art.

During July 1997, in Catalonia, a Network of Towns and Cities commited themselves to the principles of sustainability, this involved 128 affiliated municipalities which covered 70% of the regions population (SUSTAINABLE, 1998).

In Barcelona, an independent group concerned with the environmental, social and economic health of the city, gathered for the so named Civic Forum Sustainable Barcelona (FCBS, 1998), and launched a set of sustainability indicators in 1998.

The European Conference on Sustainable Cities was carried out in Aalborg, Denmark, in May 1994. That was the starting point of the commitments by European local authorities to set out local Agenda 21, which is established in chapter 28 of Agenda 21. At the moment several European municipalities and cities are working on their own development plans in which sustainability has become the core of their strategies. (DIPUTACIÓ, 1997; ICLEI, 2000).

A fact that should be pointed out is that the industrial sector started being interested in the application of the sustainability principles, which is confirmed through the visionary speech and the concrete projects that are known from transnational leader industries like DuPont, Dow Chemical, 3M Corporation, IBM, among others (FIKSEL, 1996; GRAHAM, 1997). The biggest Japanese construction company, Shimizu Corporation, has adopted a global environmental agreement by means of which commits to take into account the topic of the environment in the development of their activities, and it is introducing measures gradually to change the procedures of lineal construction for a cyclical construction: design of buildings that optimize the energy use, use of ecological materials, use of machinery and equipment environmentally clean, minimization of waste in site, reuse of materials, among other measures (MIYATAKE,1996; RODDMAN, 1995).

In the American Continent there are several examples that illustrate the sustainability approach: Curitiba, Brazil; Boulder, Chattanooga and Seattle, USA, among others. Also for initiative of the United Nations Development Program, on 1993 works began to constitute an Latino American Net for sustainable development, which states to be consolidate in some Countries of the region, offering services and support for sustainable projects mainly through the Agenda 21 framework (RED, 1998; URQUIDI, 1997).

In Mexico, a chapter of the International Council of Industries operates for sustainable development; the steel industry is pioneer on ISO 14 000 standards, the private sector had set up the Studies Centre for Sustainable Development , and official agencies had developed sustainability indicators (ISO, 1998; UN, 1998).

On the other hand, construction experts have prepared national reports of fourteen countries (CIB W82, 1998). They have been integrated these reports into a whole study about sustainable development and the future of construction and have conclude that next step should to be to reach a more consensus vision through a global common model and to set up indicators and policies to translate the sustainable construction vision into reality. The case of study of Spain is included in this study.

It is important to highlight initiatives close to us, such as the proposed Plan of the UPC, through the document "Environmental Approaches in the Design, to Construction and Use of the Buildings". This proposal aims to achieve construction of high environmental quality in buildings, the pilot project is another step to acquiring knowledge in the sustainable construction of buildings.

The previous examples indicate that the state of knowledge in sustainability is beyond the conceptual threshold to be applied in specific programs, projects, and actions. However, in the case of the construction sector the advance is incipient, according with the research developed and the link from the sustainability theory and construction application needed (ALAVEDRA, 1997; ROODMAN, 1997)

Nevertheless, although there is a slow advance, there are examples of projects that show the feasibility and concern for applying the sustainability principles into practice, through the introduction of ecological approaches, energy efficiency and eco-efficiency issues in general. The following projects are some of the examples quoted :

In Edinburgh, Scotland, a development constituting 121 houses is built in an area formerly occupied by an old railway station (grey area). The most interesting characteristic to be highlighted is the energy supply for efficient use and not allowing the tenants to possess automobiles. People interested in buying or renting the houses will sign an agreement which prevents them from possessing or planning to acquire an automobile. The development does not include parking spaces and as a result there is more area for gardens and open spaces. The residents will commute on two bus lines and possibly on a suburban train.

As a pilot project, in Limelette, Belgium, a recycled house will be built that will incorporate a significant proportion of materials coming from recycled, re-used, and by-products from diverse industrial activities. The purpose of the project is to demonstrate that in the construction sector it is possible to use a high percentage of recycled materials and to reuse them without any risk to the health of the users and without increasing the construction costs. The prototype covers the traditional stages of planning, project, selection of materials, etc., until completing the construction of the house and their access routes. (CIB W82, 1998).

The Rocky Mountains Institute is one of the first and more successful green buildings, among other interesting things it has a passive solar farm located in a cold mountain almost the whole year round and where fruits and tropical animals grow up. The main characteristics of the building is their rounded stone walls in the corners, specially insulating windows, the orientation toward the south and the absence of mechanical noises, the lack of conventional machinery commonly found in buildings of nowadays.

The design of their special equipment and their operation have been thought to obtain a bigger quality of their occupants' life and an extraordinary saving of energy, which is achieved thanks to the isolation efficiency and to the solar facilities. The paying-off of the investment happens in a surprisingly short time (WEIZSÄCKER, 1997).

In New York, the United Nation Environment Program building is being refurnished, and a 1.6 million square foot building is close to Times Square, in both cases sustainability principles for design, construction, and operation has been adopted. (ENVIRONMENT97, 2000).

On the other hand, one of the biggest companies in design in the world is based in the United States, they have created a guide for sustainable design (CIB W82, 1998), which contains procedures, information, databases, and protocols on projects to help to make sustainable designs. The topics about sustainable design, planning, construction materials, indoor air quality, energy and water saving, recycle and waste management are included.

In addition to this guide, there are other manuals such as the "Sustainable Building Technical Manual" (OSSO, 1996) and the Handbook of Sustainable Building" (ANINK, 1996).

The sustainable model district of Vauban), Friburg, Germany is to be highlighted (FORUM, 1999). That is a 38 ha ex-military base where 2000 housing units are being constructed. In this development, ecological aspects are considered from the very beginning. Some sustainable measures that had been undertaken are: re-use of materials, clay finishes, no use of PVC products, photovoltaic solar panel facilities, low in energy passive houses, the urban design favours alternative transport instead the use of cars, among other measures to be undertaken.

Lastly, from the analysis taken into the state of the art, the usefulness and feasibility of addressing sustainable construction were noted, at the same time the difficulties to tackle sustainability challenge were also noted.

SYNOPSIS OF CHAPTERS II AND III

SUSTAINABLE DEVELOPMENT, GENESIS AND EVOLUTION

1. The Concept of Sustainable Development
2. Sustainable Development and Sustainability
3. The Brundtland Report
4. Agenda 21

1. THE CONCEPT OF SUSTAINABLE DEVELOPMENT

There are over 160 definitions of sustainable development (HILL, 1998), but the most widely used and quoted is the one set out by the United Nations World Commission on Environment and Development (WCED, 1987) in the report "our common future", also known as Brundtland Report, which states that sustainable development is "development that meets the needs of the present generation without compromising the ability of future generations to meet their own needs" (P.8).

But there are little coincidences among the definitions made in Brundtland Report and the semantic from dictionaries. The terms **development** and **sustainable** were consulted in some dictionaries. Larousse Dictionary (LAROUSSE, 1972) defines the term *sustain* like.... "to support, bear (a weight, etc.), to prevent from falling, collapsing or giving way, especially for a time".

The Oxford Dictionary (OXFORD, 1995) says that *development* is the ... "industrialization or economic advance of a country or an area".

The etymology of the word development maybe has Celtic roots, although its current meaning comes from the old French words "des" and "veloper", those which together mean: to unwrap, to expand, to acquire a form or specific function gradually.

On the other hand, sustainable comes from the Latin root "sostinere", that means to conserve in existence, to maintain, to sustain.

So, it can be concluded that the main significance of the expression sustainable development comes from the explicit meaning that has been attributed to it, rather than from linguistic definitions in the dictionaries.

As was pointed out above, there are several sustainable development definitions varying in purpose according with the interests and needs of authors. However, it is more or less agreed that there are some crucial components, these are as follows:

- Intergenerational equity._ the current environmental goods should be maintained to share with future generations.
- Intra-generational equity._ opportunities to access to environmental goods for present generations.
- Economic growth and environmental well-being._ these concepts are not necessarily incompatible.

These three elements mean that sustainable development requires reductions in consumption in the industrialized countries; education and technology transfer in the developing countries, and reparation of environment damage in the economies in transition countries (ex-socialists).

Regarding with this thesis, in an engineering context, meeting the three components of sustainable development quoted above, it is believed that we are concerned with two fundamental limits that nature imposes on our activity: sources limit and sink limit.

Sources limit refers to the environment's finite capacity to provide resources. The sink limit refers to the environments capacity to assimilate the wastes that the economic activities cause.

2. SUSTAINABLE DEVELOPMENT AND SUSTAINABILITY

Having discussed the concept of sustainable development it is now possible to explore the sustainability concept.

The Brundtland Report not only defines sustainable development, but also the single meaning of sustainability as "leaving sufficient resource for future generations to have a quality of life similar to ours" (WCED, 1987).

Another brief definition says that "sustainability is a feature of a process or state that can be maintained indefinitely". That is to say, sustainability does not mean for ever but for a prolonged period.

Exposed this way, sustainability is a wider concept than sustainable development, and it can be applied at several levels, from a sustainable household or project to a local or global sustainability (KOREJ-De Villa, 1997). Meanwhile, sustainable development is a process referring to a region or sector usually leaded for a governmental agency.

Thus, sustainability can be focused to diverse topics of interest as the ecological system, a particular species or all the species (biodiversity), the economic system, a culture, a business or a particular industry (construction industry in this case), but invariably, it will relate to the global socio-economic system in the context of the ecological life. That's why the fundamental pillars of sustainability are: economy, environment and society.

In the body of this thesis the noun sustainability and the adjective sustainable are frequently used, even more than the dual expression sustainable development, since this academic work is dealing in particular with the building products and materials for a punctual engineering project. But despite the small scale, we have to figure out that choosing construction materials is a part of sustainable construction, and this sector is just a component of the overall process of sustainable development.

3. THE BRUNDTLAND REPORT

In 1983 the General Assembly of the United Nations created a special commission to elaborate a global programme for the change. The name of that group was World Commission on Environment and Development (WCED), and was chaired by a defender of environment and of women's rights, and the Prime Minister from Norway, Gro Harlem Brundtland.

After three years work the commission concluded that the transition to sustainable forms of development was possible, and published the corresponding report "Our Common Future", also called Brundtland Report. In this report the concept of sustainable development was defined.

The urgent strategies that were intended to follow through sustainable development responded to basic objectives, such as:

- Revitalize the growth
- Change the quality of the growth
- Satisfy essential needs of work, food, energy, water, and hygiene
- Assure population level
- Conserve and increase the base of resources
- Reorientation of the technology and control risks
- Integrate the Economy and the environment in the adoption of decisions

The Brundtland Report was broken down into three parts. In the first part set out the threatened future, the sustainable development and the paper of the international Economy.

The second part analyses the common tasks to carry out for sustainability of population and human resources, food, security, species and ecosystems, energy, industry and urbanization.

The third part refers to the administration of the common spaces, peace, development and environment, it makes a proposal for the change of institutions and law, and also makes a call to action.

At the very end, the commission proposed the realization of regional conferences and an international conference, in order to launch the idea of sustainable development. In June 1992, an Earth Summit was convened in Rio de Janeiro, Brazil.

4. AGENDA 21

The most important document that brought about the earth summit in Rio de Janeiro was a blueprint for a global partnership that contains the duties of all the nations on the 21 Century, to reconciling the requirements of a good quality environment and a healthy economy for all the peoples of the world. This blueprint is known as Agenda 21, the original version of which is a book of 800 pages broken down into 40 chapters.

Agenda 21 provides options for:

- The roles of governments, business, trade unions, teachers, indigenous, women, men and youths;
- Combating degradation of land, air and water;
- Conserving forest and preserving the diversity of living species;
- Dealing with poverty and excessive consumption, health and education, cities and rural communities.

Its 40 chapters are integrated into four sections. Section I (Chapter 1 to 8) refers to social and economic aspects of development and highlights the fight against poverty, rationality in the consumption and the necessity to control the disproportionate demographic growth.

Section II (Chapters 9 to 22) addresses the preserve measures: protection of the atmosphere, deforestation and drought, biodiversity, preservation of seas, and makes solid waste of all types stand out.

Section III (Chapters 23 to 32) is about the reinforcement of the main groups for eco-development, emphasizing women's emancipation and the improvement of infantile conditions.

Section IV (Chapters 33 to 40) proposes the execution of proposals from financial points of view, technological transfer, science for the sustainable development, environmental education and international cooperation.

From all these important chapters it is important to highlight number 7, related to the aims of this thesis.

Chapter 7 is dedicated to the promotion of sustainable human settlement development. A set of actions is exposed, related to shelter, land-use, planning, management of human settlements, energy and transport systems, infrastructure of services, and construction.

With regarding to this last action, the activities of the construction industry are crucial to reach the goals of socio-economic development, providing shelter, infrastructure and employment. However, Agenda 21 also warns that construction activities can be an important source of damages to the environment through the natural resources depletion, degradation of fragile eco-areas, chemical pollution and use of harmful materials against human health.

To tackle these issues, it suggests adopting standards and technologies that minimize the risks of such damages, in being bent on approaching the objectives of sustainable human settlement development and the creation of employment. The activities that are intended are the creation of construction industries, for instance construction material industries, using natural resources of local origin and the use of vernacular techniques.

The chapter also recommends that measures be taken to increase the efficient use of energy and the sustainable use of natural resources. Recommendations are also put forward to formulate specifications for the appropriate use of land, and special regulations to set out protection for eco-sensitive areas of the dysfunctions propitiated by the construction activities.

Especially in developing countries, the intensive use of manpower in construction activities would be advisable, and maintenance of technologies that create employment (and do not pollute). It is also considered equally important to promote standards and practices for DIY (do it yourself) in housing construction, undertaking measures to make possible the access to the construction materials by means of soft credit procedures.

Chapter 31 is focused on the scientific and technological community (researchers, engineers, architects, urban planners, industry designers, among others), and demands from them a more open and more effective contribution to the process of decision-making concerning environment and development. Also required is the participation of science and technology in human issues to be more known and better understood for those who make decisions as well as the broad public.

This thesis commitment is strongly supported on Agenda 21.

SECOND PART

TECHNIQUES AND TOOLS USED IN SUPPORTING SUSTAINABILITY

SYNOPSIS OF CHAPTERS IV AND V

TECHNIQUES AND TOOLS FOR SUSTAINABILITY SUPPORT

1. Live-cycle assessment
2. Standards ISO 14000
3. Analytic hierarchy process
4. Life-cycle cost

The second part of the thesis deals with subjects that are familiar to engineers and in this case must to be linked with the idea of sustainability. Main construction raw materials whose energy and matter are addressed, and some tools that will be used to support the approach of the sustainability principles to the construction sector are exposed.

The concept of sustainability presents challenges far beyond those normally identified within the construction sector. When it is viewed as a major component of the set of tools for the future of the built environment it must also be viewed as a significant participant in determining the future level of environmental impacts and, thus, participating in decisions about the sustainability of the biosphere.

It is clear that human actions cause uncertainty that responsibility for the future emerges as an issue. It is then that the flows of material and energy through the biosphere become a question not only of thermodynamic issues but the ethics.

This common encounter point is analysed in chapter IV entitled interrelation between Thermodynamic and environment, and its sustainable implication.

The sections developed in that chapter are: energy and materia, the entropy law, entropy and life, entropy and environment, and sustainable production and consumption.

Chapter V deals with tools to support sustainability remarking on the application of those tools in the assessment method chosen to select building products and materials.

In order to extend the meaning of the tools that support sustainable construction, which also are used in the BEES method and other attempts that pursue sustainability (FULLANA, 1997), the main tools are explained as follow:

BEES measures the environmental performance of building products using a life-cycle assessment approach specified in ISO 14000 set of standards. Economic performance is measured using life-cycle costs. Both environmental and economic performance are combined into an overall performance measure using multiattribute decision analysis, more specifically an analytic hierarchy process.

The most relevant tools exposed in the thesis are:

1. LIFE-CYCLE ASSESSMENT (LCA)

Life-cycle assessment is a method internationally accepted for assessing environmental impacts (BALDWIN, 1998). According with standard ISO 14 040, LCA is used for assessing the environmental aspects and potential associated with a product, by compiling inventory, evaluating environmental impacts and interpreting the results.

- Inventory entails quantifying the flow of relevant inputs and outputs of a product system, it includes water, energy, and raw materials, and release to air, land, and water. Data categories are used to group inventory flows, for instance, in the BEES model flows such as aldehydes, ammonia, and sulfur oxides are grouped under air emissions data category.

A number of approaches may be used to collect inventory data for a LCA.

- The environmental impact assessment quantifies the potential contribution of a product's inventory flows to a range of environmental impacts. There are several LCA impact assessments, such as, direct use of inventories, critical volumes, ecological scarcity, environmental priorities system, classification/characterization, among others.

The BEES model uses this last process in order to assess global and local impacts assumed: global warming potential, acidification potential, nutrification potential, and natural resource depletion. Solid waste and indoor air quality impacts are also included in the model.

- To interpret the result of the two previous steps combined, the performance measures for the six impact categories need to be synthesized. This involves combining different measures of impact performance, for this reason the technique Analytic Hierarchy Process (AHP) is used.

Finally it could be said that in order to adhere with sustainability principles, the building products and material selection process needs to incorporate life-cycle assessment elements.

2. STANDARDS ISO 14 000

LCA studies should always use functional units, which are defined by Standard ISO 14 040-043. This is a family of international voluntary standards still under development.

ISO 14 000 specifies requirements for an environmental management system (EMS), to enable an organization to formulate policies and objectives. It applies to those environmental aspects which the organization can control and over which it can be expected to have influence. It does not specify environmental performance criteria.

