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Green Buildings: Analysis of State of Knowledge

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Abstract Green building practices emerged to mitigate the effects of the increasing impact on the environment and to improve the building construction process. In this context, a systematic bibliometric analysis is provided. As a result, 124 articles were found in 40 internationally recognized scientific journals related to green buildings. A quantitative analysis is done to the articles in order to know about the authors and countries with most publications; in addition to their evolution from 1980 to 2011. Then a qualitative analysis which aims to obtain the key aspects and obstacles to consider in Green Building and recommendations are given for each aspect. The goal of this paper is to provide building researchers and practitioners a better understanding of how to effectively make decisions to promote energy conservation and sustainability of green buildings.

Keywords Green Buildings, State of Knowledge, Bibliometric Analysis

1. Introduction

Green Building is the practice of improving the building's efficiency by using energy, water, and materials available on site; with the main goal of reducing the impact on the environment and human health, throughout the whole building life cycle (design, construction, operation, maintenance and demolition)[1]. Improving today's conventional design, building practices and standards, extending the building life by making it more durable and efficient, and minimizing its operative cost, increasing its productivity, and giving a healthier living and working environments to its occupants[2].

Nowadays, more people are moving to the city causing a significant increase in the construction of buildings and/or skyscrapers, and hence a booming in the city economy but with great repercussions in the environment. This activity urge for a huge demand on material supply[3], this activity is responsible for 30% of all greenhouse gas emissions, 65% of waste output, 70% of electrical consumption and 12% of water consumption[4]. Therefore, it seems crucial to incorporate design criteria to minimize these impacts[5-6].
For this reason, Green Buildings is intended to reduce construction costs and building maintenance. Reducing energy costs and environmental impacts of not only the structure but also the site on which it will be placed. Other benefits are an increment of comfort, safety and health of building users, and provide a friendly environment to increase productivity.

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Accordingly to this concept, the purpose of this study is to analyse the state of knowledge up-to-date. Additionally a qualitative analysis provided a decision making tool for the construction of green buildings. This research was made as a Master Thesis[7].

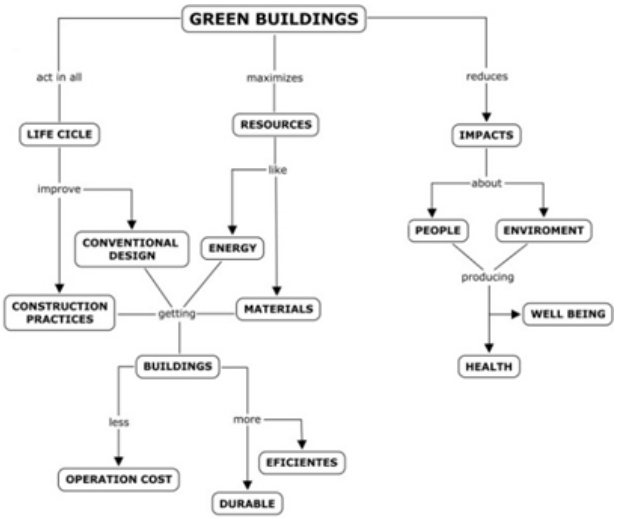

Figure 1. The meaning of Green Building

2. Research Method

The study was conducted through a literature research and a subsequent process and analysis of the papers found. The structure of the research follows five phases:

1) Preliminary approach and initial tests.
2) Bibliometric search and revision of references.
3) Quantitative analysis.
4) Exploitation and analysis of results.
5) Qualitative analysis.

Phase 1 was an initial approach to the topic, which allows familiarization with the main concepts related to Green Buildings, identifying keywords, and designing search strategies. A non-meticulous research was done in commonly use search engines such as Google, using keywords like Green Building, LEED, materials, costs, Green Building Council. After reading the literature available on different web sites, a better understanding of the topic was achieved. As a result of this first review, Green Buildings subject is really interesting for many people, organizations, companies, and is growing up in lot of countries.

