BUILDING MATERIALS TO IMPROVE INDOOR AIR QUALITY: AN APPROACH TO MARKET ACCEPTANCE

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ABSTRACT

Increasing concern over the negative effects of building materials on the environment and people's health has spurred the development of alternative, safer materials. Many people have changed the way they live by undertaking a healthier lifestyle through proper nutrition and increased exercise. Nevertheless, the quality of the indoor air we breathe has not drastically improved, and this is a vital component that still remains an issue to be improved while attempting to fulfill a healthier lifestyle. Health Canada (2005) demonstrated that interior environments are up to five times more polluted that exterior environments – even though it has been 30 years since indoor air quality was identified as a health concern.

Having developed a theoretical framework highlighting the importance of indoor air quality, the author devised a methodology for the selection of healthy, safe materials options in the regional marketplace. A list of products was selected for three interior systems of materials: flooring, wall finishings and complementary materials, based on North American standards and guidelines to achieve healthier indoor environments. The author evaluated and compared them with conventional materials, based on five criterions of study, in order to identify the advantages and disadvantages of each while competing in the open market.

The results showed that the main weakness of 'safe' alternatives is the lack of a variety of options for design purposes. In addition, the evaluation demonstrated that many healthy alternatives are consequently more effective options overall due to applied research that has served as means of development for new products. In contrast with the author's hypothesis, the economic concerns (i.e. price) are **not** the deciding factor with respect to market acceptance of healthier products.

RÉSUMÉ

L'inquiétude croissante face aux effets négatifs de matériaux de construction a généré une série des stratégies alternatives pour réduire cet impact négatif non seulement dans la planète, mais aussi dans la santé des gens. Un grand nombre d'eux ont décidés de changer la façon dont ils vivent en prenant un comportement plus sain (alimentation, exercice, etc.) Néanmoins, la qualité de l'air intérieur demeure toujours une question qui devrait être améliorée tout en essayant de remplir une vie plus saine. Santé Canada (2005) a démontré que les environnements intérieurs sont jusqu'à cinq fois plus pollués que l'extérieur (même après plus de 30 ans que la QAI a été trouvée comme un cadre qui devra être résolu).

Après avoir développé un cadre théorique sur l'importance de la qualité de l'air intérieur, l'auteur a développé une méthodologie de sélection pour les options saines dans le marché régional. Une liste des produits a été sélectionnée pour trois systèmes de matériaux intérieurs: sols, matériaux de finition des murs et complémentaires. Ces choix remplissent les normes nord-américaines et les lignes directrices pour permettre d'assainir les environnements intérieurs. L'auteur a évalué et comparé les matériaux choisi contre des options régulières basés sur cinq critères d'étude afin d'identifier leurs avantages et désavantages afin d'être acceptés dans le marché.

Les résultats ont montré que la principale faiblesse des alternatives saines se trouve dans les options de variété pour la conception architecturale. En outre, l'évaluation a démontré que les fabricants ont travaillé non seulement dans l'offre de propriétés saines, mais aussi basé sur la recherche appliquée, ils ont amélioré les qualités générales. Au contraire de ce que l'auteur a pensé au début de l'œuvre, le principal problème qu'affecte l'acceptation des produits plus sains dans le marché n'est pas un problème économique.

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Introduction

1.1 RATIONALE OF THE STUDY

In recent years, more and more people have become concerned with living a healthy lifestyle. Households have increased their interest in healthy environments, and, at the same time, placed a greater emphasis on the need for quality space.

Several scientific studies have demonstrated the effects of Indoor Air Quality (IAQ) on people's health. Health Canada maintains that reducing concentrations of pollutants in household environments helps to minimize the risk of allergies and breathing-related illnesses (Canada Mortgage and Housing Corporation, 1999). It has been found that specific construction materials, techniques and furnishings produce Volatile Organic Compounds (VOCs) like formaldehyde, benzene, vinyl, and chlorofluorocarbon (CFC). These VOCs can have a negative effect on inhabitants' health (Kim, Kang, Choi, Yeo, & Kim, 2006). Green's (2002) research report states that "there is convincing evidence that poor indoor air quality (IAQ) is damaging people's health." Indeed, Green's work relates the increase of some respiratory diseases (*e.g.:* asthma, allergies, and bronchitis) to indoor air quality problems, and Canada Mortgage and Housing Corporation (2002) states that in Toronto one in five Canadian houses has some form of respiratory affectations present (Fig. 1.1). In fact, indoor air quality researchers have accepted that these pollutants cause the Sick Building Syndrome (SBS) that produces headache, dizziness, difficulty concentrating, throat irritations and tiredness (Xiong, Zhang, Wang, & Chang, 2008). Ventilation, as a mechanism for purification, must be treated with special attention, as proper ventilation is one of the most important strategies that can be used to 'clean' spaces (Feng & Jianlei, 2006).

Type of Pollutant	Pollutant	Effect on people's Health	Source of Contamination
Inorganic Gases	Carbon Monoxide	Reduced endurance, nausea, headache, dizziness and death in very high concentrations.	Gas stoves, heaters (kerosene), vehicle exhausts.
	Ozone	Coughing; chest discomfort; nose, throat and windpipe irritation.	Electrostatic air cleaners, arcing electric motors, photocopiers, outside air.
	Nitrogen dioxide	Breathing difficulty in high concentrations; respiratory illness with prolonged exposure	Vehicle exhausts. Industrial emissions, gas stoves and kerosene heaters.
Volatile Organic compounds (VOCs)	Formaldehyde and other aldehydes, hydrocarbons, alcohol, phenols, ketones.	Eyes, nose and throat irritations; central nervous system depressant; possible carcinogens; prolonged exposure may cause sensitization.	Building materials; furniture, carpets, synthetic floor coverings, wallpapers, plastics; household products, beddings, toiletries, etc.; tobacco smoke; gas stoves; space heaters; pesticides.