An EMS is a part of the overall management system which includes: organizational structure, planning activities, responsibilities, practices and resources for developing and maintaining the environmental policy.

The current series of standards ISO 14 000 is set out in Table1. From that list ISO 14 040 – ISO 14 043 are related to LCA, and the ongoing ISO/TC59/SC14 deals with life span of constructions.

BEES methodology follows guidance in ISO 14 040 series of draft standards for LCA.

Table 1. Standards ISO 14 000

Standard(s)	Name
ISO 14 001	Environmental Management Systems (EMS) Specifications
ISO 14 004	Guide for general principles, Systems and support techniques
ISO 14 020-24	Environmental Measurement
ISO 14 040-043	Life-cycle Assessment
ISO 14 050	Terms and Definitions
ISO 14 064	Guide for Products Specifications
ISO/TC59/SC14	Life-span Construction Planning

3. **ANALYTIC HIERARCHY PROCESS** (MULTIATTRIBUTE DECISION ANALYSIS).

This is a multiattribute decision analysis method of measurement within hierarchic and network structures.

The structural dependence is determined by the number and arrangement of the parts to perform a function. The relative importance of the elements in performing various functions may be affected by additional structural information that is available.

In the Analytic Hierarchy Process (AHP), the methodology uses relative comparison and normalization and requires that the structure should be considered along with function in developing the priorities (SAATY, 1966).

The axiomatic basis of AHP gives greater attention to the mathematical foundations of the method. T. L. Saaty the developer of AHP sets forth primitive notions on which axioms are based:

(1) Attributes or properties, for instance, **A** is a finite set of **n** elements called alternatives, and **C** is the set of properties or attributes with respect to which the elements of **A** are compared.

(2) Binary relation: when two objects are compared according to a property, it can be said that one is performing binary comparisons.

With AHP methodology a person (decision-maker) uses an individual understanding together with a way to convert his judgements to ratios to deal with optimization. At first this may go contrary to intuition, in the end the question of whether traditional manipulations gives rise to better answers than actual and complete understanding must be faced.

An important observation made by the developer of AHP regarding rank reversal under relative comparison is that it is similar to introducing additional variables and additional equations or inequalities in an existing model. The solution of the model may be changed dramatically.

But all the processes outlined can be avoided nowadays, since the method AHP has been integrated into a computerized support system namely Expert Choice, and is offered commercially and on the internet (EXPERT, 2000).

In relation to environmental concerns, verbal importance rankings, for instance "relatively high risk", may be translated into numerical importance weights by following guidance provided by AHP methodology. In a process known as pairwise comparison, numerical comparison values are assigned to each possible pair of environmental impacts. Relative importance weights can then be derived by computing the normalized eigenvector of the largest eigenvalue of the matrix of pairwise comparison values.

The relative importance weightings for each of the six impact categories assumed in BEES can be made through different criteria, even the user of the method is free to use any weight set through entering those weights under the user-defined software option. This last option was chosen in this academic exercise.

4. LIFE-CYCLE COST

The life-cycle cost (LCC) method sums over a given study period the costs of a project or investment. The sum is expressed in either present value (present worth) or annual value terms. Alternative building materials for a given functional requirement, for instance, can thus be compared on the basis of their LCCs to determine which is the least cost of providing flooring over the study period.

LCC includes the costs over the study period of initial investment (less re-sale or salvage value), replacements, operations, maintenance and repair, and disposal. The same study period must be used for each alternative whose LCCs are to be compared, even if they have different useful lives. The appropriate study period varies according to the stakeholder perspective.

The LCC for building products and materials is computed by discounting all costs occurring over the study period to the present and then summing up. The discount rate converts future costs to their equivalent present values and accounts for the time value of money.

It is important to distinguish between the life-cycles underlying the LCA method (used to measure economic performance). LCA uses an environmental life-cycle concept whereas LCC uses a building life-cycle concept. These are different.

The environmental life cycle of a building material begins with raw materials extraction and ends with recycling, re-use, or disposal of the material. The building life cycle of a building material begins with its installation in the building and lasts for the duration of the LCC study period, which is determined in part by the useful life of the material and in part by the time horizon of the investor.

The reason why LCC uses a building life cycle rather than an environmental life-cycle is because out-of-pocket costs to the investor are borne over this time frame. It is these costs to the investor upon which financial decisions are made.

Balancing environmental and economic building products and materials are made for BEES on the basis explained.

THIRD PART

SUSTAINABLE CONSTRUCTION

SYNOPSIS OF CHAPTERS VI, VII, VIII AND IX

SUSTAINABLE CONSTRUCTION

1. Introduction
2. Buildings environmental impacts
3. Conceptualization
4. Sustainable criteria and sustainability principles
5. Design, construction, maintenance, and deconstruction phases
6. Environmental analysis of common building materials

1. INTRODUCTION

The construction industry makes a vital contribution to the social and economic development of every country, but at the same time, at least one part of that industry, the building sector, has a major impact on the environment.

Construction is a major consumer of non-renewable resources, a substantial source of waste, a polluter of air and water, and an important contributor to land at lon. As a consequence of these impacts, a more socially responsive construction is needed whose name has been said is sustainable construction.

Generally speaking sustainable construction represents a new way of thinking in planning, designing, building, operating and maintaining constructed facilities. This new way of thinking should meet the challenges of satisfying the growing human needs for shelter while conserving and protecting environmental quality and natural resources, which are essential for future generations.

Choosing appropriate building products and materials is an important issue, and component, of sustainable construction. Therefore, in order to address the dissertation core topic it is unavoidable to deal with the sustainable construction framework and then the building products selection methodology will be addressed.

With that purpose, the concepts are explained in the following section.

2. CONCEPTUALIZATION

Since there are many definitions of sustainable development, there are many of sustainable construction. However, to identify the contribution of the building sector to sustainable development, it is unavoidable to set out a basic tion of sustainable construction as a reference to develop this thesis.

The first registered meeting to discuss construction within the broad context of sustainability was the "first international conference on sustainable construction" held in Tampa, Fla., in 1994. In that congress several attempts to define the concept of sustainable construction were made. One of the most accepted definition establishes that sustainable construction is the way to "create and maintain a healthy and responsibly built environment, taking into account ecological principles (to avoid environmental effects) and using resources efficiently" (KIBERT, 1994).

Such a generic definition encompasses a wide variety of sustainability issues not interconnected and therefore a hard task to fulfil. Fortunately, relating to the topic of this thesis there are research efforts underway to identify technical criteria in order to assess the environmental effects, and more recently environmental-economic effects, of materials choices for creating the built environment.

The starting point to attempt to gauge the large range of building material alternatives is setting out the sustainable construction issues, as follows:

a) Resources:
- Energy consumption
- Water use
- Land use
- Materials selection

b) Healthy:
- Exterior environment quality
- Interior environment quality

c) Design:
- Building design
- Community design

d) Environmental effects:
- Construction operations
- Life cycle operations
- Deconstruction

These issues are now explained briefly, considering each issue in general.

a) Resources:

The construction industry is a major consumer of resources. A wide range of materials are used with environmental consequences during their production, use and final disposal.

Particularly, buildings consume energy, demand land, consume minerals, fossil fuels, other natural materials, and their occupants use water and energy.

For these general reasons, material selection is a crucial issue to be undertaken.

b) Healthy Environment:

External environment includes fertilizer and toxics such as pesticides, herbicides, and fungicides from landscape maintenance; and minimize the need for landscape irrigation.

Indoor environment quality includes the prevision of good indoor air quality (IAQ), lighting, noise control, and temperature/humidity control.

c) Design:

The early stage of design is crucial because the creation of passive heating, cooling, and lighting systems may well be accomplished with good design and adequate tools to implement them.

Also building and communities need to be well designed in order to induce the occupants to maintain and care for them. At the same time, community scale design must consider appropriate transportation, infrastructure, and other services for the community to be successful.

d) Environmental Effects:

The stage of construction consumes energy and water, generates noise, and can cause substantial damage and produce large quantities of waste; so, changes in the process are needed to protect the environment during the construction operations.

Deconstruction and/or demolition of buildings should result in a source of materials for new construction and avoid causing more pressure on landfills.

As can be figured out, all these sustainable construction issues are linking with the appropriate selection of building products and materials.

3. SUSTAINABLE CRITERIA AND SUSTAINABILITY PRINCIPLES

The built environment quality can be improved through the application of sustainable criteria to the material selection process. As was established before, this thesis concerns with the limit of resources available at source and the sink limit to assimilate waste. So, the general criteria for a sustainable construction are: minimizing resource depletion and preventing environmental degradation, and a third connected criterion is added to provide a healthy building environment.

These criteria must be translated into *sustainability principles* in a way that would able an approach to sustainable construction, so five principles are proposed in the framework of the above criteria:

a) (Conserve): Rationalize use of energy.
b) (Conserve): Maximize resources use and minimize resource consumption
c) (Renew/Recycle): Use renewable and/or recyclable resources.
d) (Protect nature): Protect the natural environment (air, soil, water) when building.
e) (Non-toxics): Create a healthy, non-toxic environment.

Of course, this list of sustainable principles is not exhaustive, because this academic work is just an attempt to explore the selection of building materials in the conceptual framework of some of the most relevant principles of sustainability, assisted by the few current assessment methods available, and on the other hand, taking into account that the green building decision-making process nowadays is based on little structure and even less credible scientific data (LIPPIAT, 1998), so in this experimental phase it is not the right time to be comprehensive in sustainability principles.

Each of the five sustainability principles listed above is explained in building terms as follows:

a) Rationalize the use of energy

This conservation principle leads to the use of passive measures to provide heating, cooling, ventilation, and lighting for the buildings. This also means considerably high efficiency systems, high levels of insulation, high performance windows and low flow fixtures. Appropriate building orientation and use of energy saving facilities and appliances are important, and designing buildings, structures and regional planning with optimum energy efficiency and minimum energy consumption including application of the concept of life-cycle assessment. This principle is also closely related with global warming, are mainly refers to CO_2 production from fossil fuels released to the atmosphere.

b) Maximize resource use and minimize resource consumption

It is desirable to reuse resources that have already been extracted. Items such as windows, doors, and bricks can be reused in new constructions and renovations, which is a profitable business for owners and builders. Resources such as water can be reused through greywater systems. Also land can be reused creating new spaces in grey areas and brownfields.

c) Use renewable and/or recyclable resource

Recyclable resources, recyclable content or those from renewable resources must have priority overall others. This is also valid for energy where renewable sources such as solar or wind power are available.

This set of principles is not exhaustive. Each author can set out different sustainable principles, but this can be the minimum group of sustainable principles to the construction sector.

There is a huge quantity of materials that have recycled or waste content such as agriboard panels, tiles with recycled tire or glass content, roofing shingles with recycled plastic, etc.

Special stress is for fly ash (to be dealt with in this dissertation), a post industrial waste which is successfully utilized to displace cement in concrete; cement is a high energy content building product and one of the largest generators of carbon dioxide. The fly ash is an inevitable by-product of power generation and steel production.

d) Protect the natural environment

Creating the built environment will impact the natural environment and its ecological systems. It is important that the construction industry parties become aware of creating the built environment which can lead to resource depletion, destruction of plants and wildlife, water and air pollution.

e) Create a healthy non-toxic environment

Products constituting the built environment are accompanied by a wide variety of hazardous and toxic substances that ultimately threaten human health, such as lead, asbestos, dioxins, and mercury are typical. An example of these substances is mercury used in thermostats, fluorescent light bulbs and television sets.

Indoor air quality is a major issue in this principle also, selecting products that will not off-gas or contribute particulates to the interior environment is crucial.

The exterior environment of buildings should be designed so as to provide plants and vegetation native to the region, this strategy will allow for hardy vegetation, and insect resistance, and will minimize the application of pesticides, herbicides, fungicides and fertilizers that pollute groundwater.

4. DESIGN, CONSTRUCTION, MAINTENANCE AND DECONSTRUCTION PHASES

To the conventional process for a construction project, the social or environmentally responsive process adds the concepts of integrated building design, design and construction team collaboration, and the development of environmental design guidelines. These new elements must be incorporated into the project from the early beginning and carried out on all the phases of the project and final occupancy of buildings.

The so called green buildings, through an integrated design approach, take into consideration the effect of factors like interrelationships among building siting, design elements, energy resources constraints, building systems, and building function. In addition, climate and building orientation, design factors such as daylighting opportunities, building envelope and system choices, as well as economic guidelines and occupant activities, are factors that need to be considered in an integrated approach.

The first concept of this section can be broken down into two branches: pre-design and true design.

Pre-design: In fact, this stage is the first step in the building process incorporating green building practices (see a list of these practices in Appendix A) into the project, so this juncture is critical. Decisions and measures taken during pre-design set the project direction and must prove cost-effective over the project's life. A clearly developed project framework guides the decision making process throughout the project, incorporating aspects related to site selection and design, the building design and its systems, the construction process, and building operations and maintenance.

The above mentioned integrated building design, is a cornerstone related to sustainable buildings, which are efficiently combined systems of coordinated and environmentally sound products, materials, systems, and design elements. Building designers can obtain the most effective results by designing various building systems and components as interdependent parts of the entire structure. This conceptual framework starts at the pre-design stage and is carried throughout design and construction to building completion and operation.

The integrated approach can be illustrated in passive solar design strategies that combine siting, architectural, mechanical, and electrical features in a systemic way that results in improved building function and increased occupant satisfaction. Incorporating increased daylighting into a building design, for instance, will affect many other factors in the buildings. This strategy, which takes into account the buildings orientation, as well as covering choices and location, will permit reduction of artificial lighting. This reduction in electricity use and internal heat loads will allow the downsizing of air-conditioned systems. As a result, overall energy usage and energy costs in buildings are reduced.

A team approach to design and construction is another important aspect of sustainable construction, that is established during the pre-design phase. This approach assures the development and implementation of an integrated building design. For this approach to be successful, all parties on the design team must commit to the sustainable goals of the project not working in isolation to their own areas of expertise, but in a multidisciplinary approach in which the interrelated impacts of design, systems, and materials are recognized.

Environmental design guidelines, also an important component of green building development, direct the activities of the design team from the pre-design stage through all subsequent stages of the project. The green building issues to be taken into consideration when developing project guidelines are resource conservation and recycling, energy efficiency and renewable energy, direct and indirect environmental impact, indoor environmental quality, and community issues.

Design: Vanguardist design strategies from the recent past, have become prominent and economically feasible since sustainable construction started to emerge. These strategies include passive solar design, indoor environmental quality, and environmentally sensitive design.

Passive solar design refers to basic issues like daylighting, building envelope, and renewal energy. Meanwhile indoor environmental quality deals with heating, ventilating, and air-conditioning (HVAC) systems; which must be integrated to passive design in an efficient and appropriate manner; also includes air quality and acoustic.

Environmentally sensitive design takes into account decision process and criteria for selecting environmentally sound materials and products for construction and the means to incorporate environmental components into construction specifications.

The integrated approach to include such strategies is to build in a systematic way, with the building siting, form, envelope, systems and contents simultaneously interacting together and fitting their setting in nature. The resulting building will perform as a resource-efficient and cost-effective system designed to enhance occupants' productivity and health. A whole team commencing early in the design process is necessary to achieve this. In this academic work it will not be possible to develop the concepts quoted above, since they are not a specific part of the objectives set out in Chapter I.

Construction: The construction process can have a significant impact on the resources of the site and surroundings. Environmentally conscious construction practices can reduce those disturbances, and also can reduce the quantity of solid waste to send to landfills and the use of natural resources during construction.

It can also minimize the prospect of adverse indoor air quality in the finished building. In addition to yielding environmental benefits, all of the actions mentioned can lower project costs.

Frequently construction clears and disturbs the existing natural resources on site, such as the native vegetation and wildlife, natural drainage systems, and other natural features. These resources are replaced with artificial systems such as non-native vegetation and artificial drainage.

Waste generated from construction and demolition accounts for more than 50 per cent of total municipal solid waste generated in Europe (ROODMAN, 1995). Emissions from new construction materials as well as dust, particulates, and other airborne contaminants generated during the construction process are suspected of causing health problems. Furthermore, almost all constructions of today require new virgin materials, adding to the depletion of limited natural raw materials if those materials are not renewable.

When approaching construction to sustainable perspective, builders have to ensure that the construction contract and specifications address the design and construction team´s environmental requirements for the construction process. Many of these issues and practices are typically under the direct control of the construction contractor, who was most likely selected by competitive bidding.

The goal of the contractor is to fulfill the construction in accordance with the construction contract, construction drawings and specifications, project schedule, and project budget. And so, he will try to build the project for the lowest cost within the shortest time, and the highest profit. For this reason, the contractor is not likely to implement sustainable practices unless they involve no additional costs, have been required contractually, or are economically beneficial to him.

That is why it is important that the teamwork should develop guidelines and get agreement with the contractor in order to ensure that the contractor understands and agrees to the sustainable construction required.

Maintenance: Codes and professional standards for building design and construction exist to ensure quality buildings. But they alone are not sufficient, because even a properly designed and constructed building will not provide a cost-effective, healthy environment unless it is properly operated and maintained.

Building operations and maintenance (O&M) impact the internal and external building environment. These activities play several important roles: they should maintain proper building temperature and humidity, promote the ventilation, dilution and removal of airborne contaminants. They can also ensure the safety and cleanliness of building systems so that they do not generate pollutants and hazards.

The implementation of professional standards for a quality building environment usually ends upon completion of building construction. Sound building O&M is not assured by codes or regulatory authority, that is why practices for quality indoor environment while conserving resources during buildings operational phase must be promoted.