Phase 2 use the search strategy in Table 1 to start the research in Scopus and Science Direct (bibliographic databases online containing published scientific research as abstracts and citations for academic journal articles, book series and handbooks), delimitating the search since 1980 to 2011. These data bases were chosen because they are scientific, international, and related with the topics. By means of a comprehensive review of all articles found (some of them were only abstracts and were not taken into consideration), in this process the result was export to RefWorks to be classified by year, country, database, type of paper (article and handbook), author and nine categories identified as common aspects in the literature. Six of them –sites, water saving, energy efficiency, interior quality, materials, design and innovation – are based on reviewing points used already in well recognized Green Building certification processes as LEED certification. Two of the remaining categories – costs and tendencies – are important aspects that will impact the feasibility of a Green Building project. The "other" category refers to aspects that cannot be placed into the categories mentioned before, but are worthy of mention. In this phase, the papers found were filtered, removing duplicate articles, and eliminating papers which were not strongly related with the topic of the study.

Table 1. Keyword combinations per search strategy

SEARCH STRATEGIES		
SS-1	TITLE	"Green Building"
SS-2		"LEED Certified Building"
SS-3		"Green Building" AND "LEED Certified Building"
SS-4		"Green Building" AND "Cost"
SS-5		"Green Building" AND "LEED"
SS-6		"Green Building" AND "Water"
SS-7		"Green Building" AND "Sustainable Building"
SS-8	TITLE-ABTRACT-KEYWORD	"Green Building Council"
SS-9		"Green -Building" AND "Material"

Phase 3, a quantitative study was done using some aspects of the article such as the number of articles published per journal and the indexes given by the Journal Citation Report (JCR), most recognized authors (taking into account authors with two or more publications), publications countries, the articles evolution throughout time, publication by category and the articles evolution over time and per category

On phase 4, the data gather on the preview phases was analysed using the categories on phase 2 as reference. The articles with the highest references number and their keywords are the main focus on this phase.

Finally on phase 5 a qualitative analyses was done by an exhaustive study of the articles and summarizing all the main contributions of the most relevant ones.

3. Results

3.1. Quantitative Analysis

A total of 218 papers were found and reviewed, 21 of these papers were duplicated and 73 papers were not strongly related with the topic of the study. Therefore 94 papers were eliminated, leaving 124 articles to be used in the study.

3.1.1. Relevant Journals

To assure the veracity of the research, the Journal Citation Reports (JCR) index was used as a resource to know the impact of these articles in the scientific community. More than a half of the articles (69.4%) were published in journals with Q1 ranking.

Table 2. Journals with the highest scientific production

JOURNAL	JCR	#PAPERS	%PAPERS
Building and Environment	Q1	36	29.0%
Energy and Building	Q1	17	13.7%
Building Research and Information	Q1	12	9.7%
Landscape and Urban Planning	Q2	5	4.0%
Others	--	54	43.5%

3.1.2. Relevant Authors

The authors with more publications are: Dai, Y.J.; Ma, Q.; Wang, R.Z.; Zhai, X.Q. from Shangai Jiao, with 4 publications each one.

3.1.3. Countries

The countries with most publications are U.S.A, China and Canada, with 27.7%, 16.7% and 8.6% respectively.

3.1.4. Evolution throughout Time

The evolution of Green Buildings research from 1980 until 2011 is shown on Figure 3. The first article appeared in 1997. Before 2007, the number of articles was very few and intermittent. After that year, an increase on interest was evident: 70% of the papers were published.

3.1.5. Research Categories

The most researched categories, based on phase 2 are: Energy Efficiency (25.8%), Tendencies (15.3%), and Design and Innovation (14.5%).

3.2. Qualitative Analysis

3.2.1. Research Approach

As a result of the first approach (phase 1), LEED was the rating system most mentioned. The country with the highest number of publications is United States with 27.7%. This could be attributed to the fact that LEED Rating System is the rating more internationally recognized, developed by US Green Building Council.

3.2.2. Green Buildings Aspects

The first step to contribute with the sustainability is the design of the structure. As a prelude to the construction phase, which has a great influence on many other aspects, a good design takes into account: costs, energy efficiency, water saving, materials, etc.