Figure. 1.1. Types of pollutants that affect Indoor Air Quality and their implications on occupants' health. (Source: Friedman *et al*., 1994)

The proposed study aims to address the following concerns: What construction materials have been introduced in North America to reduce indoor air pollution? Are they more expensive? While significant evidence has been unearthed from existing research, developers and homebuyers have not realized the importance of the problem and remain unaware, since they still continue using unhealthy products and construction techniques. The causes and consequences of this phenomenon will allow for the development of a series of evaluations and recommendations, not only for builders, but also for homeowners. This is the first step to understanding the problem, and to begin to become critical and demanding of the spaces that people select to live in.

1.2 ANTECEDENTS

The concept of Healthy Housing was introduced by the Canada Mortgage and Housing Corporation to “promote the health of its occupants while considering the environment and preserving our natural resources” (CMHC, 2007). For that purpose, five essential elements were presented to develop this new concept:

- Occupant Health
- Energy Efficiency
- Resource Efficiency
- Environmental Responsibility
- Affordability

For the purpose of this research, the first of these ‘essentials’ will guide the study and serve as a background to set the basic concepts in the developing process of achieving better indoor environments.

Moreover, a primary literature review has been undertaken to understand the basics of the problem as a part of the first stage that will be explained in the methodology. The core of this first stage is based on research reports from the CMHC (2002a; 2002b; 2004), specialized books as well as research reports from focused experiments and works from researchers that have studied the topic in depth.

Green (2002a) argues that the influences of poor Indoor Air Quality are affecting inhabitants’ health, citing the rating of the United States Environment Protection Agency in which poor IAQ is listed among the top environmental risks to human health. His research was based on 20 case studies of attempts to provide healthy indoor environments, and it offers an initial framework to start developing specific concerns about the topic. An analysis of Green's results leads to the inevitable conclusion that a great deal more research is needed in the field. He encourages further researchers to study related questions that remain unanswered. Based on Green's recommendations, the author plans to develop the framework focusing on the number, significance and sources of indoor pollutants. In particular, the study will commence with a review of which pollutants are really affecting IAQ, their effects on human health, and where they are coming from.

Craig, Bourassa, Rouest, Hill and Marshall (2004) research has been instrumental in understanding the basic problems, and classifies contaminants as falling into one of two categories: biological, and chemical. The former refers to mold and bacteria that can grow within dwellings caused by moisture; the latter is more related to materials and their components, and these chemical contaminants will be developed in depth in this work. According to Craig *et al.* (2004) it is crucial to precisely identify the origin of each pollutant, and its possible effects and influences. Knowing the origin of a pollutant will make it far easier to reduce or eliminate the source of emission.

Nugon-Baudon and Lhoste (2005) focus their book on the elements that affect and modify indoor air quality. They extensively develop concepts, origins and characteristics of volatile organic compounds, and based on French and European guidelines, offer critical data about the safe limits that one can handle in indoor dwellings' environments. Contrasting this data to Health Canada guidelines for these contaminants will be interesting, as Canada research on the topic is still very sparse, and it may truly be necessary to update Canadian standards in this regard. Citing Green (2002a) when introducing his research he says "Europe and United States are notably much further ahead".

Recent research has been reviewed, and a variety of perspectives in the same field have been developed. At this time, two research reports present important information that can be used to support the framework, and leave open ideas to be considered in further studies. In Li and Niu (2006), the authors test a model to measure emission of VOCs in rooms. The effects of various construction materials were investigated, and the effects of natural ventilation on the space were assessed as well. One of their important conclusions is that providing natural ventilation does reduce the concentration levels of pollutants in indoor environments. In the second report, Kim *et al.* (2006), takes this a step further, by comparing two methods to reduce VOC concentration levels in indoor environments. One method is natural ventilation; the other is based on decomposing principles. The latter has to do with chemical compounds that can reduce or even eliminate volatile organic compounds. They measured VOCs concentration in six apartments in the same building and having identical construction characteristics. Their results demonstrated that either natural ventilation or decomposing elements (chemical techniques) can deal with pollutants; however, even with treatment, the concentration levels of formaldehyde and toluene remained higher than international guidelines. On the other hand, the concentrations of benzene and styrene were not analyzed because the apartments were not carpeted and did not have painted walls, as they often do in Canada. That means that there is an interesting concern that needs to be studied in order to compare and analyze the results of these experiments in Canadian housing to fulfill the gaps that the actual system represents.

The above provides the initial approach to understanding and analyzing the problem, and establishes the objectives and goals of this study. A more specific and detailed literature review will support the framework and will be described in the first stage of this work in the second chapter as is presented below in the methodology.

1.3 RESEARCH QUESTION

The key research question of this study is:

> **What factors affect the acceptance of materials that help to achieve and improve indoor air quality in the North American residential housing industry?**

While developing this research project, complementary questions are to be answered in the understanding and analysing information process:

- Are there enough options in the market for people to select healthy products?
- What are the characteristics that safe products offer to achieve healthier indoor spaces?
- Are these products easily available in the local market?
- Why does the construction industry still use unhealthy products and procedures?
- Are there affordable alternatives to improve indoor environments?

1.4 OBJECTIVES

This study promotes strategies that will serve as a practical *'manual'* for builders and homeowners to reduce the risk of diseases caused by poor IAQ while selecting interior finishes for a given project. A detailed list of materials and their compounds must be developed in order to evaluate their advantages and disadvantages with regard of their market acceptance. Much has been said on this topic; however, most new houses and many renovations are still constructed using unhealthy procedures and strategies. This research aims to provide some additional thrust and motivation for people to learn more about employing modern building alternatives to promote healthier indoor spaces and improve their quality of life. In addition, a detailed study of the physical and economic properties of healthy materials will be described in order to establish the effectiveness and affordability of the proposed safe products.

In that sense, the main objective of this research is:

> To develop an evaluation of available products in the North American building market that help to achieve indoor air quality in order to identify the causes that affect their market acceptance. And create a list of recommendations that give additional thrust for them to be introduced as healthy interior alternatives.