Deconstruction: according with the conservation principle, deconstruction aims to maintain the value for materials in existing buildings by dismantling the building components in a way that allows the re-use and recycling of the materials and products that comprise the building.

That inverse building process has the advantage of potential re-utilization and recycling building components, enhance environmental protection on raw material sources, and saving raw materials.

But to take this advantages the building has to be designed and constructed for dismantling and disassembling, and more research is needed in order to determine the environmental and economic benefits as well as to create tools for deconstruction.

5. BUILDING ENVIRONMENTAL IMPACTS

As was already discussed, buildings of today impact significantly on the environment. The adverse impacts come from both building construction and renovation. For instance, raw materials extraction can lead to resource depletion and biological diversity losses. Building product manufacture and transport consume energy, generating emissions that lead to global warming and acid rain; landfill problems may arise from construction solid waste; poor indoor air quality may lower worker productivity and adversely affect human health.

These issues can be illustrated by means of some facts contained in Table 2 It is remarkable that 55 per cent of wood produced is for construction, 40 per cent of materials and energy is used in buildings, 30 per cent of buildings confront “sick building syndrome”, and so forth (ROODMAN, 1995). If those trends continue the buildings will be the cause of the global environment problems getting even more strain than nowadays.

As Table 2 suggests, most of the raw materials used in buildings are extracted directly from the earth by surface excavation or underground mining techniques. Many of the required materials are produced from low-grade ores, with the consequences that large quantities of ore must be excavated and, at the same time, large amounts of energy are needed to refine it. The processing of the refined ore into appropriate building products and materials requires further inputs of energy, and the process may have adverse environmental effects such as the emission of pollutants into the atmosphere and the discharge of toxic wastes into surrounding waterways.

Table 2. Some facts about building impacts.
Source: (ROODMAN, 1995).

ACTIVITY	BUILDINGS-SHARING	ENVIRONMENTAL IMPACTS
Raw Materials Extraction	40% of the world's gravel, sand and raw stone is used by buildings	Air and water pollution. Toxic effluent from mines and slag. Landscape damage
Wood Processes	55% of the wood cut for non-fuel uses is for construction	Deforestation, flooding, biological diversity losses. Obstruction from sedimentation
Energy use	Buildings consume 40% of total energy and account for 30% of CO_2 emissions	Pollution, acid rain, nuclear waste, global warming, dam construction and its associate problems
Water consumption	Buildings consume 16% of extracted fresh water	Water pollution, land salinization, competition with agriculture and ecosystems
Waste Generation	Industrialized countries produce as much construction and demolition waste as municipal garbage	Landfill problems: over capacity, leaching of heavy metals, air and water pollution
Indoor-Air - quality	30% of newly-built or refurbished buildings suffer from "sick building syndrome"	High sick incidence and disease, low worker productivity of building occupants

Thus, the materials used for construction impact on the environment in many different ways during the various stages of the building construction and related processes of the buildings. But more attention must be paid to the energy embodied in the building materials and the implications of their selection for energy efficiency. This issue is usually overlooked because their effects tend to be indirect and in many cases the impacts are remote to the building site.

In recent times environmental concerns have focused on the implications of rising concentrations of the greenhouse gases (related to global warming) in the earth's atmosphere, mainly carbon dioxide (CO_2), as a result of the increased consumption of fossil fuels. This is a trend in which the construction sector plays a significant role.

Most conventional building materials are fossil-fuel intensive in their production and this contributes directly to the rising greenhouse gases concentrations. For instance, cement, firebrick, steel, aluminium, glass and many plastics. These production processes, building materials transportation and the building occupants consume 40 per cent of total energy as was exposed in Table 2.

From this brief summary it is evident that the selection of building materials and construction processes which will cause the least environmental impacts it must be the target.

6. ENVIRONMENTAL ANALYSIS OF COMMON BUILDING MATERIALS

The aim of the case study developed in this thesis deals with the selection of building materials. The architectural design is excluded because it is beyond the scope of the thesis.

The way proposed to make that sort of sustainable selection of building material is, on the one hand, through a green product classification (see Table 3) and, on the other hand, being the designer assisted by an assessment method. Adding the results from both ways will produce an outcome of a suggested list of common building materials to be used in buildings, specifically in our case study.

Table 3. Criteria for classification of green building products and materials.

Products made from environmentally attractive materials

- Reduce material use
- Salvaged products
- Post-consumer recycled content
- Post-industrial recycled content
- Certified wood products
- Made from agricultural waste material
- Natural or minimally processed products

Alternatives to conventional products considered problematic

- Alternatives to ozone-depleting substances
- Products made from PVC and polycarbonate
- Alternatives to conventional preservative-treated wood
- Alternatives to other hazardous components

Those that reduce environmental impacts of building operation

- Heating and cooling loads
- Equipment that conserves energy
- Renewable energy and fuel cell equipment
- Fixtures and equipment that conserve water
- Exceptional durability or low requirements
- Prevent pollution or reduce waste
- Reduce or eliminate pesticide treatments

Products that contribute to a safe, healthy indoor environment

- Do not release significant pollutants into the building
- Block development and spread of indoor contaminants
- Remove indoor pollutants
- Warn occupants of health hazards in the building

- Improve light quality

Products that reduce impact during construction, renovation, or demolition.

From the directories of green building products available a list was compiled, thinking about what makes a product or material green and thinking, at the same time, of the sustainability principles set out. The finding is that all the materials have impact load, but some of them are environmentally friendly or can be used with less harm if the designer/decision-maker is well informed.

With this guide as a basis, some generic groups of building products and materials are analysed taking into account three sustainability principles: minimizing energy use, minimizing natural resource use, and creating a healthy, non-hazardous space for building occupants:

6.1. Generic groups of common building products and materials. Environmental analysis

- Rock like Products
  - Concrete

One un-sustainable building product *par excellence* is cement. Manufacturing cement for making concrete requires substantial energy, causing significant carbon dioxide emissions. Concrete is used in buildings in large quantities; so, considering alternatives is important. If the selection is based on life-cycle assessment principles other materials may be preferable.

However, concrete has only 10-15 per cent of cement (the remaining materials are gravel and sand); so, the proportion of this intensive energy consumer product is quite low in terms of the whole mass concrete. As a consequence, we can say that concrete has rather a moderate environmental impact.

Extraction of raw materials to produce concrete components has ecological implications on the surroundings of the sources. On the other hand, air pollution emissions from concrete are low, and often are confined to foundations and concealed structures where exposure to building air is minimal, although testing on radon emissions is ongoing.

Some ways to minimize natural resource use might be:

- Use fly-ash concrete, as an alternative to conventional mixes
- Use recycled aggregates for some concrete applications
- Use low-waste formwork
- Anticorrosion agents such as epoxy coating, extending the life of steel reinforcement on applications close to the sea.

- Ceramic

Ceramics, and similar materials like terrazzo, are the most durable building finishes and also have extremely low emissions. They do not absorb odours, are easily cleaned, and resist abrasion and wear. Their life-cycle cost is among the lowest of all finishes because of their long life and the minimal maintenance they require.

The energy content of ceramics is a consequence of the high temperature required for firing the clay as are made adding glaze. Energy use in manufacturing should be considered as part of life-cycle assessment.

Ceramics can be converted into aggregates to be used in concrete and also can be used as filler or foundation material. Some tiles are available with recycled content (up to 70 per cent) using scrap glass and feldspar waste from mining.

Another by-product such as fly ash can partly replace raw materials of ceramics. Glazed tile and high-fired tile usually do not require sealers (sealers containing hazardous solvents contribute to indoor air pollution). If a porous tile is chosen, the safest sealers are the low-volatility, acrylic or water dispersed silicone types.

- Rock

The huge quantities of stone used in construction leads to environmental problems including the process of extraction itself can damage the landscape, in other cases the ecosystem characteristics are unable to recover after extraction has ended, and the natural drainage is changed.

Another issue is related to the large quantities of energy needed for transportation. In addition, there are emissions and nuisance caused by heavy transportation (dust, noise, vibration).

The emissions from production processes are mostly limited to combustion gases and dust, since those processes are simple: crushing, riddling, mixing, pressing, drying and baking.

Stone and related products last the whole life span of buildings. So, when they are demolished they cause a lot of solid waste which are for the greater part harmless because they are inert, but problems arise regarding the use of space on landfills.

Recycling this class of materials provides a saving of raw materials and reduction of solid waste.

- Metals

In addition to depletion of reserves of some metals, the impacts resulting from metal production are related to the large amount of mineral rock that needs to be extracted when ores are mined. The surroundings of the mining area are seriously damaged and also by changes in the groundwater level and the emission of harmful substances.

Furthermore, environmental effects result from the energy required for production, and of the emission of harmful substances during treatment. When metals are exposed to flowing water, metals ions can leak into the foil and water, harming a number of organisms and polluting water reservoirs.

- Steel

Steel is the most common metal used in building products. The extraction of raw materials to produce it, iron ore and coal, cause great environmental damage, and the production of iron and steel also cause considerable pollution. The energy content per kilogram of material is rather low compared with other metals.

An advantage of steel is its high suitability for re-use and recycling and its scrap has an attractive value. Primary re-use of steel is preferred to secondary use because work with existing steel construction requires only little repair. To avoid corrosion, an alloy of nickel and chrome is frequently used; however, that can lead to harmful emissions of these heavy metals.

- Zinc

Extraction of zinc minerals involves emissions of cadmium which is a heavy metal damaging to the environment, reduction of these emissions can only be avoided by limiting the use of zinc.

When zinc is applied outdoors, its particles migrate to the soil, water stream, and groundwater from large surfaces of zinc and galvanized steel. The harm zinc causes to water organisms is currently under discussion.

The relatively quick corrosion is that zinc products which are exposed to weather influences have a short life span.

Waste from zinc production is a considerable problem because of the high content of heavy metals, currently waste is stored. Recycling zinc is possible but expensive.

Depletion of zinc reserves is expected just in a few decades.

- Aluminium

After steel, aluminium is the second most common metal, and is the most recyclable material in building.

The environmental impacts of this metal occur during metal extraction and mainly during conversion of the Bauxite (raw material) into semi-manufactured material, that process requires a large quantity of electricity. The pollution from secondary aluminium is much less than from primary aluminium, while the quality is equal. The degree of recycling decreases the release of harmful substances incorporated in raw material surface treatment.

There are other common metals in construction, such as lead and copper.

Lead is a heavy metal, in extremely limited supply.

Copper is highly recycled and the life span of copper products is very long. But unfortunately the use of copper outdoors is pollutant, its particles can go into the soil and water and kill organisms.

- Plastics and other synthetics

Plastic and most synthetic products are made from non-renewable petroleum or natural feedstocks. The amount of oil petroleum is enormous, although only 4 per cent of the consumption is used for production of synthetics.

Disasters during extraction and transportation of petroleum occur, causing harm to the ecology. Oil field surroundings are frequently damaged.

The process to obtain semi-manufactured products (ethylene, propylene, benzene and styrene) used in the manufacture of synthetics, causes the emission of organic hydrocarbons and requires a considerable quantity of energy.

However, plastic and in general synthetic products involve minor problems during the construction and use phase. In fact, problems occur after demolition, synthetics are rarely degradable and additives such as heavy metals may leak out; in addition incineration of some synthetic waste can also result in environmentally harmful emissions.

- Polyvinyl Chloride (PVC)

The main raw materials for PVC are petroleum and salt. Chloride is extracted from salt by means of electrolysis which is a cause of environmental impact because it releases mercury and asbestos. The extraction of PVC from ethylene and chloride also releases mutagenic materials which may cause continuous harmful emissions; furthermore, high-quality PVC requires many additives.

Because PVC contains chloride, its incineration results in harmful emissions, including dioxins. Recycling PVC is not attractive from a quality point of view of quality, so primary raw material is needed.

Dumped PVC is less degradable and may produce emissions of harmful additives, such as heavy metals.

- Polyurethane (PUR)

Similar to other synthetics the pollution caused by PUR results in the extraction of petroleum and production of semi-manufactured. Polyurethane is obtained by the process of polymerization of polyol and isocyanate, this last is extremely harmful to human health. The foamed characteristic is achieved using chlorofluorocarbons (CFCs) which affect the ozone layer. PUR also has adverse impacts during waste disposal, and is not easily recycled.

- Bitumen

The blowing process, of this product obtained from specific petroleum types, releases a large molecular compound of hydrocarbon and vapour. Sometimes bitumen is incorrectly compared with tar, but tar is obtained from coal or petroleum particles which cause pollution and has carcinogenic components, both products (bitumen and tar) are used for roof covering.

Bitumen can be re-used easily, but not recycled because of pollution of the material.

There are some other petrochemical products commonly used in construction such as polyethylene, polypropylene, polymers, expanded polystyrene, etc. All of them have the same characteristics related to the petroleum depletion, although some of them, the so-called thermoplastics, can be recycled successfully.

- Wood

The main renewable raw material used in construction is wood. The relatively simple process of obtaining usable products from trees makes wood a clean material with little energy contained (embodied energy).

An important issue related to wood is that appropriate forest management is vital to ensure more sustainable wood source. In many cases (rates of extraction can not exceed rates of planting), the following environmental aspects should be taken into account when selecting wood: forestry management, the need for preservatives and transport distances.

It is important to be well informed when selecting wood. Tropical wood needs to be transported large distances and wood from non-tropical countries can lead to exhaustion and deterioration of ecosystems. The key seems to be the plantations or forests with sustainable management, although this can be difficult.

Low-grade fiber, small-diameter trees, and fast growing can be used in engineered wood products. Structural shathing made from presses post-consumer is appropriate to use since it is a recycled material and adds substantial insulating value and acoustic absorption to the wall or roof.

Indoor-air-pollution emissions from glues in some wood products are substantial, those made with exterior-type glues and urethane adhesives have some of the lowest emissions.

One of the most used wood species in construction is pine.

- Paints

This finished building product is an important indoor air pollution and toxic waste. The volatile emission from paints decrease to a small fraction of the wet emission in a few days or a week.

Some of the most toxic emissions from paints are from evaporating solvents and a wide variety of volatiles released by oxidation.

An important environmental aspect of paints are organic hydrocarbons, they harm the health of painters and occupants of buildings.

- Acrylic Paints

This type of paint has acrylic resin as a bonding agent, and use water as the main solvent. Acrylic paints contain many harmful substances, such as biocides, anti-corrosion agents and emulsifiers.

- Natural Paints

The raw materials of natural paints are mostly of vegetable or animal origin, this is in contrast to other kinds of paints with petroleum products as raw materials. That is why waste from natural paints is generally degradable.

There are other types of paints and sealants on the market, but a common aspect for most of them is the organic hydrocarbon components which are harmful for human health.

The first priority when selecting paints is to avoid paints containing lead, mercury, hexavalent chromium and cadmium.

The final comment in this analysis about the generic group of common building products and materials is that, of course, it is not exhaustive. A summary ranking for environmental impacts is shown on Table 4.

In addition to environmental and economic factors, is important that the signer be aware about the social issues, in particular case employment creation during the extraction of raw materials and manufacturing the building products. This is remarkable when dealing with developing countries, as stated in Agenda 21, Chapter 7 (UNCED, 1992).

Table 4. Ranking for Environmental Impacts of common building products and materials.

Products and materials	Environmental Impacts						
	Energy consumption	Solid Waste	Pollution	Heavy Metals Emission	Global Warming	Ozone Layer Depletion	Acidification
Rock-like products.							
Cement	3	1	3	2	3	1	2
Concrete	2	3	1	1	2	1	1
Ceramic	1	1	1	1	1	1	1
Rock	1	1	1	1	1	1	1
Metals.							
Steel	2	3	3	2	2	1	2
Zinc	2	3	2	2	3	1	2
Aluminium	3	3	2	2	3	1	3
Plastics.							
PVC	2	2	3	2	2	1	2
Polyurethane	3	2	3	3	2	3	3
Bitumen	3	2	3	2	3	2	2
Wood.							
Pine	1	2	1	1	1	1	1
Paints.							
Acrylic	2	1	2	2	2	2	2
Natural	1	1	1	1	1	1	1

Environmental Impact Weight:		
	1	Low
	2	Medium/Moderate
	3	High

FOURTH PART

TOWARD SUSTAINABILTY MEASURING

SYNOPSIS OF CHAPTERS X AND XI

EXPERIMENTAL VERIFICATION OF SUSTAINABLE SELECTION OF BUILDING MATERIALS-A CASE STUDY

1. Available Assessment Methods
2. Choosing the Appropriate Assessment Method to be Applied in a Case Study
3. Summary Description of BEES, The Chosen Method

Although sustainability is not a thing to be simply measured, in the fourth part is attempted an exercise to gauge main regional and project scales components.

Taking into account sustainability criteria in Agenda 21, a case study is developed, for which aim a real region and a building project are addressed in three chapters. First, a north-western Mexican region was selected (chapter X), sustainability indicators for regional construction sector was developed (chapter XI), and then, an assessment method was chosen and applied in order to show the sustainable selection of building products and materials (chapter XII).

The most important measurable demonstration is the assessment method application, which is entitled Building for Environmental and Economic Sustainability (BEES). The related applying process is now exposed.

1. AVAILABLE ASSESSMENT METHODS

The adaptation of existing impact assessment methods to their new role as sustainability assessment tool is currently leading to the search for so called sustainability assessment methods, although honestly speaking most of those methods are environmental assessment methods, and those that approach sustainability principles can be named quasi-sustainable as such.