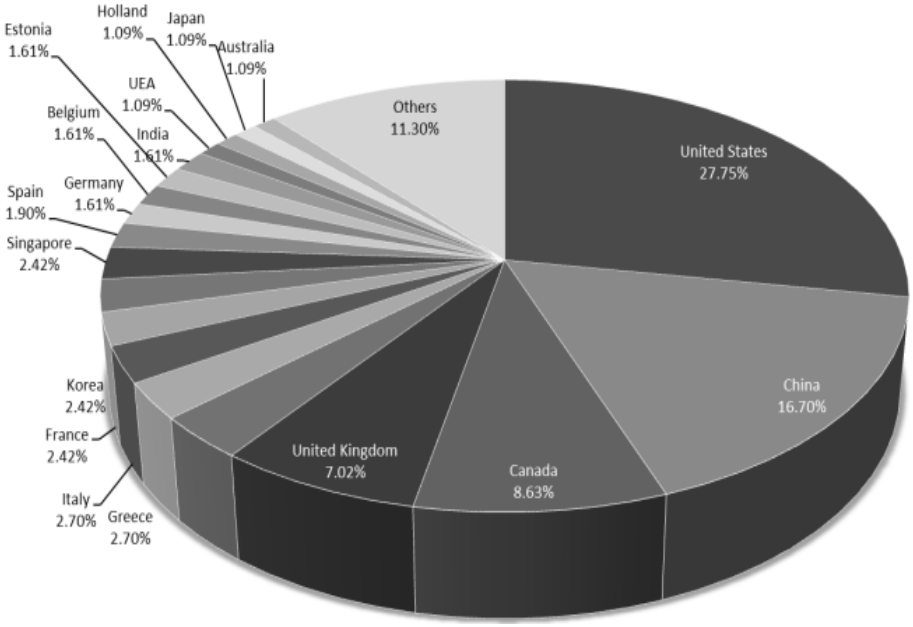

Figure 2. Publications by country

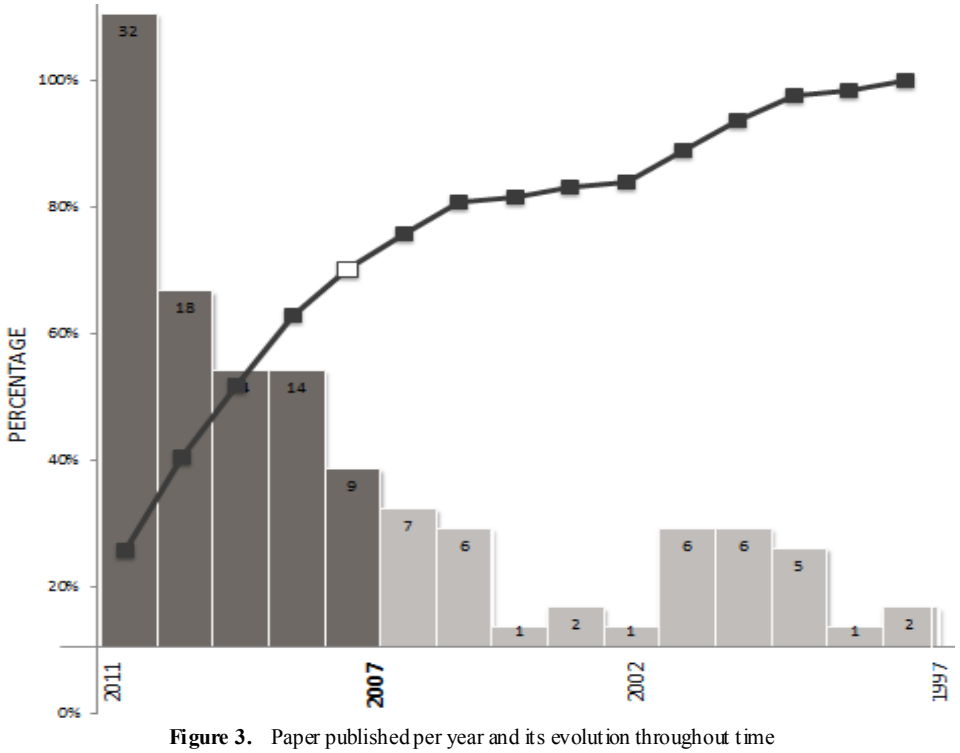

Figure 3. Paper published per year and its evolution throughout time

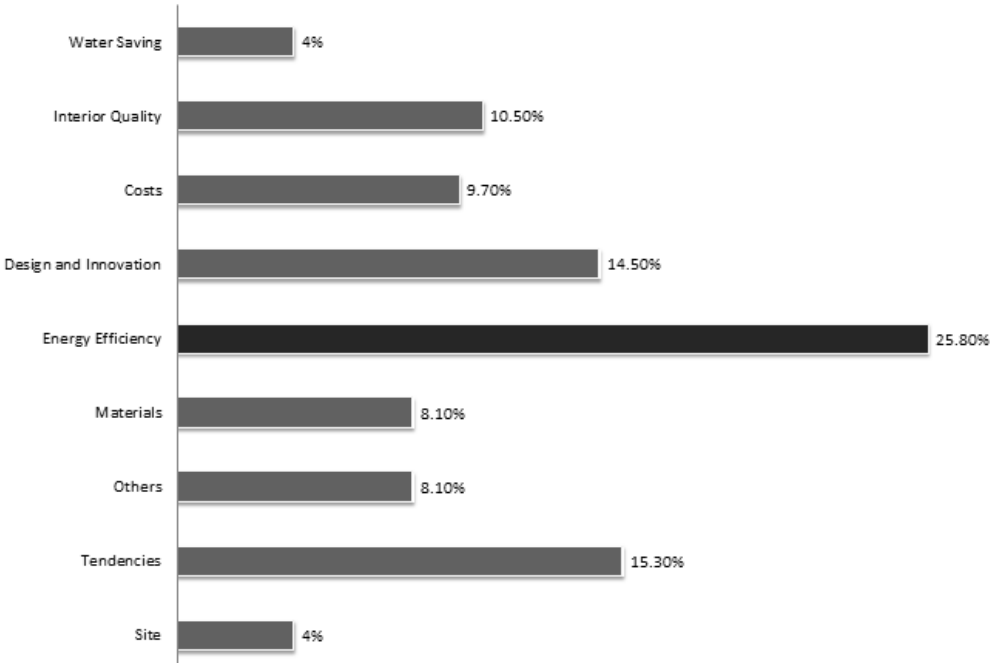

Figure 4. Papers related with Green Buildings aspects

BIM is a 3D modelling design method used in this phase because it generates results very fast compared with traditional methods. One of BIM tools is Autodesk Revit which allows the user to overlay designs (structural, architectural, plumbing and so on). The user can be able to see and avoid mistakes in the construction phase. Also Autodesk Revit can lead to gain, directly or indirectly, up to 38 LEED points. However, this tool requires initial training and adaptation, which costs about 70% of the acquisition cost of the software, additionally the initial productivity falls 50%. Following the training period (3 months approximately), the investment is recovered with a productivity increased of 25%[8].

Several authors agree that buildings consume 30-40% of energy[9-10]. Although energy efficiency measures in the design phase can achieve savings up to 40%. Otherwise, there was no statistically significant relationship between LEED certification level and efficiency measure. In other words, a LEED-Silver building did not show better energy performance than a LEED-Certified building. This could be attributed to many efforts focused on energy efficiency, and LEED certification requires a minimum score of 40 and the maximum score of Energy Efficiency ranges from 33-37 (depending on category), so if the stakeholder is looking for building energy efficiency then is very easy to meet a couple of additional requirements to obtain LEED-certified, not being the case if the goal is to obtain a certification LEED-Gold/Platinum[7].