To fulfill the objective stated above it will be necessary to develop the following secondary objectives that will lead this investigation to the final stage:

- Identify the source of pollutants (VOCs) that are affecting Indoor Air Quality.
- Identify what materials should be changed to avoid chemical influence on IAQ.

- Find a list of healthy products that may replace noxious options in interior environments.
- Encourage the expansion of the production of safe products to enlarge the possibilities of selection for costumers.
- Present an analysis of availability and cost-effectiveness of the findings.

1.5 METHODOLOGY

The structure of this research method will be inspired by Zeisel's (2006) work on research approaches. The process will be structured in stages, in order to fulfill the needs of the methodology separately and then it will be put together to analyze the data. After all the information is processed, the findings should deliver a compound of results that will be studied to generate the conclusion and recommendations.

It is necessary to begin collecting as much information as possible to build a vast knowledge about the topic. After setting limits and goals based on the review and analysis of the knowledge, the information must be filtered. Zeisel states that there are two types of studies that could be combined in order to develop a research project when the objective is to understand a topic: *Diagnostic* and *Descriptive*. The diagnostic study will permit the illustration of the topic in its amplitude, characteristics and essence (answering the *'what'*). Additionally, the descriptive study offers the opportunity to measure, analyze and evaluate the findings achieved previously (answering the *'how'*).

First, an explorative and/or diagnostic study will be developed. The questions will be: How do people in Canada build? What influences does this construction have on occupants' health? What safe materials are used in this construction system? And are these healthy options widely accepted in the market? Answers to these questions will enable a deep understanding of dwellings' component needs. It is important to identify the material properties and housing elements which have a possibility of generating pollutants that will affect the Indoor Air Quality (IAQ). Secondly, the information that results from the first stage will be analyzed and contrasted through a descriptive study. Answering the *how* will enable to evaluate whether or not a given indoor air quality promoter represents a valuable selection for a homeowner/designer. If there are healthier compounds in alternative materials it is important to assess how their performance is. It is important to identify how much effective and convenient these safe products may be compared with standard selections.

Finally, and as a contribution of this research, a list of recommendations for selecting construction and renovation materials in interiors of dwellings will be outlined. This must be presented in order to offer alternatives that can improve indoor air quality in housing. According to these guidelines one must take into account the basic principles of affordability and adaptability to permit households reaching better conditions of habitability in their environment.

1.6 OUTLINE OF THE REPORT

Chapter 1: Introduction

Presents the objectives and value of the study and its scope. In the introductory chapter, the importance of the topic and a brief background that serves as a foundation to support the research is presented. Additionally, the objectives and the methodology are detailed.

Chapter 2: Theoretical Framework

The chapter is divided into three sections. The first aims to situate the discussion in its historical context. Relevant information about its antecedents will be presented to understand the origins and the causes of it. The second part will detail all the concepts and definitions that will be presented through the work. The last part will show the influences and implications that Indoor Air Quality has had on occupants' health. By the end of this chapter, the reader should have a solid background understanding of the problem in order to move on the second stage.

Chapter 3: Evaluation Indoor Alternatives to Achieve Indoor Air Quality

The second stage begins here, with the development of a 'descriptive' study in which alternative materials will be presented, analyzed and evaluated. First the author will develop a selection process of safe products that can be undertaken after understanding the consequences of uncontrolled sources of harmful emissions in the interior environment. Secondly, the author will undertake an evaluation stage in which he will assess the upsides and downsides of every healthy option in order to establish the strategies of improvement for them to be more suitable in the building field.

Chapter 4: Conclusion and Recommendations

In this final chapter a discussion about the findings, its analysis and evaluation will result in a set of guidelines and recommendations based on the principles of affordability and influence on inhabitants' health. The detailed discussion and analysis of the evaluation results will be presented in order to deeply treat the advantages and disadvantages of the selected products. In addition, this report will identify potential areas for further research, in order to ensure further opportunities exist for developers as well as homebuyers to 'achieve indoor air quality'.

CHAPTER 2

Theoretical Framework

> *"There is no such thing as a "sick building," but it is a useful term to describe buildings that are unsafe or unhealthy for those who occupy them. Facility managers need to start an indoor air quality plan to identify, correct, and prevent indoor air quality problems. In many cases, taking action can limit exposure to liability, increase productivity, and save energy."*
>
> *Bas, Ed 2004*

2.1 SICK BUILDING SYNDROME

The energy crisis of the early 1970s resulted in a series of changes in the North American context. The need to conserve energy was realized in several important sectors of the economy, including the automobile industry which saw a significant reduction in earnings during the oil embargo between 1973 and 1974 (Frum, 2000). Governments became more aware of the situation and began to develop a series of alternative solutions to reduce their dependence on oil. Similarly, the construction industry was also affected by this heightened awareness of energy efficiency concerns. Hess-Kosa (2002) notes that, *"in an effort to conserve fuel in commercial and residential buildings, builders started constructing airtight buildings, inoperable-airtight windows, and reduced air exchange rates."* (Fig. 2.1).

In addition, new building materials were introduced in an attempt to reduce energy consumption and improve the effectiveness of insulation, but the use of previously unknown materials resulted in construction delays that generated extra expenses in ongoing projects. These new materials, while energy-saving in and of themselves, were based on chemical components that have since been identified as having potential negative effects on inhabitants' health.

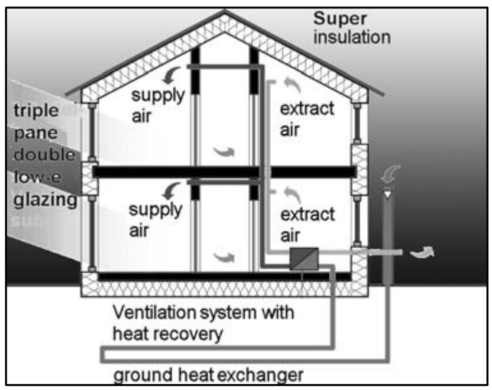

Figure 2.1. Diagram of the air tight interiors. Fixed windows are another important element as well as the ventilation system. (Source: CMHC, 2004)

Bass (2004) lists a series of effects and symptoms that began to be frequent in people that shared the same indoor environment (Fig. 2.2).