There is a recent effort to identify the quantity and type of this kind of tool that exists nowadays, which includes a survey carried out for the International Council for Research and Innovation on Building and Construction (CIB), on whose outcome the choice of a method to assist the selection for building products and materials is based.

Approximately 70 people were contacted to participate in the reporting of assessment methods in the Autumn of 1998 and the Winter of 1998/9 (CIB W-100,1999). From them, only nine assessment methods were reported. Table 5 shows a comparison among the main features of these methods.

This list of methods is not comprehensive, although the small quantity of responses shows the range of methods available.

The majority of these methods include office assessment or are developed/adapted from an office base, also most of them include global and regional issues and use both quantitative and qualitative data for assessment.

Almost all of these methods have been developed for Northern European Countries' environments. So, that characteristic above implies the restriction that they may be used only in such countries.

One of the most consolidated assessments is BREEAM (The Building Research Establishment Environmental Assessment Method), which was launched in 1990. It sought to provide guidance on ways of minimizing the adverse effects of building on the global and local environments while promoting a healthy and comfortable indoor environment.

However, this environmental assessment method was developed thinking of the British environment, where it has been widely accepted. It is a commercial method; so, to get it on commissioning or to obtain an assessment license, substantial payment must be made.

Table 5. Comparison of Impact Assessment Buildings Methods
Source: (CIB W-100, 1999)

NAME	OBJECTIVE	ORIGIN COUNTRY	COMMENTS
ATHENA	To reduce the building's life-cycle environmental impact	Canada	The tool is limited to steel, wood and concrete sub and superstructures
BEARS (Building Environmental Assessment and Rating System)	Focus on commercial office space with reference to global, local and indoor issues	South Africa	It is the primary tool within the green building for Africa Programme
BEES (Building for Environmental and Economic Sustainability)	To select environmentally and economically balanced building products	United States	It assesses six environmental impacts. The scope is for building elements and in the future will cover components or collections of elements
BREEAM (Building Research Establishment Environmental Assessment Method)	Review and improve environmental performance throughout the life of buildings	England	There are various versions available. The criteria used is both quantitative and qualitative
ECOPROFILE	Its main focus is on energy flexibility and use of hazardous materials	Norway	It covers issues as emissions to air, water and soil, waste handling and transport and other outdoor issues
ECO PROP	Environmental quality during design, construction or at delivery	Finland	Is a requirement management system consisting of various assessment methods
ECO-QUANTUM	Calculates the environmental of building during the entire life-cycle	Netherlands	There are versions domestic and versions research
GREEN BUILDING CHALLENGE 98	Assesses the environmental quality of building during design or after completion	Canada	The systems development is ongoing in terms of criteria and structure
PIMNAQ	Assess the environment quality of building and sites	Finland	Is only appropriate for residential buildings

Another appropriate method is BEES (Building for Environmental and Economic Sustainability), which includes both environmental and economic variables, what is to say, two of the three main pillars of sustainability, and is adaptable for different (some) United States of America regions. This is a young method that has great researching work behind it, and currently no payment is required to use it.

2. CHOOSING THE APPROPRIATE ASSESSMENT METHOD TO BE APPLIED IN CASE STUDY

Since building assessment is currently voluntary in nature, there is enough flexibility to choose any available/suitable method. Regarding this assumption, on the method selection to fulfill the aim of this dissertation two main aspects were taken into consideration.

One aspect is concerned with Agenda 21 Statements (Chapters 34, 37 and 40), related to the international community to be solidarity with developing countries on issues such as available technology, information, and expertise and general cooperation to pursue sustainable development. This suggested setting the case study in a non-industrialized country.

The other aspect is with respect to the author's origin, which implies a moral commitment to support my own country through a sustainable example to be addressed on this academic work.

As a result, a region of the northwest of Mexico was selected for a case study. Figure illustrates the area in question. Since the Building for Environmental and Economic Sustainability method addresses the bordering southwest USA region, extrapolation of the method to the northwestern Mexican environment is assumed.

The BEES method has advantages over other methods, since it breaks down application by regions, one of those regions is Arizona, USA, which in addition to the similar environment quoted above, has economic relationships with the Mexican border construction sector.

3. SUMMARY DESCRIPTION OF BEES, THE CHOSEN METHOD

BEES measures the environmental performance of building products using the life-cycle assessment (LCA) approach specified in ISO 14000 standards. The methodology takes a multi-dimensional environmental and economic impacts over the entire life of the building products.

This approach supposes that all stages in the life of products generate environmental impacts. Those stages include raw material acquisition, manufacture, transportation, installation, use, and waste management. The economic performance is measured using life-cycle cost (LCC) method, that includes the costs over a given study period of initial investment, replacement, operation, maintenance and repair, and disposal. Both sustainability pillars, economic performance and environmental performance are combined into an overall performance measure using analytic hierarchy process (AHP), which is a tool of multi-attribute decision analysis (SAATY, 1996; EXPERT CHOICE, 2000).

Although environmental performance cannot be measured on a monetary scale, it can be quantified through the evolving multidisciplinary LCA, which is used in the model of BEES.

A number of support tools for sustainable construction and for the BEES method are included in chapter V of the thesis. A summary of those tools is included in second part of this English synthesis.

Environmental performance. The goal of LCA is to generate relative environmental scores for building products alternatives based on USA average data. These will be combined with relative average economic scores to provide support for selecting environmentally and economically balanced building products.

Transport of raw materials is taken into account, also energy requirements for production, USA geographic areas, and technology (when possible).

Inventory analysis includes inputs of water energy, and raw materials; and also release to air, land and water.

The impact assessment of the model supposes six impacts: global warming, acidification, nutrification, natural resource depletion, indoor air quality and solid waste. Table 6 shows the links between these environmental impacts and the sustainability principles set out in the third part of this synthesis.

Table 6. Links between sustainability principles and BEES environmental Impacts

SUSTAINABILITY PRINCIPLES	**BEES ENVIRONMENTAL IMPACTS**
Rationalize use of energy	Global Warming
Maximize resources use and minimize resources consumption	Global Warming Natural Resource Depletion Solid Waste
Use renewable or/and recyclable resources	Natural Resource Depletion Solid Waste
Protect the natural environment (air, soil, water) when building	Natural Resource Depletion Acidification Nutrification
Create healthy, non-toxic environment	Indoor Air Quality

AHP combines these impact category performance measures through weighting each impact by its relative importance to environmental performance, to be set out by the user or designer (the thesis author in this case).

Economic Performance. According with BEES developers, the most appropriate method for measuring the economic performance of building products is life-cycle cost (LCC). Economic performance is evaluated beginning at product purchase and installation, for a time of a 50-year study period.

The LCC method accounts for the time value of money by using a discount rate to convert future costs to their equivalent present value. The computational algorithm used for the discounting technique is as follows:

$$LCC_j = \sum_{t=0}^{n} \frac{C_t}{(1+d)^t}$$

LCC_j	=	Total life-cycle cost in present value dollars,
C_t	=	Sum of all relevant costs,
n	=	Number of years in the study period,
d	=	Discount rate used to adjust cash flow to present value.

Overall Performance. BEES overall performance scores combines the environmental and economic results into a single score. The environmental performance score reflects relative environmental performance or how much better or worse products perform with respect to one another. The economic performance score, reflects absolute performance, regardless of the set of alternatives under analysis.

The two performance scores are combined into a relative overall score by weigthing environmental and economic performance by their relative importance values. Figure 2 illustrates the environmental and economic performance results from the BEES overall performance score.

The author of the thesis set the impact weights, the BEES developer suggested the discount rate for American dollars (2.9 per cent), and equal weights for environmental and economic performance are used (50 per cent).

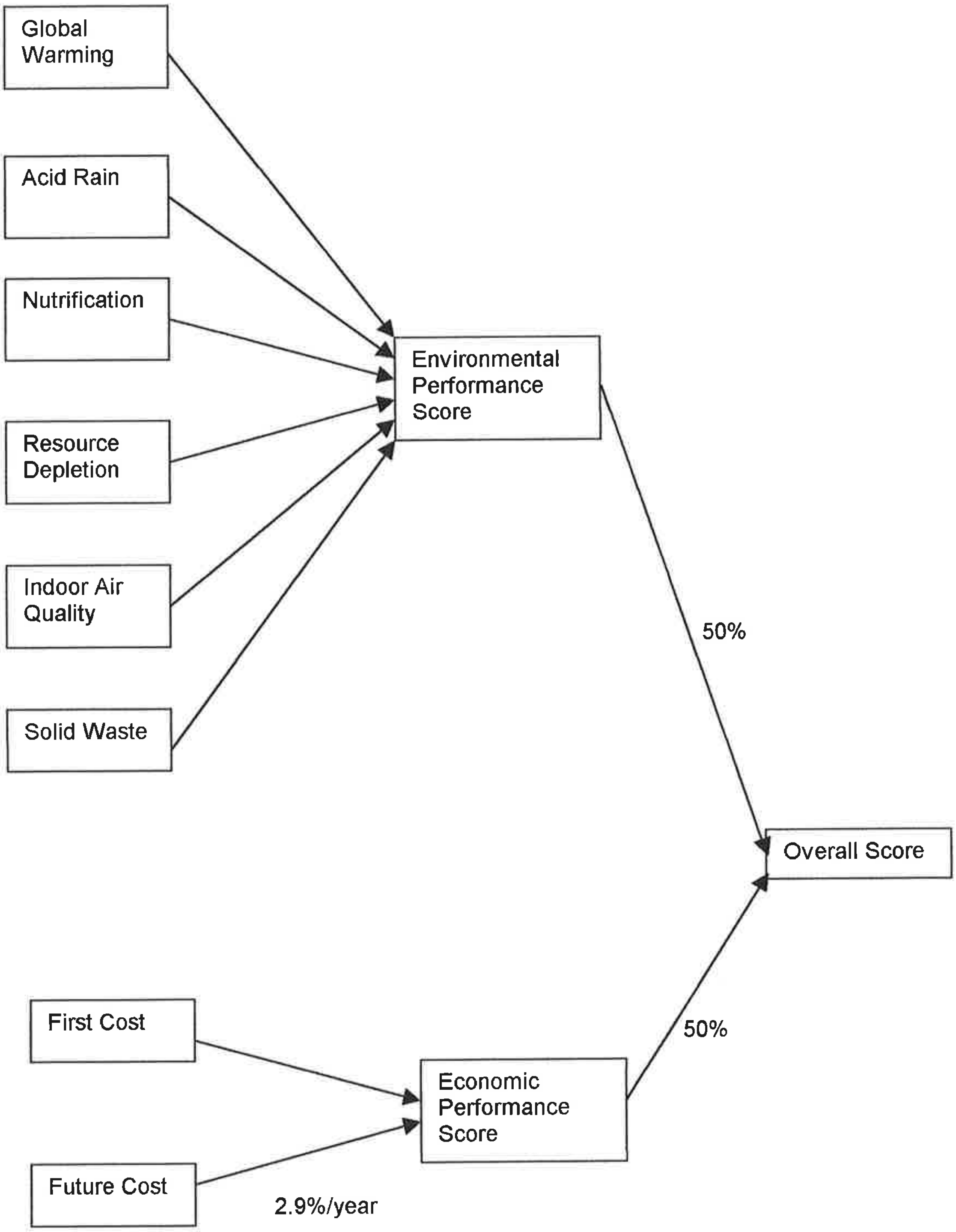


Figure 2. The BEES Overall Performance Score

SYNOPSIS OF CHAPTER XII

APPLYING THE BEES METHOD IN SELECTING BUILDING PRODUCTS AND MATERIALS– CASE STUDY

1. Introduction
2. Setting up the Study Parameters
3. Defining the Alternative Building Products and Materials
4. Viewing the BEES Results
5. The sustainable building products and materials selected

1. INTRODUCTION

In chapter XII of the thesis a sample to be assessed is introduced, using it as a reference to demonstrate the BEES results.

The building selected to apply the BEES method is the typical house of an urban upper middle class in the north west of Mexico. That region (see figure3) is environmentally and economically linked to the Arizona State (USA) which BEES includes in its simulation process.

It should be noted that the standard house, although typical of houses in northwestern of Mexico, may not be typical of those in the rest of that country or in another country. And also, it serves only as a generic illustration to the application for the assessment method we are dealing with.

A brief specification for the 260 m^2 house is summarized as follow:

Three bedroom house, level site, foundation concrete walls in expansive clay, flat ceiling, 2.50 m average high, optional air-conditioning and heating, additional front parking area, and subject to the regional construction standard rules.

Once the BEES software is installed into the computer, to balance the environmental and economic performance of building products and materials, three main steps must be followed:

- Set study parameters
- Define the alternative building products and materials
- View the BEES results

These steps and related explanations will now be considered in turn.

2. SETTING UP THE STUDY PARAMETERS

Setting the study parameters to customize key assumption, is made from the BEES main menu (select analysis/set parameters). A window listing these parameters appears and the first set of parameters have to be weighed for environmental versus economic performance, their values must be between 0 and 100 and these values must sum 100.

In this case equal values for both sustainability components were set out, that is:

Environmental performance weight	=	50 per cent
Economic performance weight	=	50 per cent

Next, the user is asked to select his/her relative preference weight for the six environmental impact categories included in the BEES environmental performance score.

The user is presented with four sets of alternative weights: (1) He/she may choose to define their own set of weights, or select the built-in weight sets derived from and (2) USA-EPA Scientific Advisory Board Study, (3) a Harvard University Study, or (4) a set of equal eights.

For this case study option (1) was selected, user-defined, which implies to enter weights for all six impacts quoted above, as show by the following:

Global Warming Potential	19 per cent
Acidification Potential	15
Nutrification Potential	16
Natural Resources Depletion	18
Indoor-Air-Quality	17

Solid Waste	15
SUM	100 per cent

3. DEFINING THE ALTERNATIVE BUILDING PRODUCTS AND MATERIALS

BEES results may be computed after alternatives are defined. So, the next step is to define alternative building products to compare them for the building elements organized by means of analytic hierarchy process, then compute and display BEES environmental and economic performance scores and, as a result, we can know the environmental-economic balance for each of the building products we consider.

As it can be seen, the environmental performance results displays the weighted environmental impact category scores and their sum, the environmental performance score. On this graph, if an alternative performs worst with respect to all six environmental impact categories, it receives a score of 100, the worst score.

For all BEES graphs, the larger the value, the worse the performance. Also, the values displayed across the back row are the sum of the values in the proceeding rows.

4. APPLYING THE METHOD BEES

BEES VIEWING RESULTS

4.1. Building siteworks

4.1.1. Site improvements

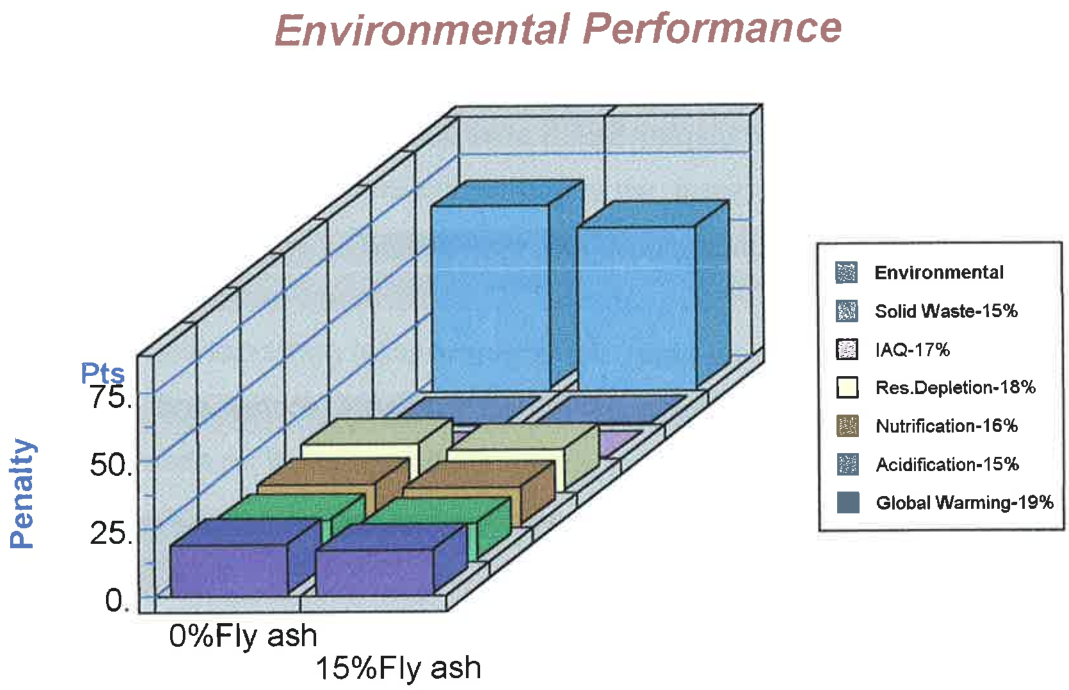
Driveways and pavements (sideways)

Selecting building products alternatives:

- 0% fly ash content concrete
- 15% fly ash content concrete

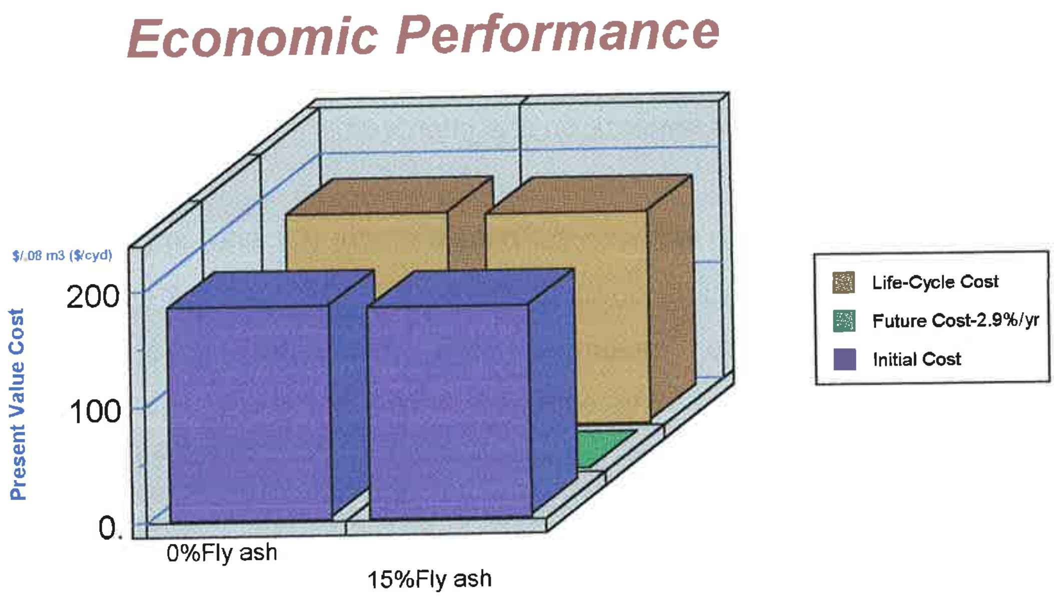
• Compressive strength for concrete driveways and pavement: 3 000 psi

• Assumed distance for transportation from manufacturing plant to site: 300 mi

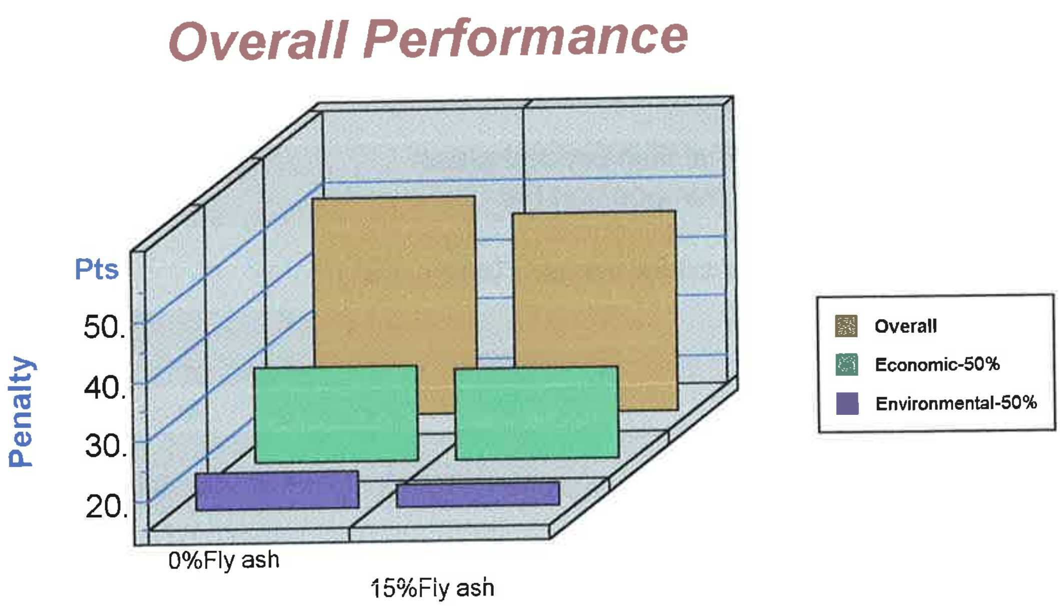


Since the larger the value, the worse the performance, the best environmental performance is 15% ash fly content concrete.

20% fly ash content concrete is available also, but being cautious it was decided since care must be take with the use of some by-products like this one as bonding agent substitutes (ANNINK, 1996).



From an economic point of view also, 15% fly ash content concrete is the better alternative (roughly 1% of price difference). Although future costs are similar.



Logically the best overall performance is for 15% fly ash content concrete, so this building product is selected for driveways and pavements on site improvements.

In addition to these building element (for site) improments, BEES analyses other building elements made of concrete, such as beams, columns, basement walls, and slabs. The outputs computed for all of these elements were that the best alternative is 15% fly ash content concrete. The only difference is the compressive strenghth wich is 5 000 psi for all the building elements but for fundations slabs, which is 4 000 psi.

As a consecuence, the graphic results for these elements are not displayed in this appendix.

4.2.Interiors

4.2.1. Interior finishes

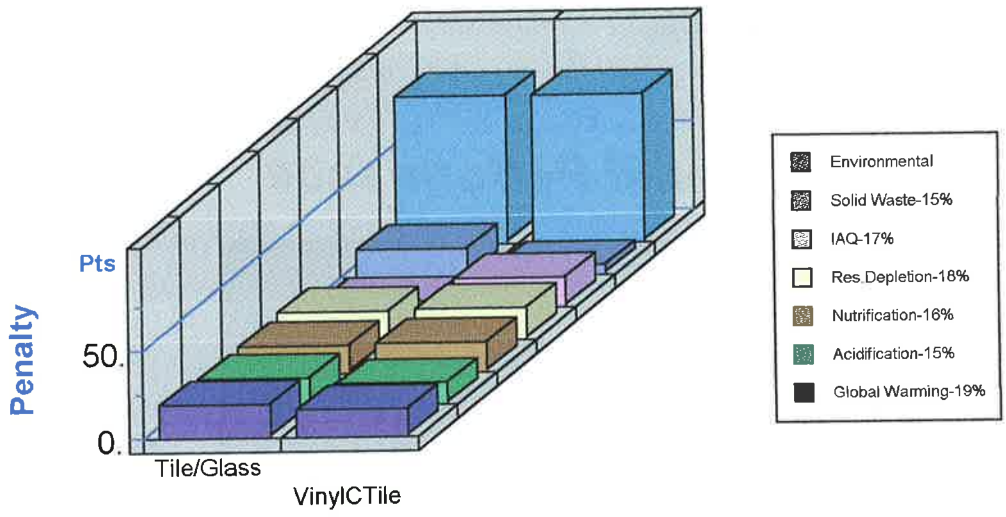
Floor covering

Selectin building products:

- Ceramic tile/recycled glass
- Vinyl composition tile.

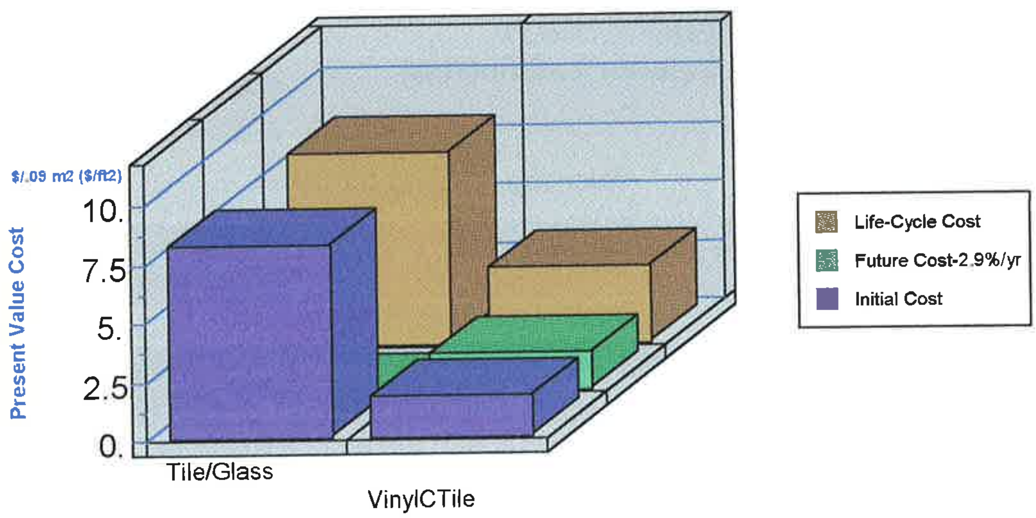
• Distance for transportation: 500 mi.

Environmental Performance

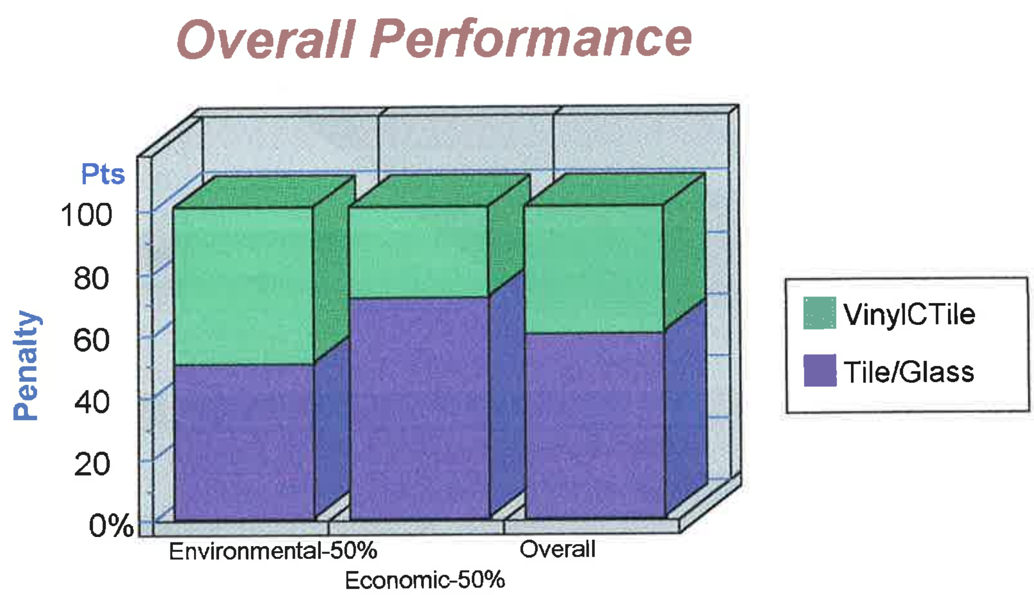


Both products have practically the same environmental performance, although there are differences between some impacts, for instance solid waste(vinyl produces is better) and IAQ (vinyl is worse).

Economic Performance



Vinyl fairly cheap at initial cost and life-cycle cost, except on future cost because of replacement



The product to be selected is vinyl composition tile because overall performance is better.

4.3. Shell

4.3.1. Exterior closure

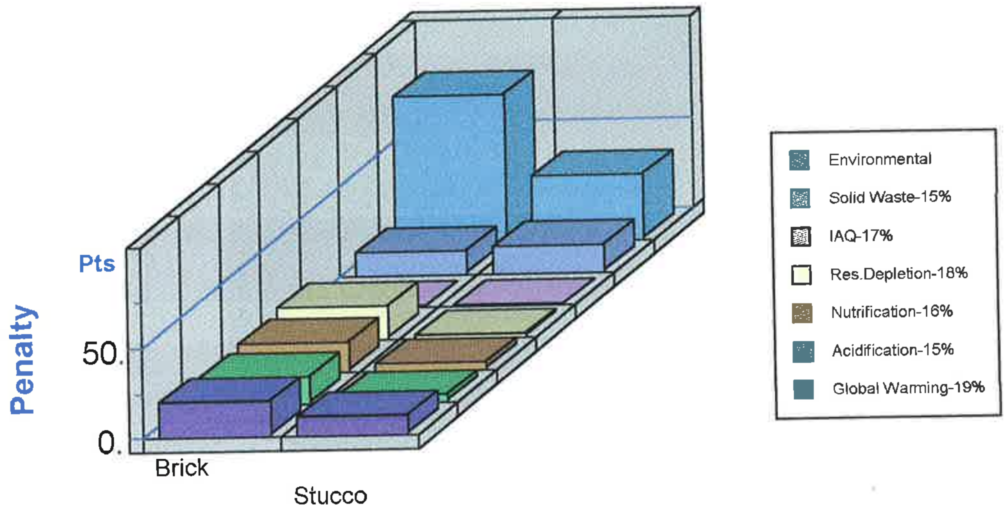
Exterior wall finishes

Selecting building products:

- Brick and mortar
- Stucco

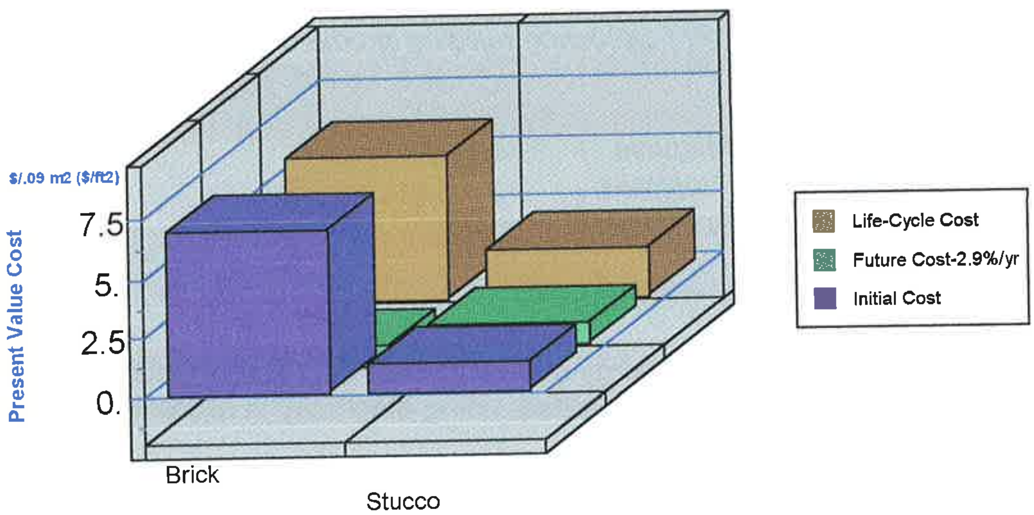
• Distance for transportation 100 mi.

Environmental Performance

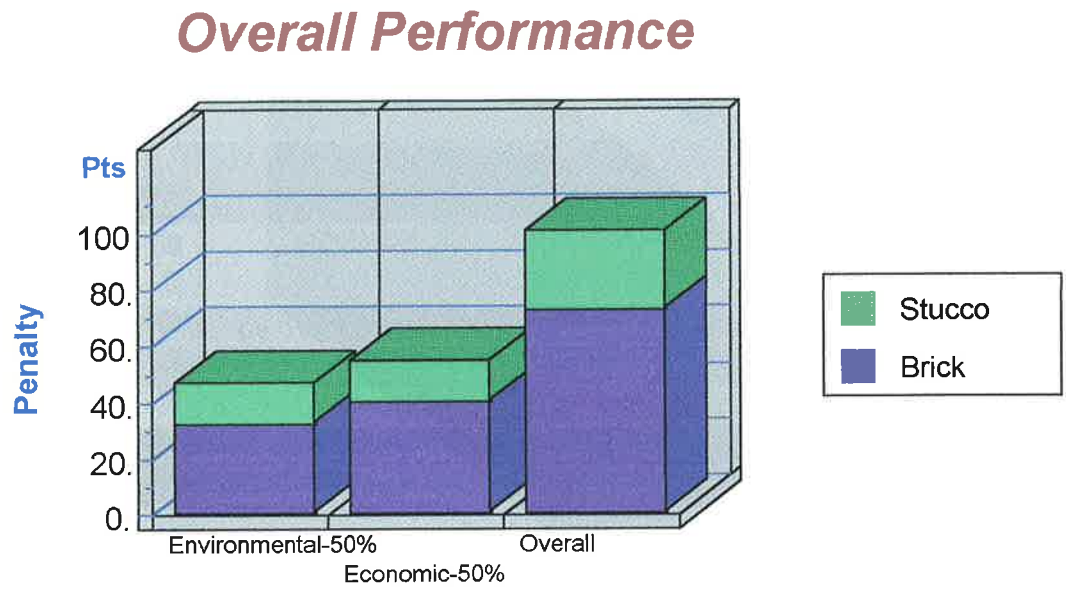


Stucco is better for all the environmental impacts because we are confronting it with fired (industrialized) brick which has important embodied energy. Using craft brick the environmental performance would be better.

Economic Performance



Stucco is far cheaper than fired brick.



According with this conclusive result, the exterior wall finish will be stucco.