Water conservation is one of the critical categories of LEED evaluation system, and is linked with energy savings[11]. Green roof is one of the strategies closely related with water use improvement, but in some cases buildings are promoted as "green" just because they have a "skin vegetable or green roofs." Green roofs can purify the air, reducing the possibility of floods and act as a thermal insulator[12], but if they do not act in conjunction with other elements these do not make the building green.

Otherwise there are some very common diseases such as asthma, rhinitis, and dermatitis, among others that could propagate causing poor performance in the worker. Also, the Sick Building Syndrome could appear creating symptoms such as dryness and itching eyes, nose, throat and skin, nasal congestion, drowsiness, headache among others that only occur in the work area but once outside the building these symptoms fade[13].

Concerning to materials, concrete is the most commonly used in building construction; however the manufacturing of it have a great impact on the environment. Recent efforts are aimed to produce a new type of clinker with a lower carbon footprint, reducing 25-30% of CO_2 emissions in their production process[14].

Glass selection becomes a main element to contribute towards achieving a green building, according to LEED. A large percentage of glass is used on the facades of buildings, 25-40%. Excessive daylight causes heat inside and visual discomfort, causing the cave effect[15]. Also, ecological materials such as natural stone, native wood, clay brick, linoleum, lime or silica paint, etc. are recommended.[16].