Respiratory	Nervous	Skin	Eyes
- Irritation of nose and throat - Airway infections - Cough - Hoarseness of voice - Wheezing	- Mental fatigue - Headache - Nausea - Dizziness	- Dryness - Erythema - Unspecified hypersensitivity and reactions	- Irritation - Dryness - Hypersensitivity

Figure 2.2. Classification of effects and symptoms by systems and organs. (Source: Bas, 2004).

The concept of the *Sick Building Syndrome* was introduced in 1982 by the World Health Organization (WHO) to describe a condition in which the influence of particular elements in the indoor environment causes these specific problems for workers in particular buildings and living spaces; however, *Sick Building Syndrome* has not been defined as a medical diagnosis (Wood, 1999). Instead, the term has been used as a descriptor for those buildings where occupants present these reactions, the reactions cannot be linked to any previous medical antecedents, and the reactions diminish and disappear when the victim leaves the building (Service Employees International Union, AFL-CIO, CLC, 2005).

2.1.1 The Influence of Ventilation in Sick Building Syndrome

A wide variety of actual causes of *sick building syndrome* have been identified through the many years of studies. Research results implicate two major elements that produce these unhealthy effects. First, new alternative construction components designed to reduce heating loss involved the use of many potentially harmful chemicals. For instance, the formaldehyde present in many construction materials (particleboard, glues and so on) and from some specific furnishings has been linked to many of these symptoms (Fig. 2.3); indeed, it has even been identified as a *“deadly”* component (Hess-Kosa, 2002). Second, biological pollutants became more numerous and prevalent, due to the minimization of all forms of natural ventilation (Fig. 2.4).

In fact, the lack of appropriate ventilation has been identified as the main cause of problems related to inhabitants’ health and their relationship with the buildings they occupy. Godish (2000) asserts that the *“relatively low rates”* of ventilation used in buildings is the reason that these two elements have such a negative influence. Harmful emissions from various building materials, furnishings, finishes, and so on are not properly ventilated to the outdoors. In other words, the lack of effective ventilation systems has been the major concern while facing indoor environment issues.

Figure 2.3. Particleboard elaborated with formaldehyde as adhesive.

Figure 2.4. Sample of improper ventilation that causes mould and generates ideal conditions for bacteria and biological pollutants. (Source: CMHC, 2005)

2.1.2 Achieving Indoor Air Quality to Reduce Risk of Sick Building Syndrome

As a result of these studies, the concept of *indoor air* quality, or IAQ, has been developed. Bas (2004) defines *"quality"* air as *"air in which there are no known contaminants at harmful concentrations as determined by cognizant authorities and with which a substantial majority (90 percent or more) of the people exposed do not express dissatisfaction."* This definition is vague because it does not unify criteria or provide specifics as to what concentration of contaminants might be considered 'harmful'. Since the Sick Building Syndrome phenomenon was first discussed by the WHO in the mid-1980s, various governments have initiated discussions about setting guidelines and recommendations to control the level of pollutants in living spaces. However, these codes have not been standardized and there still remain disagreements (Fig. 2.5).

WHO (World Health Organization)	U.S.			U.K.	Canada
	OSHA (Occupational Safety and Health Administration)	**HUD** (Dep. of Housing and Urban Development)	**OEHHA** (Office of Environmental Health Hazard Assessment of California)	**London Hazard Centre**	**Health Canada**
100 ppb	**750 ppb**	**300 ppb**	**23 ppb**	**1000 ppb**	**100 ppb**

Figure 2.5. Guidelines for formaldehyde in different organizations. (Source: http://www.who.int/en/; http://www.osha.gov/; http://portal.hud.gov/portal/page/portal/HUD/; http://oehha.ca.gov/; http://www.lhc.org.uk/; http://www.hc-sc.gc.ca/index-eng.php)

In fact, divergence has existed since the start of the SBS discussion, and a variety of scopes have been proposed. For instance, Brightman and Moss (2001) identified differences among international institutions while attempting to define Sick Building Syndrome when they state that: *"Common to each of the definitions are symptoms of the central nervous system (headaches, lethargy, and fatigue) and mucosal membranes (eye, nose, and throat irritation). Although both European panels identify skin symptoms as part of the SBS complex, the American panel does not. Further, the WHO panel lists odor and taste sensations, while the other two do not."* (Godish 1995).

Godish (2000) claims that much research has suggested that there is no such thing as *Sick Building Syndrome*, and that the cause of these reported symptoms may be a variety of *"exposures"* in particular buildings; however, Hess-Kossa presents interesting data to support the fact that more than one million office buildings have occupants who have developed these symptoms. At the end of the day, whether or not one ascribes to the belief that *sick building syndrome* exists, it is clear that Indoor Air Quality concerns remain an important issue to be considered when providing healthy indoor environments.

Indoor Air Quality having been accepted as a basic issue to be taken into account when facing health problems linked with build environments, another definition has become a part of the discussion: *Building-Related Illness.*

2.1.3 Building-Related Illness

Building-Related Illness (BRI) differs from SBS in the sense that symptoms do not disappear when the victim leaves the building, and BRI has been recognized as a diagnosable medical condition or disease (Brightman & Moss, 2001). BRI's are typically caused by chemical and biological agents. Brighman and Moss rely on Kreiss (1996) to classify theses diseases depending on their nature as: *"airborne infectious diseases, hypersensitivity diseases, and toxic reactions."* Some of these illnesses as mentioned by the authors are: Pontiac fever, Legionnaires' disease, histoplasmosis, tuberculosis, measles, rubella, chicken pox, influenza, and the common cold caused by adenoviruses and some rhinoviruses.