4.3.Shell

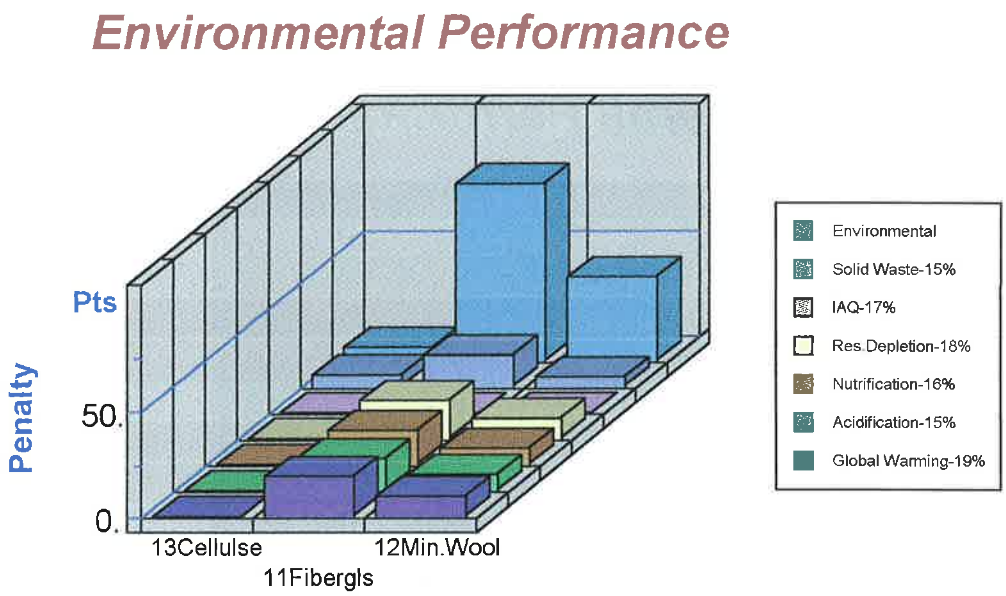
4.3.1 Exterior closure
Wall insulation

Selecting building products:

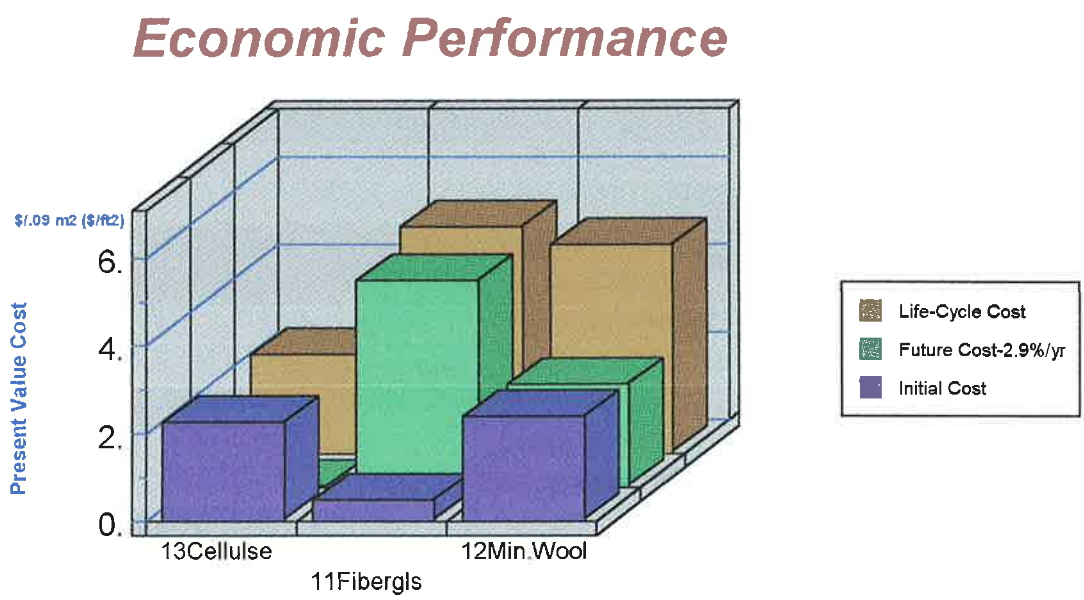
- R-13 Cellulose
- R-11 Fiberglass
- R-12 Mineral wool

• Distance for transporting: 300 mi.

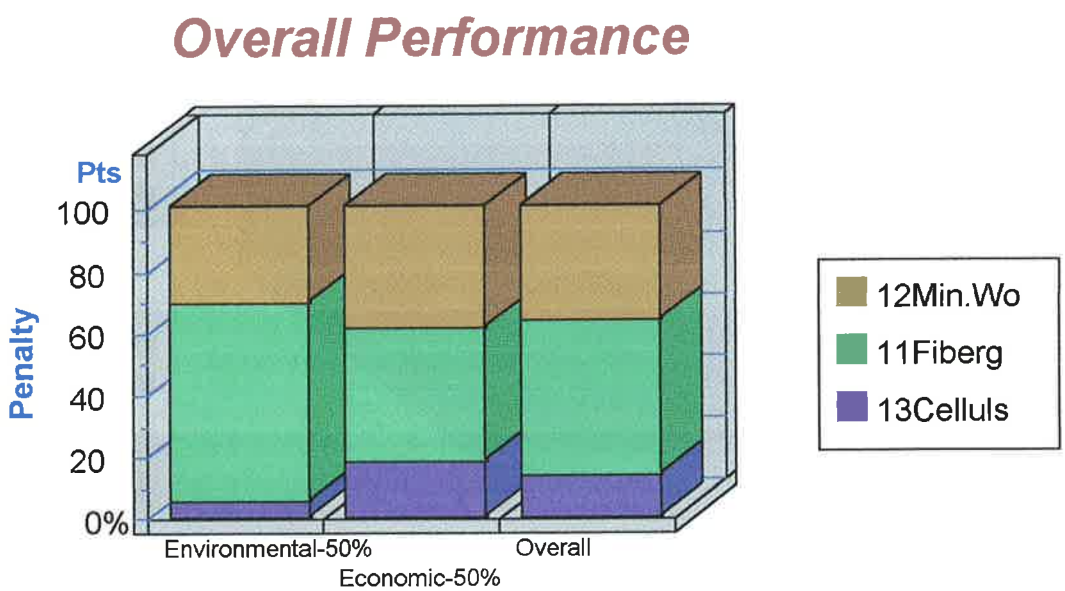
Nota: use phase energy consumption parameter: insulation will be instaled in a building heated using electricity in alocation closest to Phoenix Arizona, USA.



Form the three products, cellulose is the most attractive environmentally speaking.



The initial cost of fiberglass is the best, since general economic performance (life-cycle cost) cellulose is cheaper than the other products.



Previous the environmental-economic balance for cellulose (constitued by pulp waste newspapers) confirmed to be the elective option.

4.3.Shell

4.3.1 Exterior closure

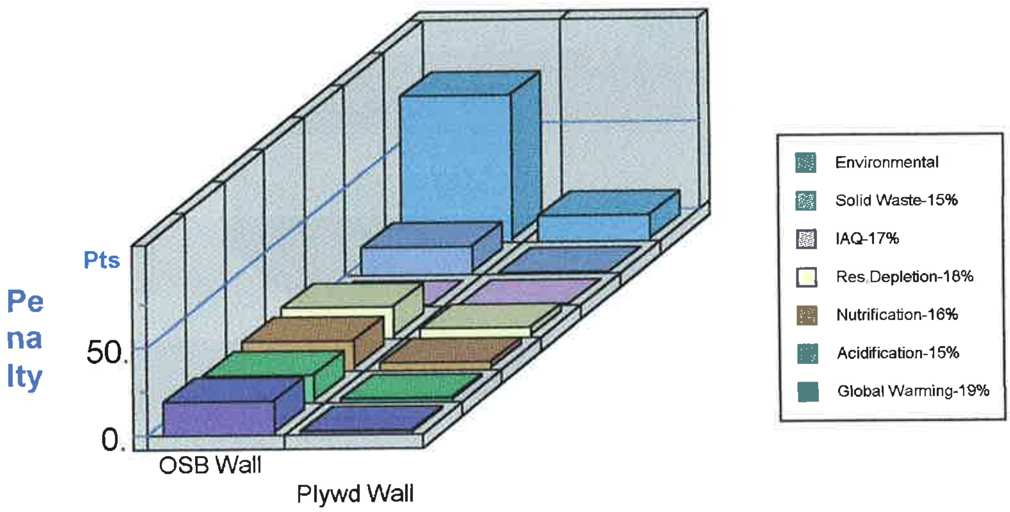
Wall sheating

Selecting building products

- Oriented strad board sheating
- Plywood sheating

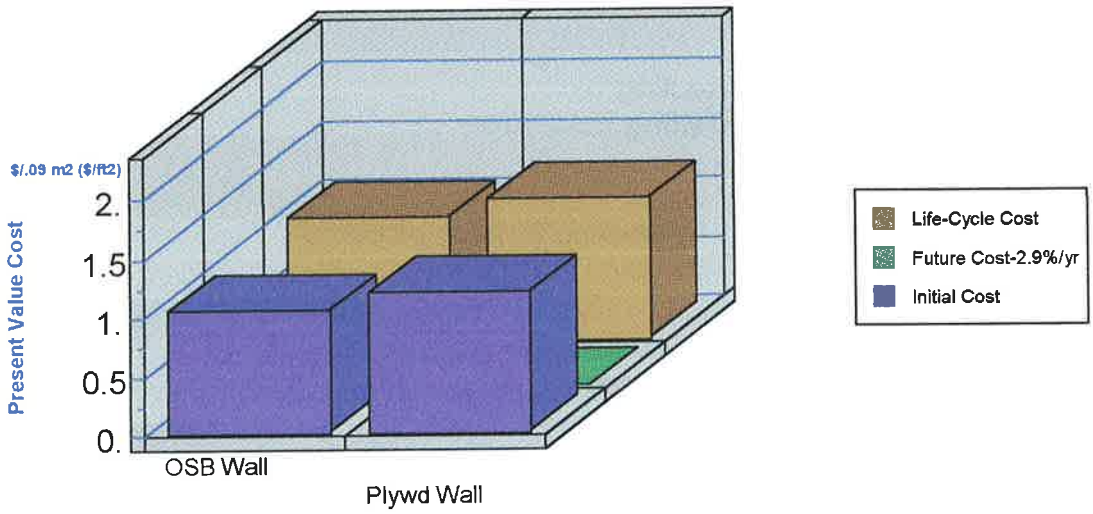
• Distance for transporting: 100 mi.

Environmental Performance

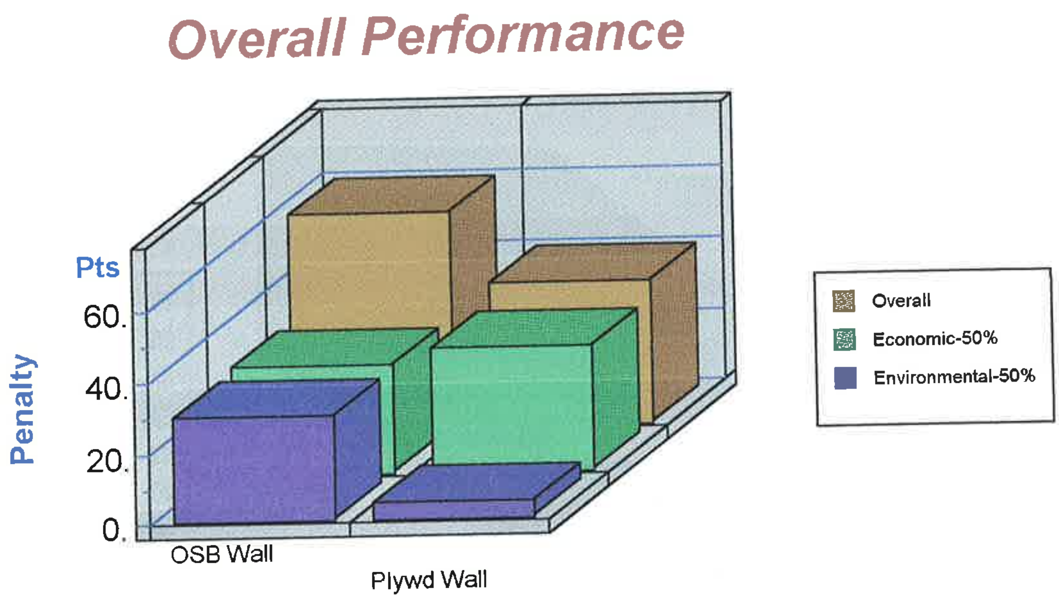


Without discussion, plywood sheating is the best alternative to sheating the exterior walls.

Economic Performance



Playwood transported from 500 mi.is 3.4% more expensive than oriented stread board. This time we can shoose a local building product (fibercell sheet) wich is 40% cheaper than plywood and has similar raw materials and performance.



Plywood results to be the most appropriate product, but when related to the initial cost, local fibercell sheet will be selected. Since roof sheathing (superstructure) requires similar material, fibercell sheets will be used.

4.3. Shell

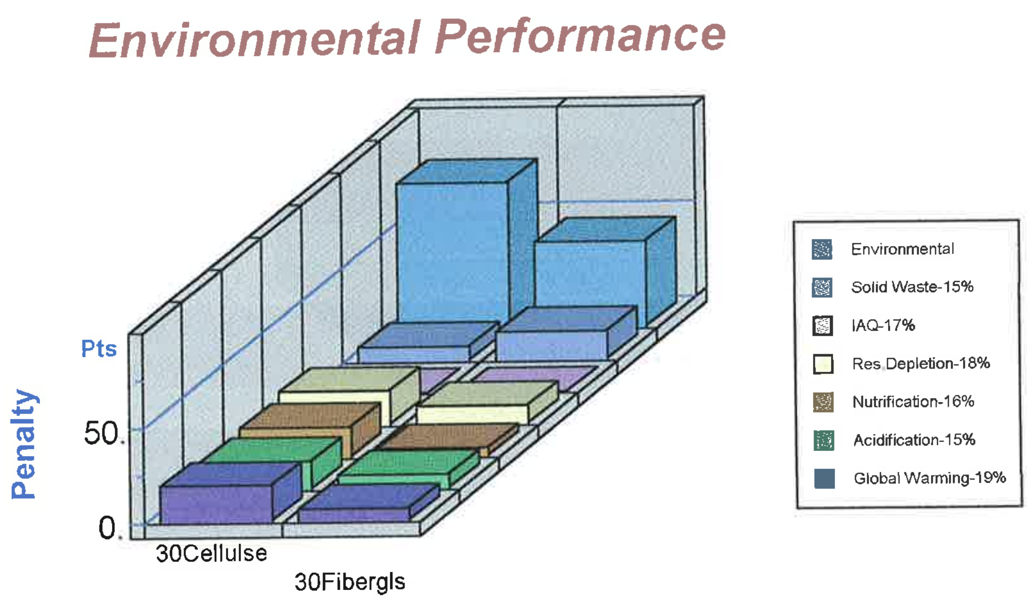
4.3.4. Roofing

Ceiling insulation

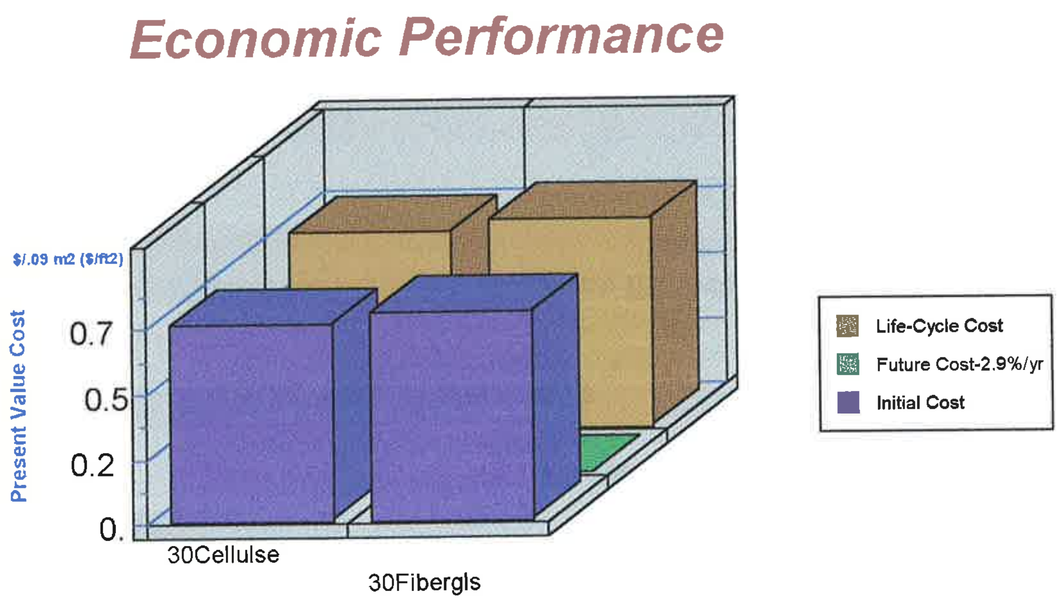
Selecting building products:

R-30 Cellulose
R-30 Fiberglass

- Distance for transporting: 500 mi.

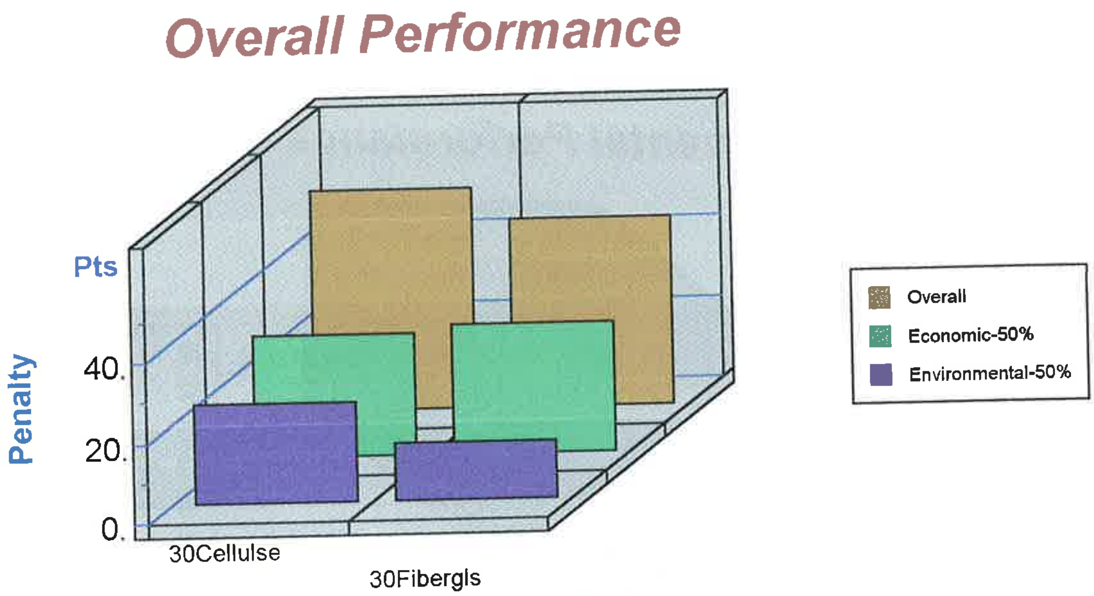


For all the environmental impacts taken into account, fiberglass is the more appropriate product.