The World GBC promotes Green Building certification rating system without imposing any certification system. There are differences between the certification ratings systems because they must adapt to the governmental and building regulations, weather conditions, designers specifications, etc. in each country, but these differences do not affect the result of the evaluation.

Countries with green legislations play an important role being one of the main engines of the Green Building. Developed Countries have rules and standards that help

highly marked Green Building tax incentives to promote them. However, Green Buildings in developing countries are entirely voluntary and are paid by the owner, and does not exists an economic incentive from the government to speed up this process.

Green Buildings show an average increase in initial costs, but this increase results in a subsequent life-cycle savings, and can quickly return the initial investment and then contribute to the profitability of the building because is a cost effective investment. Therefore, Green Buildings are economically viable.

The economic benefits are one of the most important factors for all stakeholders: low cost of operation, increase of the value of the construction, increase in market share through marketing, saves on costs and productivity health, profits increase and reduction of respiratory illness, although the last is very difficult to measure[17].

Some barriers that may be mentioned are: insufficient efforts to implement policies, technical difficulties during the construction process, lack of knowledge and awareness of green technologies, among others, and in general, the initial extra cost is considered the greatest (more significant) barrier for the application of green technologies

4. Recommendations

Use BIM and other tools such as Autodesk Revit, IES Virtual Environment, among others, which allow 3D modelling simulations to see the operation behaviour of buildings, calculation of energy requirements; and some manual controls to prevent errors in the documentation LEED.

Implement the use of green roof and building automation to improve water saving, energy efficiency. Furthermore, green roof and building automation can help to improve interior quality, adding user comfort and efficiency.

Using of low toxicity finishes, allowing occupants more control over lighting and including ergonomics aspects can contribute with a better indoor quality. Furthermore, it is recommended a POE (Post Occupancy Evaluation).

Apply ecological materials as natural stone, native wood, clay brick, linoleum, lime or silica paint, and also double or triple window glazing in façade to reduce cave effect.

The legislation as mandatory encourages, promotes and contributes to the green building construction. In other words is the main starter of green buildings.

Table 3. Green Building aspects

	MAIN ASPECT	RECOMENDATION	OBSTACLES
DESIGN	The shape and orientation can significantly influence the design and then affect costs, energy efficiency, water savings, materials, etc.	BIM is a 3D modelling design method. It generates results very fast compared with traditional methods. Also with this method it can be obtained a gain, directly or indirectly, LEED points.	Initial training and adaptation are required, which costs about 70% of the acquisition cost of the software, additionally the initial productivity falls 50%
ENERY EFFICIENCY	Buildings consume 30-40% of energy.	Implement the use of green roof, solar collectors, building automation, triple glazing	A huge number of proposals with lack of data, lack of time, low budget, low technical experience. Furthermore, the uncertainty about what concepts or elements need to be improved and/or can be improved.
WATER SAVING	Water saving is necessary to conserve water and its closely linked with reduce energy consumption (contributing to energy efficiency)	Implement the use of green roof to water reuse and energy performance, and building automation as infrared sensors in bathrooms to improve the performance water.	Initial cost of water reuse systems, the design of one strategy varies and depends of building characteristics, and aesthetics.
QUALITY INDOOR	Related directly to health, comfort and productivity.	Use low toxicity finishes, allowing occupants more control over lighting, including ergonomics aspects. Furthermore, it recommends a POE (Post Occupancy Evaluation).	There are many diseases such as asthma, rhinitis, and dermatitis, among others that could propagate causing poor performance in the worker. Also, the Sick Building Syndrome could appear. .
MATERIALS	Concrete and glass are the most used materials.	Ecological materials as natural stone, native wood, clay brick, linoleum, lime or silica paint, etc. The use of double or triple window glazing.	"Green" is not clearly defined, making it difficult to find green materials and in most of the occasions green materials are more expensive than conventional.
LEGISLATION	As mandatory encourages, promotes and contributes to the green building construction. In other words is the main starter of green buildings.	Encouraging the use of evaluation systems in state agencies or public building projects.	Poor or non-existent in development countries. There is no single plan.
COSTS	Determine the profitability of the project	Perform of a cost-benefit assessment and plan projects, taking into account the additional investment cost.	Some of the benefits are hard to measure such as health and, productivity, performance

5. Conclusions

The amount of papers found through the literature search shows that there is a lot of information available about Green Buildings. Every day, more people, groups, associations, governments, countries are interested in joining the "Green Movement", mainly aware of the importance it has on the environment and also helped by the economic benefits that are available and last but not least, the prestige and recognition that this brings.