One particular example can be cited to highlight the causes and effects of BRIs and the importance of improving IAQ to avoid creating conditions that encourage these affectations to be presented in indoor environments. Wood (1999) describes the case in which fungi cause a tremendous affectation not only on people's health but also on the economics of a county in Florida. He describes how over $30 million needed to be invested to renovate the courthouse of the county as well as the headquarters of its Transportation Department. Another important case described by the same author is the one in which 221 attendees became ill and 29 died after the America Legion Convention in Philadelphia in July 1976. Wood sustains that after five months, the Centers of Disease Control found that the cause was a bacteria (called Legionella for the tragedy it caused) *"that had been around for a long time."* The *"Legionnaires' Disease"* was very effectively distributed throughout the building by the heating, ventilation, and air conditioning system, which afforded conditions necessary for it to incubate and contaminate the re-circulated air.

It is true that the notion of Sick Building Syndrome has been applied mainly to office buildings and workplaces; however, with the passage of time, new substances have been related to the problem (*e.g.,* carbon monoxide, organics, so on) and some of these new materials have been introduced into the housing industry. Some residential tenants now share the same concerns as their commercial counterparts. The origins and effects of these harmful emissions will be treated in the next section of this study. A detailed analysis of their negative implications will be identified, and a series of changes that ought to be undertaken to improve indoor environments will be suggested.

2.2 INDOOR AIR QUALITY

2.2.1 Introduction

As discussed with respect to the brief historical reference to Sick Building Syndrome (SBS), Indoor Air Quality (IAQ) has developed as the main means of defining the characteristics of the indoor environment, its properties and its effects on occupants' health. As mentioned above, one can state that IAQ is a broad concept that describes and evaluates the composition of the air that circulates in interior spaces, regardless of their intended use. The significance associated by former studies to the influence of this 'interior air' on inhabitants' health establishes the need to discuss the elements that influence and affect IAQ. This part of the study will develop complementary concepts and definitions that are important actors in the process of achieving improved IAQ.

It is important that clear definitions and boundaries of Indoor Air Quality be established, such that strategies for improving IAQ and achieving healthier interior environments may be identified and implemented. For that reason it is necessary to distinguish the elements that, together, alter the composition of the air in interior spaces. For instance, the pollutants that are present in the air will be described, their origins identified, and implications assessed. In addition, the ventilation characteristics of the space will be treated as a very important component of IAQ management protocols, as well as the characteristics and properties that some materials must have to be considered as a 'healthy option' in construction.

2.2.2 Definition

Turiel (1985) reported that North Americans spend 80 to 90 percent of their life indoors. Concerns over the impact of this lifestyle arose after the energy crisis began to affect the way buildings were constructed. The new tendency was to build airtight spaces that avoided heating loss and exterior air leakage (Tate, 1994). New synthetic materials developed specifically to improve the effectiveness of this airtight construction were introduced into the marketplace (Fig 2.6). At the same time and after the appearance of the SBS, the concept of Indoor Air Quality was introduced. Until this point, researchers and those interested in environmental issues had been primarily concerned with the importance of the composition of exterior air and its influence on people's health. After the early 1970s, the idea of exploring the consequences of some inadequate interior air components became part of the discussion due to the presence of some building-related health problems (Levin, 1993).

Figure 2.6. Fixed windows, synthetic materials and more effective insulation elements were introduced in the constructions. (Source: http://us.stollar.pl/okna-pcv.php)

Upon reflecting on the myriad of concepts and definitions on this topic, one realizes that the notion of Indoor Air Quality is merely a condition that can be assumed from the composition of the air in interior spaces. This composition must be tested in order to determine whether the air may be considered “healthy” or not; however, this study does not aim to measure (in a scientific fashion) the amount or levels of components and pollutants in the air. The main objective is to understand the relevance of maintaining safe levels of potentially hazardous compounds when they are in the insulated indoor environment. IAQ is the condition of interior environments. It is affected by several factors associated with the building itself, including construction materials, ventilation and heating systems, and furnishings.

As previously mentioned, the increased use of chemical substances in building materials has increased the prevalence of health affectation on occupants. Since the introduction of formaldehyde and other compounds to the building industry, notable degradations in IAQ have been indicated. From structural elements to finishes, even residential housing has been filled with unhealthy components that have negatively impacted the quality of the interior air. Among the offending compounds are the Volatile Organic Compounds (VOCs), the most recognized actors that affect the condition of indoor environments.

VOCs are most common when inappropriate heating, ventilation and air conditioning systems (HVAC) are utilized as a means of air control in a cloister environment. In addition, room temperature conditions are ideal environments in which these VOCs evaporate and mix with the air. It is important to mention that a good ventilation and heating system is an effective alternative to improve indoor environment, but it is not the only element that needs to be reviewed.

The furnishing industry also includes many of these VOCs in its production, primarily as bonding agents, despite the damage they can produce to IAQ. The particular odour that new furniture transmits is characteristic of the presence of these pollutants.

2.2.3 Volatile Organic Compounds

Volatile organic compounds are one of the main contributors to poor indoor air quality, and have been implicated in several human affectations. VOCs are chemical substances that come from a variety of sources (Nugon-Baudon, 2008). They are characterized by their tendency to evaporate at warm temperatures, and thus become part of the indoor air. VOCs can remain in the air for anywhere from a few hours, to several months, depending on their origin and concentrations. The concentration levels depend on many factors, including materials, furniture, the season, the age of the building, and ventilation. VOCs have a tendency to be more prevalent in the winter, as many evaporate more efficiently at warmer temperatures (i.e. the heating system may generate even more favourable conditions for these pollutants to be emitted to the air). In addition, if the space is not well ventilated, these conditions and concentrations can quickly rise. These chemicals have been identified as being responsible for the 'new odour' not only in dwellings but also in cars.