From costs, it makes no difference selecting any product.

Since cellulose is made from pulp waste (newspaper), it is not an appropriate product to be used in ceiling insulation as it was appropriate for wall insulation.



The overall performance was influence by the environmental performance. As a result, fiberglass is the more attractive product for ceiling insulation.

4.3. Shell

4.3.5. Roofing

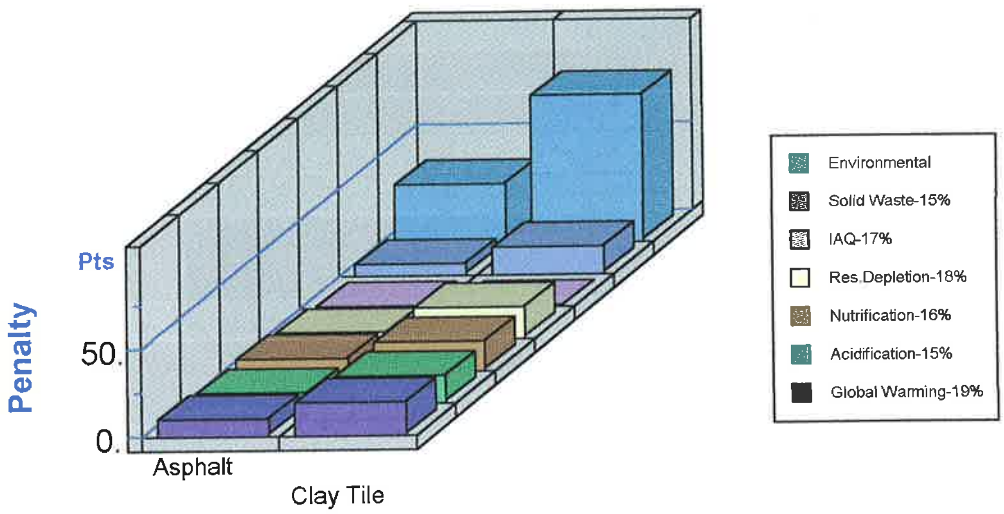
Roofing covering

Selecting building products:

- Asphalt shingles
- Clay tyle

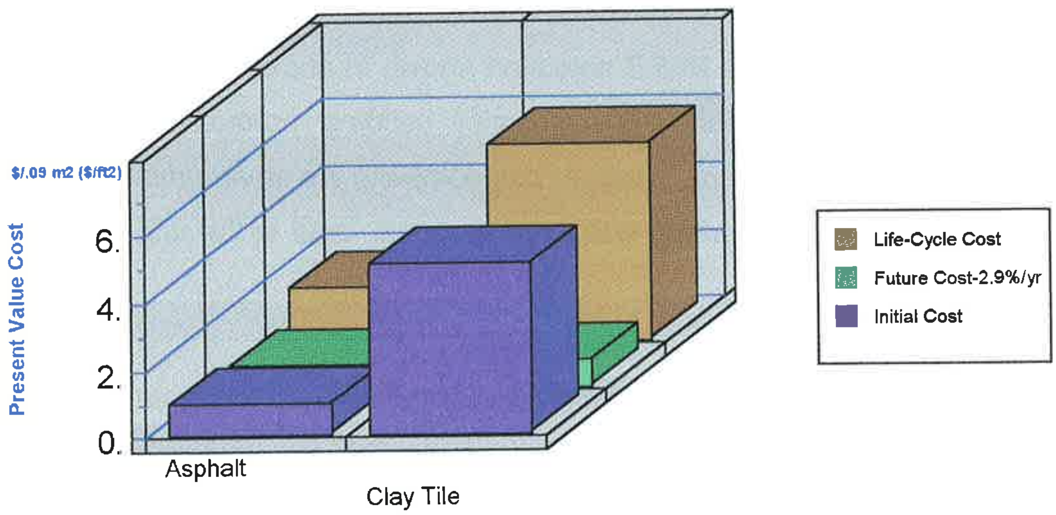
• Distance for transporting: 500 mi.

Environmental Performance

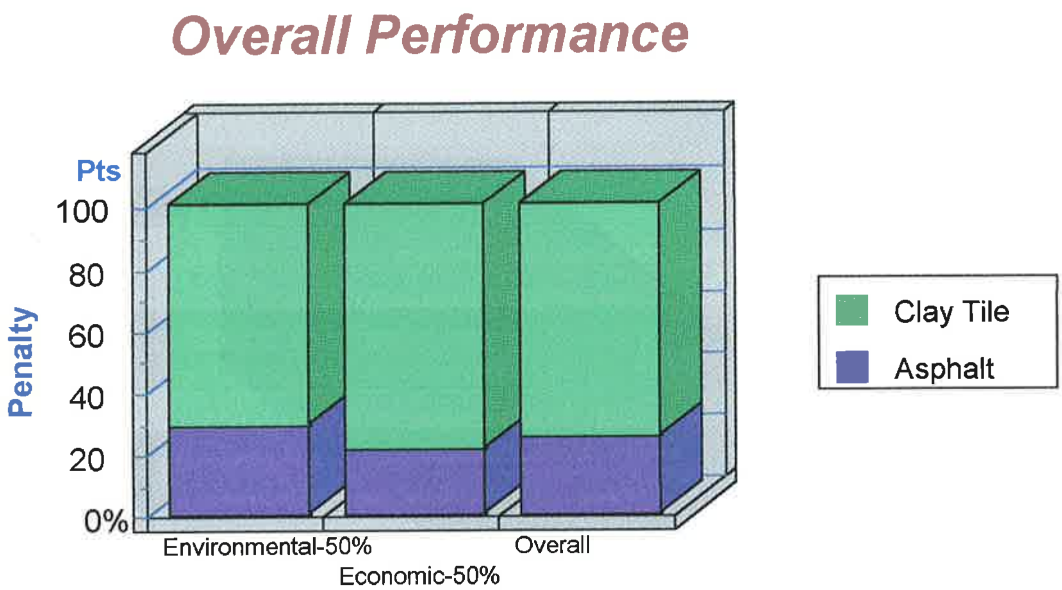


For any environmental impact asphalt is the more appropriate product.

Economic Performance



Asphalt is a much more economic product.



From any point of view (environmental or econimic), asphalt is the most appropriate product; so it will used for roof covering.

Applying BEES results are summarized in table VI.1.

5. THE SUSTAINABLE BUILDING PRODUCTS AND MATERIALS SELECTED

From the BEES selection shown in above we have a basic group of balanced (ecological-economic) building products, see table 7. In addition the building designer can complete the environmentally friendly list of products, materials, and systems to be used in the implementation of a building project.

The regional environment and local construction sector features were taken into account to complete the BEES selection shown in table . So then, handcraft brick is recommended to be used for all building walls, and natural paint must be used to paint indoor areas. The sustainable characteristic to these building materials are explained ahead.

It can be said that in the case study region there are previous cases of using natural paints for vernacular projects. Related to handcraft brick, roughly 80% of brick used in the region is from this type (INEGI, 1998).

In building a house or office building many products and materials will be used that are not themselves environmentally friendly or green material, but they can be used in a manner that helps reduce the overall environmental impacts of the building.

The method used to assist the sustainable selection of building materials is far from being exhaustive. The first BEES version 1.0 is limited since it is a very young assessment method; nevertheless, there is a proposed data enhancement to add building products covering many more building elements, and add more products to currently covered elements (LIPPIATT, 1998).

The reason for selecting handcraft brick (traditional process production) instead industrial or fire brick (assumed by BEES) is because craft brick is a sustainable building material *par excellence*. Its ecological price is almost 500 times less than industrial brick (since the consumption energy point of view) (ROODMAN, 1995); the traditional manufacturing process requires a large quantity of manpower leading to the creation of employment particularly in developing countries. This characteristic is closely linked with Chapter 7 of Agenda 21 concerning with the need to create employment through construction activities in such countries.

Table 7. Sustainable selection of building materials

Particular Building Element	**Selection of Building Products and Materials**
BEES Selection	
Driveways and pavements	15% Fly ash content concrete (compressive strength 21Mpa = 3000psi)
Floor covering	Vinyl composition tile
Exterior wall finishes	Stucco
Wall insulation	Cellulose
Wall sheeting	Fiberglass
Ceiling insulation	Cellulose
Roof covering	Asphalt shingles
Beams	15% Fly ash content concrete (34Mpa = 5000psi)
Columns	15% Fly ash content concrete (34Mpa = 5000psi)
Roof sheeting	Plywood sheeting (sugar cane waste)
Basement walls	15% Fly ash content concrete (34Mpa = 5000psi)
Slabs	15% Fly ash content concrete (28Mpa = 4000psi)
Designer Selection	
Building walls	Handcraft brick (local production)
Indoor areas	Natural paints
Other building elements	Conventional building products and materials used, taking into account sustainability principles

In addition, craft bricks are naturally dried under the open sky and then fired using dry firewood (which is a sustainable fuel).

The following flow diagrams shown in Figures 3 and 4 show the great environmentally and socially (employment potential) difference between the two manufacture processes.

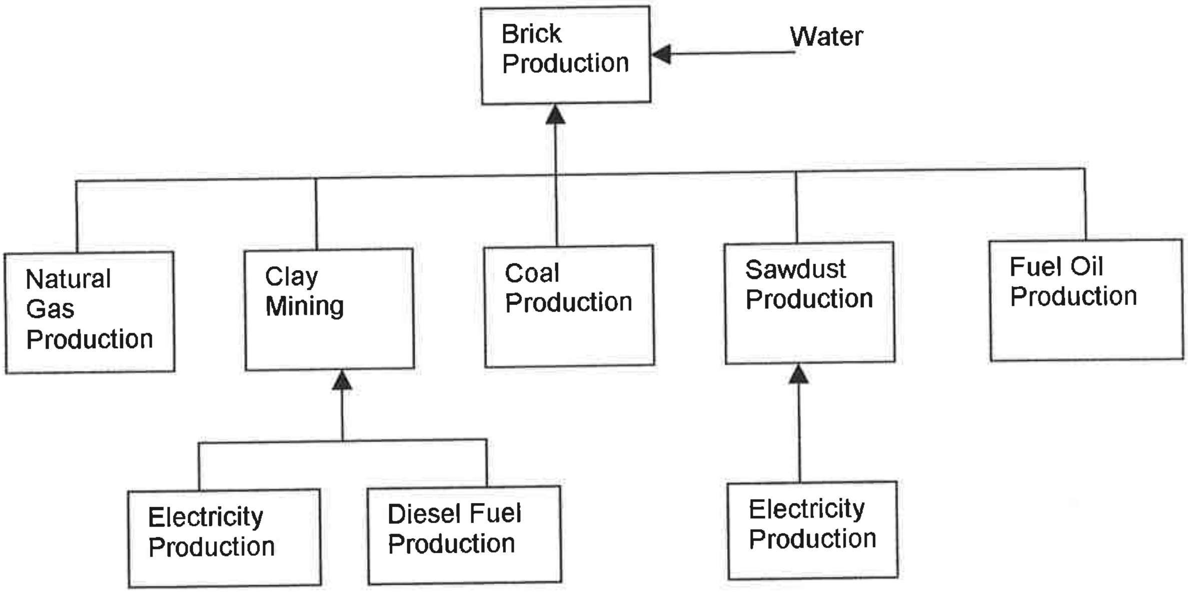


Figure 3. Industrial brick production.

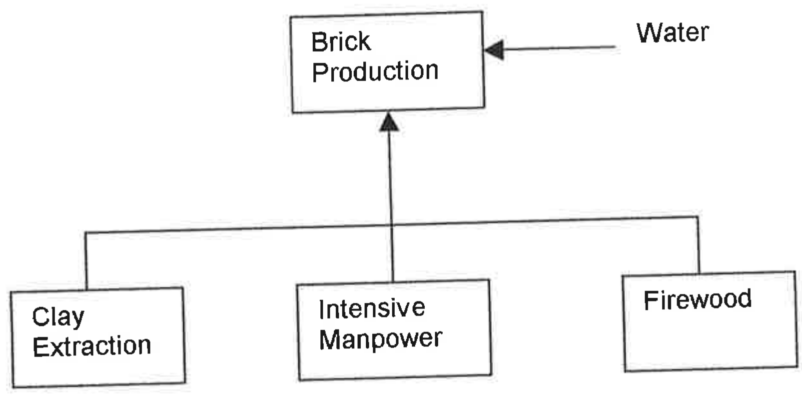


Figure 4. Handcraft brick production (Northwest of Mexico)

The energy requirements for industrial brick (drying and firing) are coal, natural gas, fuel oil, and electricity (processes); that is, mainly fossil energy. Meanwhile craft brick requires firewood and employs a number of workers that use manual tools that do not pollute.

On the other hand, raw materials for natural paints are mostly limestone and animal or vegetable products, also may contain organic hydrocarbons as solvents, as a consequence waste is generally degradable. In contrast, regular paints are made with petroleum products and synthetic solvents that represent environmental harm and non-renewable resources exhaust.

Lastly, related to the BEES method, it is important to emphasize that it is an assessment method still under development that needs to be expanded to building products coverage, it needs to include more environmental impacts and add a third performance measure dealing with specific social issues, only then would it be a real sustainability assessment method.

The BEES developers have said that in future versions of the method they will include more environmental impacts, such as human health and resource extraction impacts; add building products covering many more building elements, and add more products to currently covered elements; refine all data to permit region-specific BEES analyses, a training program is also being considered, among other updates periodically.

Is to be **noted** that in this English version, up to date was used and different impact weights were assumed in order to test and demonstrate that the BEES result are similar even with some different data.

FIFTH PART

COMPENDIUM OF THE APPROACH TO SUSTANABILITY PRINCIPLES FOR THE CONSTRUCTION SECTOR

SYNOPSIS OF CHAPTER XIII

Conclusions and recommendations

EPILOGUE

CONCLUSIONS, RECOMMENDATIONS, AND COMMENTS.

The fifth part is integrated by chapter XIII, bibliography and references, and the appendices which contain additional information related to the whole research phase. The most relevant content of chapter XIII are conclusions and recommendations, and the epilogue.

Through the thesis conclusive aspects have been addressed in each opportunity. Accordingly, in this phase of conclusions and recommendations only major issues are emphasised. Conclusions and recommendations are made for each of the five parts that are integrate the thesis.

Conclusions are presented linking its respective recommendations or just comments are made whenever no suggestions are related about some conclusions.

FIRST PART: Theoretical and conceptual framework of sustainability.

CONCLUSIONS (**C**)	RECOMMENDATIONS (**R**) OR/AND COMMENTS (**C**)
C-1) Sustainability was born from an ethical concept, expressed by the relationship that exist between the present generation and the future generations. So, it is understandable that like other pioneer initiatives, at the beginning have to be assumed in a voluntarism way. Sustainability requires the personal commitment of their sympathetic in order to be successful.	**RC-1)** The industrialized countries seek to maintain their position in the global economy and the relative high level of life they have reached. So far there are no signs that they will adopt a different development model to which they are customary. Apparently those countries are convinced that their form of development, with some adaptations, it could be the model for Sustainable Development. This was sensed among the revision and analysis of the Sustainability literature. The above mentioned is also implicit in the format and content of the documents of congresses, in the speech of the meetings of work, in the orientation of the projects that they are developed and in the composition of the groups that currently are working in the topic of the Sustainability. Consequently, a wide participation of people from all the planet countries in the decision-taking of new forms of international cooperation, removal of artificial barriers of trade, between other aspects that include to the countries in development are required.

C-2) It Seems obvious to think that between the realities of the physical type (natural) and those of political type (assumed by the humans), the lastly will yield. Then, supposedly like a logical alternative, the world society could make its way toward Sustainability.	**RC-2**) The human creativity and the vitality of the communities doesn't seem to have limits, for what it is hoped that pushes vigorously the process, now incipient, that have begun in order to improve the quality of life on the earth. Taking into consideration that limits do exist and they sometimes are imposed by the nature, also sometimes depend on the human behaviour, but in both cases could be addressed through Sustainability.
C-3) The incessant population growth in developing countries in development goes beside a permanent demand of construction and of housing, infrastructure, and services. The magnitude of that population growth is as high, that even a more efficient environment management would do, in order to balance the demand of construction and the environmental negative impacts, in some cases such efficiency would be insufficient.	**RC-3**) According to the United Nations population projections Latin America will have 810 million inhabitants by year 2050, that means 300 additional million to which it has nowadays. That represents the limit of their demographic capacity. That is a serious challenge of passing from a quasi-traditional economy to a model of balanced, just and equal development, this is to a Sustainable Development, all that in less than half century. It is indispensable then, that simultaneously to such challenge, a diminish on the demographic growth in the region, as well as moderate rates of consumption and an better efficiency of the environmental management associated with the human activities are needed.
C-4) The social and economic components of Sustainability requires to be more developed, because a clear tendency is observed of speaking and making activities in the ecological environmental field, considered sometimes as synonyms, which comes as no surprise that Sustainable Development movement has their roots in the environmentalist movement.	**RC-4**) The topic of the environment should not be dealt in independent form from the Sustainability, neither can be considered an objective in itself. In order to be believable, the environmental policies of nowadays require being elaborated and implemented in the framework of the Sustainability principles.
C-5) The initiatives aim to operativize the Sustainable concept just hardly begin. Much more research work is still required, awareness, organization, and willpower are needed to tackle complex decisions related to the topic in questions.	**RC-5**) Some of these requirements are made in Agenda 21 when refers to the scientific community in order to address the scientific and technological research (chapter 35), to the local authorities so that they support the implementation of the Sustainability principles (chapter 28), and to the education and public awareness (chapter 36). In addition it has be to be asked to the civil society their participation so guide their attitudes toward the Sustainable way and in order to reconstruct the aspects nowadays unsustainable. Is important to insist that involving the broad public is crucial for the acceptance and support to the activities to be carried out. To this challenge must to be added the policy-makers, professional associations, entrepreneurs cameras, mass media, labour unions, environmental groups, students and

	teachers, social leaders, etc. Heading the works could correspond to the civil authorities, although it is also frequent that no government organizations assume the leadership.