United States is the country with more papers published and this could be attributed to the fact that LEED Rating System is the most internationally recognized certification rating system, developed by US Green Building Council.

A building is green when successfully meets all criteria for attaining certification and all green buildings aspects are closely linked. Good design leads to implement energy saving measures which in turn may or may not influence the water savings. To implement these measures is necessary to use materials, devices, green technology and others aspects. The initial cost increment in green building is the most common of barriers.

The energy efficiency is the most interest topic to researchers, because involve in a directly or indirectly way others green building aspects (design, materials, water saving, cost). For that reason, a future line research could be energy efficiency with low cost.

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REFERENCES

[1] Office of the Federal Environmental Executive. The Federal Commitment to Green Building: Experiences and Expectations, Available: http://www1.eere.energy.gov/femp/pdfs/fedcommgreenbuild.pdf

[2] Sam Kubba, Green Construction Project Management and Cost Over site, Elsevier, USA, 2010.

[3] Sidney Levy, Construction Process, Planning and Management: Green and Sustainable Buildings, Elsevier, USA, 2010.

[4] Spain Green Building Council Available: http://www.spaingbc.org

[5] Ignacio Paya-Zaforteza, Victor Yepes, Antonio Hospitaler, Fernando Gonzalez-Vidosa, "CO_2-optimization of reinforced concrete frames by simulated annealing", Engineering Structures, vol. 31, no. 7, pp. 1501-1508, 2009.

[6] Victor Yepes, Fernando Gonzalez-Vidosa, Julian Alcala, Pere Villalba, "CO_2-Optimization Design of Reinforced Concrete Retaining Walls Based on a VNS-Threshold Acceptance Strategy", Journal of Computing in Civil Engineering, vol. 26, no. 3, pp. 378-386, 2012.

[7] Diana Owensby-Conte, "Green Buildings: analysis of the evolution, present and future" Minor Thesis, Universitat Politècnica de València, Spain, 2012.

[8] Salman Azhanar, Wade A. Carlton, Darren Olsen, Irtishad Ahmad, "Building Information Modeling for Sustainable Design and LEED® Rating Analysis", Automation in Construction, vol. 20, no. 2, pp. 217-224, 2011.

[9] Luis Pérez-Lombard, José Ortiz, Christine Pout, "A Review on Buildings Energy Consumption Information", Energy and Buildings, vol. 40, no. 3. pp. 394-398, 2008.

[10] Ashwin Sabapathy, Santhosh K.V. Ragavan, Mahima Vijendra, Anjana G. Nataraja, "Energy Efficiency Benchmarks and the Performance of LEED Rated Buildings for Information Technology Facilities in Bangalore, India", Energy and Buildings, vol. 42, no. 11, pp. 2206-2212, 2010.

[11] Cheng-Li Cheng, "Study of the Inter-Relationship between Water use and Energy Conservation for a Building", Energy and Buildings, vol. 34, no. 3, pp. 261-266, 2002

[12] Cheng-Li Cheng, "Evaluating Water Conservation Measures for Green Building in Taiwan. Building and Environment", vol. 38, no. 2, pp. 369-379, 2003.

[13] Junta de Castilla y León. Manual sobre edificios saludables Available: http://www.intersindical.es/boletin/laintersindical_saludlaboral_02/archivos/edificios_saludables_2parte.pdf

[14] Cemex España. Cemento Sello Verde Available: http://www.cemex.es/ce/ce_pr_cc.html

[15] Mohsen M. Aboulnaga, "Towards Green Buildings: Glass as a Building element—the Use and Misuse in the Gulf Region", Renewable Energy, vol. 31, no. 5, pp. 631-653, 2006.

[16] Víctor Yepes, "Influencia de la calidad del proyecto y diseño de un hotel en la protección medioambiental", Forum Calidad, 113/00, pp.28-34, 2000.

[17] Gregory H. Kats, Capital E, The cost and financial benefits of green buildings: a report to California's sustainable building task force, USA, 2003.