Some VOCs are fairly commonly known of, including methane, benzene, alcohol, aldehydes, acids, acetones, dioxin, chloroform, xylem, trichloroethylene, and so on;

however, others remain relatively unknown, though they are no less dangerous, such as isocyanate (present in some plastics) and terpene (present in deodorants).

The origins of volatile organic compounds are various; however, Nugon-Baudon (2008) asserts that, in the construction industry, the most common sources are those originating from petroleum. Thus, propane, butane, benzene, xylem, toluene and styrene (usually used as organic solvents) are the former pollutants that have been introduced into the building market as ingredients added to some materials; i.e.: wall papers, paints, varnishes, adhesives, glues, carpets, and fragrances (Fig. 2.7). Baker (1998) recognizes the health implications when she sustains that “benzene is only one of many pollutants known to damage the immune system.” On the other hand, these former elements can also appear in other pollutants after more chemical processes. For instance one of the most infamous and a dangerous compound is formaldehyde. Several studies have linked formaldehyde to specific human sensitivities that will be explained in the next part of this chapter.

Figure 2.7. Products that emit harmful levels of VOCs and that need special conditions of ventilations when being used.

Formaldehyde was introduced in the industry as an attractive alternative to develop economic new materials. It originates from carbon compounds and its toxicity at high concentrations has been demonstrated to be harmful to humans' health. It can be found in most all chemically treated wood products: paneling, plywood, particleboard, fiberboard, wallboard, cabinets, hardboard partitions and furniture. In addition, it is used by the textile industry (in some clothing and linens), by the paper industry (in some waxed paper and paper towels), and in the production of personal care products such as soaps, cosmetics, and deodorants.

2.2.4 Ventilation

Efficient ventilation can remove the traces that more than 150 VOCs leave in a new house (Tate, 1994). Indeed, as previously mentioned, ventilation is often the most important component of achieving improved indoor environments. Nonetheless, poorly designed, operated or maintained the ventilation and heating systems can quickly become a detriment to indoor air quality. The technicalities of HVAC system design (such as the number of air exchanges per hour per room in a determinate unit) are beyond the scope of this study; however, an understanding of the relationship between these components and mechanisms for improving interior environments will be developed. As a part of this, it is important to analyze not only the utility of adequate ventilation and heating systems that can remove and purify the house, but also the ways in which this can be accomplished with the least consumption of energy.

A good ventilation system will evenly distribute enough air to every room in the unit, and must provide an effective exhaust mechanism. The air taken from the outdoors must be treated by a conditioning mechanism, either to heat it or to cool it to offer comfortable thermal and humidity conditions. The continuous flow must be guaranteed to avoid pollutant accumulations. Additionally, it is vital to operate and maintain the mechanical system in perfect condition to ensure that the system itself does not become a source of harmful pollutants.

In conclusion, the improvement of indoor air is achieved through the control of many different variables that, taken together, can provide a safe and healthy interior environment for people to live, work and entertain. Effective heating and ventilation systems will effectively control the most dangerous compounds that come from some materials that are used in housing constructions; however, the selection process for these materials must be reviewed in order to reduce the emission of these harmful pollutants. The risks and benefits of using these materials must be assessed in order to make reasoned decisions when designing liveable spaces. In addition, volatile organic compounds have been identified as significant contributors to interior air quality problems. In order to understand the depth and significance of these VOCs on occupants’ health, the next part will develop a series of affectations that these compounds produce.

2.3 HEALTH AFFECTATIONS

2.3.1 Introduction

Turiel (1985) describes a case in which one individual, Michael Wagner of New Jersey, had to pay $20,000 to remove the (now prohibited) foam insulation from his house, after he and other family members began experiencing several severe health affectations. They exhibited numerous symptoms, including a loss of equilibrium, headaches, nosebleeds, and an inability to concentrate. “Eventually I collapsed at work and had to be rushed to the emergency room,” he commented in an interview. Turiel asserts that after officials identified the insulation as a source of formaldehyde emission, the court ruled that the builder and the installer had to compensate the Wagner family to the tune of $225,000 in damages.

As mentioned above, poor indoor air quality affects occupants’ health. Turiel (1985) classifies two types of data used to analyze the implications of interior air pollutants on health: toxicological and epidemiological. In the former instance, the toxicologist draws upon the consequences that different substances can have on humans. In the latter, the scientist aims to analyze health issues on groups of people in specific communities to establish the factors that promote negative affectations. In this report, all data collected will, as a starting point, be classified as per Turiel’s methodology.

The toxicological data will describe the effects that VOCs have on inhabitants’ health. The epidemiological data will support the former with official statistics and charts that explain the frequency of these problems in determined groups of people.

We have already noted that there are specific environmental conditions that must be satisfied in order for pollutants to generate specific effects on people's health. Although formaldehyde and toluene have been identified as some of the most significant contaminants in indoor environments, this study will refer also to some other pollutants that are implicated in health problems.

2.3.2 Toxicology Perspective

From a toxicology perspective, the analysis begins with an investigation into the dose at which a particular substance becomes noxious, *i.e*. the threshold that will mark the separation between 'safe' and 'noxious.' Many studies and experiments have been undertaken by researchers to establish what are called 'the guidelines' that regulate the emissions that can be released by building materials into indoor air[1]. The dose will determine the toxicity of the substance based on a defined period of time of exposure. In the context of indoor air quality, acceptable levels of contaminants are typically expressed with regard to two timeframes: *short-exposure term* and *long-exposure term* (Turiel, 1985). The existence of multiple guidelines reflects the differences between spaces and their use, and the rate of air-exchange per hour. In a commercial or office environment, the number of air-exchange per hour is normally higher that in houses because of the large mechanical systems that serve large spaces and buildings thus, the exposure to harmful emission is reduced. Taking formaldehyde as an example,

[1]Public institutions and non-profit organizations have developed guidelines and accreditation programs to support and sponsors healthier building products. The author found that several research reports used in this study come from Tsinghua University in Beijin, Seoul National University in South Korea, Virginia Tech university in U.S., and The University of Tokyo in Japan. The guidelines and accreditation boards like Greenguard and Green Seal among others will be introduced in the next chapter.