SECOND PART: Techniques and tools used in supporting sustainability.

CONCLUSIONS	RECOMENDATIONS AND COMMENTS
C-6) At the same time that attempts to operativize Sustainability the tools of support to this new paradigm are ongoing, starting in some cases of the adaptation of already existent tools. Although some tools of specific assessment have also emerged together with Sustainability, even they currently are still developing, such are the cases of life-cycle assessment (LCA), standards ISO 14 000, Sustainability indicators, methods to tackle the sick building syndrome. **C-6'**) Some tools like life-cycle assessment will continue adapting along the time because meanwhile the technologies for construction are evolving, also the key elements of Sustainability can change in the meantime. For this reason the researchers and studious of the topic surely will be alert in order to introduce the pertinent adaptations and changes. **C-6"**) At this time the necessity of creating new techniques in order to make Sustainability more operative exist. Related to the field that covers this thesis, more focused efforts for the design of complex constructions are required, instead relatively simple generic buildings that have been analysed. Specific procedures for supporting the instruments of decision are also needed.	**RC-6**) Chapter 35 of Agenda 21, states that the scientific and technological sector is eligible in order to support the research of assessment, it also suggests that the countries carry out activities for the development and application of the tools that are needed for a better management of resources and for the environment assessing which is required to be healthy. This and other suggestions from the chapter 35 include the developing countries, whose would receive attendance from international organizations. Therefore, the improvement and the creation of new tools and techniques to support Sustainability such as the those quoted in the three conclusions of this second part could continue developing to the help of the commitment of the countries whose are solidarity with the agreements of the Earth´s Summit of Rio de Janeiro.

THIRD PART: Sustainable construction.

CONCLUSIONS	RECOMENDATIONS AND COMMENTS
C-7) The most important decisions that affect to the buildings happen in the first stages of the conception and the design. However, the tendency persists that the Architect designs and the Engineer takes care of the services, with a minimum concern for other matters but their respective fields. This is a sample of the little communication that exists between both disciplines. For these specialists, so far one of the central concerns has been the low cost, overlooking the life cycle of the materials and the environmental impacts.	**RC-7**) it won't be simple to change the inertia of this mercantile mentality, but could possible making compulsory some aspects like the passive systems (explained in the body of this thesis) and other efficient similar systems, simultaneously to the effective application of the environmental standards, as long as the Sustainability researchers have the task of find mechanisms in order to integrate the architectural and structural-services strategies taking into account the life-cycle costs.
C-8) One of the major environmental impact producers is the construction industry. Its solid waste occupy a substantial proportion in the landfills; there are emission of toxics substances from the materials just placed; the dust, the solid particles, and other pollutants in suspension propitiate problems to the occupants. On the other hand, the building construction demand large quantities of row materials and energy.	**RC-8**) indeed, the builders in charge might to adapt best practices in aspects like the administration of natural resources, transport, reduction of solid waste, reduction of pollution and remediation of impacted spaces which were made through traditional building practices in the past (was typical the black waters disposal into the rivers).
C-9) The members of the Construction Sector and their clients require to receive information and support in order to take measures that will diminish and palliate the adverse impacts that arise from the buildings.	**RC-9**) To speed up the acceptance and use of Sustainability principles into the building products and materials marketplace, governments, educators, and financiers-landers can combine tactics such as strengthening building codes, taking steps to educate both professionals and public, publishing business opportunities on materials such as fly ash application, and creating fiscal incentives that reward good buildings using Sustainable building products and materials. Incentives to the research and development is a crucial issue.
C-10) The environmental quality standards privilege the previous stages to the operation and maintenance of the buildings, despite to the indoor quality environment where the occupants sometimes remain even 90% of their time.	**RC-10**) Authorities of the building sector paying more attention to the creation of regulation of indoor air quality is needed.
C-11) One structural strategy that requires Sustainable Construction approach is the education of the professionals that carry out the	**RC-11**) Students of Engineering and Architecture require to learn the operation of buildings after its construction, and not only

building activities on the traditional way. That strategy also must cover to the new builder generations that now are studying in universities and high education institutions, this implies upgrade the study curricula.	lectures demanding them good aspect of drawings and calculations on the projects that students make. They must understand that in addition to a good creation of buildings a responsible operation is required, based on the efficiency of the natural resources and in ecological criteria from the extraction of the raw materials, until the residual disposal. In order to achieve these educational purposes it will be need introduce qualitative changes in the study curricula, in order to link the future building professionals to the social necessities.
C-12) The owners and buildings designers don't still consider important the possibility of re-use or recycle materials because they are not conscious of the potentiality of this type of materials, or they believe those type of material would have an inferior result beside the new materials; Although it also is due to the lack of tradition and no motivation.	**RC-12**) As part of a convincing task, it would be of utility to monitory the trajectory of some residual building elements in order to demonstrate that the materials properly separated for re-use and recycle is a healthy and efficient building practice. At the same time monitory would help to the project team to evaluate the cost-benefit of the waste to send to the landfill, with relationship to the waste for re-use and recycle. On the other hand, it would be useful to incentive an authentic "second hand" material market.
C-13) The buyers and users of the buildings generally don't have access to the decision-taking process of important aspects on the constructive processes, such as indoor air quality components, selection of building materials and products, saving energy features; so Construction Sector members decide on behalf of them.	**RC-13**) In view of the fact that the buyers and occupants exclusion, the planners, promoters and contractors who have the responsibility of the introduction of adaptations to the procedures of construction that causes the serious consequences to the environment, and frequently to the building occupants, the authorities of the Construction Sector have the high responsibility to advise and lead the requirements of the construction "consumers". On its own, the University can and should addresses studies that lead to the production of comprehensible and accessible information to building buyers and users.
C-14) Whenever owners and building designers coincide for the purpose to build with the Sustainable approach, would be indispensable negotiate and aware the building contractor, so he join to the project team in an integrated way.	**RC-14**) Besides awareness of the building contractor by means of economic attractiveness that some Sustainable practices could represent, also look for more opportunities than motivate his interest through benefits that could obtain is needed, for example suiting the re-usable and recyclable materials and allow him to bring re-usable products from other projects where he is involved. As well as the suitability for all the parts of assuring the exclusivity of the contractor in future similar projects. On the other hand, contractors that have experience in Sustainable projects will be in advantage on their competitors to carry out that kind of projects.

FOURTH PART: Toward sustainability measuring.

CONCLUSIONS	RECOMENDATIONS AND COMMENTS
C-15) The medium or long term of Sustainability evolution requires a feedback with information from assessment done through local and regional indicators, and even on relatively small projects like buildings.	**RC-15**) The identification and development of Sustainability indicators is a necessary way of assessment which should be revised and put them up to date in order to observe the tendencies toward, or away, the Sustainability approach. The purpose of assessment is an activity which colleagues of the engineering are identified must be develop much more, both Sustainability indicators and building assessment tools.
C-16) According to the experiences from some projects with the Sustainable approach, a significant participation of the citizenship is required in order to assure future support to the Sustainable projects and activities.	**RC-16**) Is interesting the fact that same local experiences have proved in the sense that formulating indicators is of great value because attracts the attention of people on the topic of Sustainability. Most communities that have adopted Sustainability indicators, began with a rudimentary notion of the concept and its implication for the life of the community. However the difficulties in order to select those indicators have motivated to the citizens to examine not only environmental, economic and social aspects but also several other values. As a result, much people have obtained an intuitive knowledge of the meaning of the Sustainability, and what Sustainability represent for them, like individuals and like community.
C-17) The proposal of Sustainability indicators for the Mexican region here set out, could represent a contribution for a civic activism and for future works on regional official policies what would propitiate a link with the Sustainable movement that can be seen in several parts of the world.	**RC-17**) With the proposal of Sustainability indicators we aspire to encourage the civic conscience from both citizens and regional authorities. Once the promotion had been carried out through the spread out of the thesis content, alumni associations, and research centers the National Polytechnic Institute has in the region.
C-18) Assessing Sustainability on small scale comprises building projects. It is remarkable that applying Sustainability principles in buildings it does not mean sacrifice costs or structural stability.	**RC-18**) Even when the assessment tools and techniques have been launched recently, the evolution they have denotes that they will continue perfecting in order to adapt their use to regions and specific projects in a more successful way than they have achieved until now.
C-19) Selecting products and materials environmentally benign is a way that lead to	**RC-19**) In order to support technically the decision-making process in the construction

Sustainable Construction. But in real terms any designer or owner aware of the importance of the Sustainability will weight the feasible environmental benefits versus the costs and economic earnings, and understandably will concede an important weight to this last concept. Through the application of the BEES method, in this work have been shown that some products have less potential environmental impact and they have a similar or minor economic cost that those of major impact.	products with less environmental impact, methods are on ongoing which aim to balance the adverse environmental impacts and the economic costs. Here the Sustainable assessment has been addressed applying an ongoing method to assist the building designer. Since there are not Sustainable materials *a priori*, once the method used have been perfected, will be a very useful tool for help the selection of building materials in projects with the Sustainable approach.

FIFTH PART: Compendium of the approach to sustainability principles for the construction sector.

CONCLUSIONS	RECOMENDATIONS AND COMMENTS
C-20) In the outset of this work was proposed the spread of the outcome of the thesis, like an immanent part of the objectives of approaching the Sustainability principles to the stakeholders of the Construction Sector and to the broad public. In order to pursue that target the author plans to carry out a series of activities in order to promote the Sustainability concept and principles.	**RC-20**) A minimum list of actions are the following: spread out the topic of Sustainability in schools, research centers and continuing education of the National Polytechnic Institute (I.P.N.-Mexico). Send copies of the thesis to libraries and centers of information. Write summaries of the subject for the I.P.N. magazines and bulletins, and for other high education institutions. Make exhibitions to groups of lectures, alumni, and students. Participate in congresses and meetings *ad hoc*. Aware authorities of the construction field, cameras of construction, associations of professionals and entrepreneurs, labour unions, and other groups. Take advantage of the current collaboration agreements as a penetration way to the groups that have just been mentioned above. Continue the feedback and bringing up to date of the Sustainability indicators and the assess of environmental-economic-social impacts of building products and materials; mainly through research projects to carry out with graduate students.

EPILOGUE

The world of today has science and technology sufficiently developed, now are required intertwine those enormous advances with a humanistic philosophy of life, simpler in the case of the industrialized countries and more feasible in developing countries. The most recent invention in order to try to amalgamate these aspirations has been called you Sustainable Development.

But accordingly with the material read and the discussions addressed during the time this academic work was carried out, that type of development and more specifically Sustainability, could not be considered as a panacea, because they are just emergent instruments in order to try to make viable the socio-economic in a space more or less certain, in the medium and long terms. Neither they could imply an indefinite duration like definitions suggest, it would be a great achievement if the humanity could cross the 21century in a Sustainable way.

Signs coming from some countries seem to indicate that the demands of a market more and more environmental conscious will propitiate that companies that offer clean alternatives, in sure way, and mainly if they also certify it fairly, will be whom survive and progress in the market.

As an explanatory fact of this interpretation could be mentioned two types of companies or Sustainable industries *par exellence*, those of organic foods and of no-renewable. This kind of business is registering growths very quick and, consequently, the difficulties by being innovators are not made wait for. Both types of companies confront rivals many less ecological but completely consolidated, such are the transnational agroindustry companies and those that exploit fossil fuels. But even these last, visionary as always, have been already intrude on the no-renewable energy business.

Is desirable that the winds of change that blow in some sectors also reach to the construction sector, for which an arduous promotion work is required, because the Construction Sector doesn't stand out in fact by fomenting structural innovations, and rather is cautious and slow in the inclusion of changes that induce the progress.

Some of the reasons that could explain that feature are the recurrent behavior of the of the construction economy (quoted in the Sustainability indicator E-2), and on the other hand, the almost non-existent interest of the society by demanding guarantees to projects such as motorways, public buildings, supply of water, among other essential components of the social infrastructure that must to work with security and efficiency related to the technological progress mentioned before. As members of that society, owners and buyers of construction generally without enough information have propitiated that designers and builders decide what and how building materials use in buildings.

Selecting environmentally buildings products and materials are not necessarily more expensive, as was corroborated in chapter XII. So, members of the construction sector should have the information, at times the indication-pressure of their clients, and also the commercial feasibility of such class of materials. This has implicit a business opportunity the environmental market of materials.

On the other hand, is also pertinent comment that the slow innovative attitude of the Construction Sector represents an advantage from the Sustainability point of view, at least in Latin America and in particular in the Mexican region case study. This advantage resides in the employment creation for people working in small and medium projects instead machinery, which avoid pollution and contribute to social security for the employees and their families.

The environmental evidences and economic patterns observed along this study indicate that humanity is steadily approaching to a stage that at least it can called ecological, which is difficult to accept for the main mercantile agents of the construction sector.

Scientific and technician groups are growing in their understanding about the adverse environmental impacts from the construction industry, such as deforestation, pollution of water and air, production of big amounts of solid waste, damages to the ozone layer, exhaustion of resources, global warming. Their knowledge is improving with the aim to moderate the environmental problems and to develop new products and materials.

Nevertheless, the members of the construction Sector seem to be satisfied with results of the practices of traditional construction, because they are interested in the environmental issues when can represent them restrictions to the business and sometimes business advantages. Therefore, the challenge for the members of the Sector whose are aware of the importance and of the opportunity that means Sustainability, is to work for the creation of a market that incorporates the practices of Sustainability design and construction. In some countries this business have already begun with perspectives of attractive earnings.

Related to such opportunities of business the case from Germany is mentioned, where important cities have stores that expend ecological materials of a growing variety. Also the case from the largest Japanese construction company that has reduced the wastes of construction materials and packing until in 70%, as a result of the adoption of a commitment that considers the environmental issues of their activities.

In addition, is remarkable the new market of efficient buildings in the use of energy that begin to emerge. Some industries aim to reduce the pollution in order to satisfy the environmental demands of their clients and the feasibility that international funds for the construction of green buildings can be created.

Consequently, those aware members of the Construction Sector could also carry out some actions that would cooperate in order to try to change the traditional inertia that has been commented, showing real cases of business of successful Sustainable Construction getting genuineness through the support of promoters and aware building companies and promote the opportunities that represent the projects of the public sector for the private sector in which it could be promote the Sustainable approach.

The transformation of the concept of sustainability from theory to practical basis for action requires a process for strengthening analytical methods, institutional structures, and human capacity. The universities can help to address such issues at least in two simultaneous ways: one is through the continuing education for sustainability on the new generations of builders and their alumni, which would imply reconsider the content of the Civil Engineering and Architecture curricula.

The other way is showing by means of studies and compelling researches, the feasibility of including the Sustainability principles in the design and construction projects without the risk to fail traditional objectives, including the economic profits and researching to develop new assessment tools and improve the existents methods and tools.

The generally unstable finance of the construction companies, mainly those from the so called Third World, don't allow them to invest in research and development. To tackle that situation, the universities and high education institutions could also make their contribution setting up agreements of specific collaboration with cameras and groupings of the construction industry in order to carry out research in new technologies, like for instance those that improve the indoor air quality the buildings, reduction and re-use of solid waste, structural design that incorporates the life cycle, saving water and energy systems, development and adaptation of tools for assessment in the construction industry, etc.

Also the educational institutions would support the industry in order to integrate and to test this technologies into practical works, through their applied research centres.

From the important leadership that corresponds to the governments they can contribute to the Sustainable practices through fiscal policies on their competition, for example, burdening with taxes instead of subsiding the extraction of resources promoting the efficient design for products of consumption and the substitution of matters prevail for recovered materials (re-use, recyling), and putting their own example by incorporating the Sustainability principles in some of the public works.

The civil and educational authorities should address combined campaigns of awareness and education for Sustainability. Is necessary to highlight that some governments should share a major proportion of budget for research and development, whose benefits would embrace the sustainable construction.

Through this synergy proposed could be able to advance for that voluntarism road that until now is Sustainability and show to the people that decide in the Construction Sector that this new paradigm called Sustainability represents business opportunities which not necessarily increase costs, or meant detriment of quality or security of the constructive elements.

We can conclude, as a last reflection, that the Sustainable alternative, the one and only thing that can assure a better future to the planet, won't be imposed for itself, because it has to confront multiple ideologies that inspires the money. However, the awakening of the world awareness related to the human solidarity and the threat to the nature have already begun, having the Sustainability philosophy as a support which begin having followers in the practice. For the Engineering on Construction adhering to this challenge means much work from convincing its members and carry out lot of research, but Sustainability, like the creation, it is a whole process not an act.