Health Canada has established the limits for two types of exposure: 1-hour exposure (short-term) at 123 μg/m³ (micrograms per cubic meter) or 100 ppb (part of formaldehyde by part of air) and 8-hour exposure (long-term) to 50 μg/m³ or 40 ppb.

The affectations that these VOCs produce on inhabitants' health can be classified by the organs and biological systems that they affect. The respiratory system is the most vital system that is typically impacted by VOCs. They can produce several complications including lung concerns, respiratory symptoms and asthma. Some authors also argue that there are linkages between excessive concentrations of formaldehyde and the risk of developing nasopharyngeal and sinonasal cancer, and that more research is required on this issue (Health Canada, 2006). The eyes and skin are frequently irritated by VOCs, and they may also be responsible for the development of some types of allergies.

"The main function of the respiratory system is to provide oxygen to the cells of the body and to remove excess carbon dioxide from them" (Turiel, 1985). However, the respiratory system also serves to transport other substances taken from the inhaled air to the rest of the body (Fig. 2.8). This is typically how harmful components of the indoor air will ultimately damage vital organs of the system. These pollutants can remain in the alveoli if not well eliminated by the white blood cells. In addition, intermediate levels of formaldehyde can produce complications in people that already have asthma (Hess-Kosa, 2001). It has been demonstrated that formaldehyde increases the risk of an asthma attack when present in indoor environments. With Health Canada reporting in 2005 that more than 2.2 million Canadians already report asthma problems, this is a significant concern (Fig. 2.9). Higher concentrations of formaldehyde have been associated to some rare types of cancer in the respiratory tract. The relationship between formaldehyde exposure and cancer in the respiratory system has been analyzed by several studies in Europe, Asia and the United States. While results are not entirely conclusive, there is not, in any case, convincing evidence that it is a safe pollutant (Health Canada, 2005).

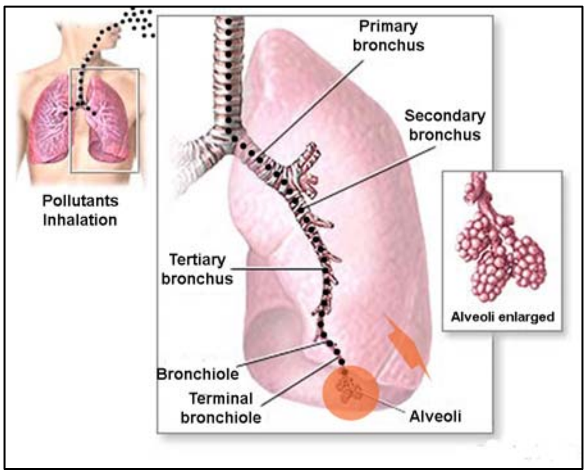

Figure 2.8. The noxious compounds travel through the airways to the alveoli where they may remain and affect the oxygen interchange. (Source: http://www.nlm.nih.gov/medlineplus/ency)

Group	1996/1997	1998/1999	2000/2001	2002/2003	2004/2005	% 10 years
Males	728,515	888,707	878,920	932,870	922,306	26.6
Females	1,049,669	1,126,226	1,292,828	1,293,900	1,327,397	26.5
Total	**1,778,184**	**2,014,933**	**2,170,748**	**2,226,770**	**2,249,703**	**26.5**

Figure 2.9. The increase of asthma has reached more than 26% in the last 10 years in both males and females. (source: Health Canada 2005)

Two additional components of the human body are affected by the contaminants compound of the poor indoor air. The eyes and skin can be irritated to varying degrees depending on the concentration of the harmful substances. The union of these noxious substances and the proteins of the tissues produces an immunological sensitiveness type 4 that is recognized by the Langerhan's cells and presented to the lymphocytes "T". This reaction is taken to the skin and eyes and contributes to the inflammation (Ring *et al*. 2005).

The above serves as a theoretical presentation of the health problems that can be derived from the concentrations of the VOCs that have been developed through this report. Practical information will be presented as follows to develop the epidemiological stage that will complete this section in order to support the exposed information.

2.3.3 Epidemiological Perspective

Several studies and experiments have been made to measure and evaluate the implications of formaldehyde and other volatile organic compounds when emitted to the indoor air. Two of the most reliable studies were undertaken by Norbäck 1995 and Rumchev et al. 2002. These studies clearly documented that children less than 12 years of age were the most vulnerable population. Furthermore, Nugon-Baudon asserted that the elderly are also at a much higher risk for complications, because of their long periods of time inside dwellings.

Norbäck (1995) measured a 2-hour exposure of formaldehyde and other VOCs in 62 dwellings. The results showed that 88 respondents aged 20-45 years-old reported respiratory symptoms. Concentrations of formaldehyde were detected in levels ranging from 5 to 100 µg/m³. Although no clear relationship could be demonstrated between these concentrations and asthma problems, the presence of nocturnal breathlessness was associated to pollutants' influences (Fig. 2.10).

Rumchev (2002) adopted a different strategy, measuring formaldehyde concentrations in two different seasons (summer and winter) in the context of long-term exposure. His objective was to demonstrate the implications of long-term exposure to formaldehyde in children under 3 years-old with physician-diagnosed asthma. While the report was ultimately inconsistent with regard to its analysis of seasonal effects, it was determinative when evaluating different concentrations of pollutants (Fig. 2.10). He demonstrated that the probability of children with asthma would return to the hospital after being hospitalized increased as the level of formaldehyde concentration rose. It is important to notice that the highest number of children returning to the emergency room was located in the concentration level of 10-29 µg/m³. Recall that Canadian Guidelines state that 50 µg/m³ are safe for long-term exposure. Interestingly, data collected from the control group of healthy children gathered by the hospital indicated that these children did not report many affectations even at levels of 30-49 µg/m³. This data suggests that those who have asthma or other respiratory conditions may be significantly more vulnerable to VOCs affectations. While the Canadian standards may be acceptable for the average person, compliance with those standards may still place vulnerable people (including children and the elderly) at risk.

Nugon-Baudon notes that elderly people are also exposed to long-term emissions of contaminants, especially those who spend most, if not all, of their time indoors. As a result, they are more vulnerable to the affectations. In addition, they often have underlying health conditions that make them more vulnerable to external elements that can affect them as well.

Study	Subject	Design	Formaldehyde	Results
Uppsala, Sweden 1991-92 **Norbäck (1995)**	88 people 20–45 years of age living in 62 dwellings	**Cross-sectional study** **E:** 2-hour active sampling at 0.25 L/min **D:** respiratory symptom questionnaire	Range: <5–100 µg/m3	A 10-fold increase in HCHO associated with Nocturnal breathlessness (OR 12.5, 95% CI 2.0–77.9, adjusted for age, sex, current smoking, wall-to-wall carpets and house dust mites).
Australia **Rumchev (2002)**	Children aged between 6 months and 3 years	**Case-Control** **Cases:** children discharged from a hospital emergency department with an asthma diagnosis (n=88) Controls: community controls without physician diagnosed asthma (n=104) **E:** 8-hour passive sampling in winter and summer **D:** Questionnaire	**Living room**: mean 27.5 µg/m3, max 189.7 µg/m3 **Child's bedroom**: mean 30.2 µg/m3, max 224 µg/m3	**Non-significantly increased risk of asthma** (OR 1.2) at 50–59 µg/m3. **Significantly increased** **risk of asthma** (OR 1.39, p<0.05) with HCHO60 µg/m3, compared to<10 µg/m3. ORs adjusted for house dust mite allergens, relative humidity, indoor temperature, atopy, family history of asthma, socio economic status, ETS, pets, air conditioning, humidifier and gas appliances.

Figure 2.10. Data of two major studies to measure the impact of formaldehyde concentrations in two different groups of people. (Source: Health Canada 2005)

Extensive studies by the World Health Organization (WHO), Environment Canada and Health Canada led to the establishment of guidelines for the safe limits to VOCs emissions in indoor environments. Formaldehyde emissions of 123 μg/m³ are allowed for short-term exposure, even though the highest level recorded by Health Canada during its 2005 study was 95 μg/m³. For long-term emission, the maximum level set was 50 μg/m³ based on the average of recordings in dwellings inspections, which ranged from 20 to 40 μg/m³.

The analysis in this chapter leads to three main conclusions. First, the introduction of new synthetic materials and construction systems has produced the ideal conditions for some pollutants to cause some specific health problems. These problems have been afforded greater recognition and attention in some countries than in others; however, the gradual homologation of guidelines based upon worldwide experience and research is resulting in improvements in the construction of new housing and renovations. Second, an effective ventilation system can dramatically reduce the concentration of contaminants in indoor environments, and is one of the most crucial components of an indoor air quality treatment system. Taking into account the guidelines that Health Canada has established for formaldehyde emissions, it is important to maintain (in an efficient manner) the ventilation systems in order to ensure that the amount of air exchange is sufficient to maintain safe concentrations of airborne contaminants. Finally, it is important to take into account that children and elderly people are the most vulnerable groups when VOCs concentrations exceed (and meet) levels generally believed to be ‘safe’. In addition, although cancer has not been demonstrated as an extreme disease associated to formaldehyde and other air pollutants emissions, several health problems remain linked to them and still represent a serious consideration to undertake. Based on the fact that Statistics Canada reports that more than 2.2 million Canadians already have diagnosed asthma, and more than 65% of the population exhibits high rates of allergies from several origins, it is important to continue the development of strategies that will ultimately allow us to offer and enjoy safe and clean indoor environments.

CHAPTER 3

Evaluating 'Healthy' Materials

3.1 INTRODUCTION

Global interest in sustainability is evident by the increasing tendency to focus not only on environmentally friendly regulations, but also on those that promote well-being, comfort, and health. These new considerations have raised different concerns about the way people construct the built environment. Around the world, several organizations have met to establish common criteria, regulations, and guidelines for a better construction process. In the author's view, when discussing alternative strategies to reinvent the building process, not only the impacts on the natural environment, but also health implications, need to be addressed. For the purposes of this research, North American standards and assessment methods designed to select building products will help to evaluate and rate a list of materials chosen for the analysis of their advantages and disadvantages, and their respective its market acceptances.

Varied assessment methods can be found internationally, with different countries adopting their own construction standards to meet their needs. Winchip (2007) states that they "were created to promote sustainable design and performance of buildings. Goals of these assessment programs include promoting sustainable practices and identifying common sustainable languages and standards of measurement."

Studying the aims of those systems one can state that among the different criteria of classification, one common concern that is often reiterated is related to people's health. For instance, the rating program promoted by the U.S. Green Building Council evaluates, through its criteria of selection, the amount of chemical emissions of building materials and the implications of these emissions on occupants' health (Haselbach 2008). Another example of this is the selection program that was introduced by the U.S. National Institute of Standards and Technology which is called Building for Environmental and Economic Sustainability (BEES). This assessment method takes into account potential health affectations on people from material from its manufacturing process through down to the final good (Winchip 2007). It is important to mention for the purpose of this study that concerns about occupants' heath are addressed by all these methods as an important element of discussion.

These methods (and others) will be briefly described, as a tool and guide to selection for materials to be evaluated in this work in the next section. For the purposes of this research, those materials that were selected to be part of the comparative and evaluative process will be rated under North American systems in order to maintain the stated criteria in the main objectives of the presented study.

3.2 ASSESSMENT METHODS FOR SELECTING PRODUCTS

The three assessment methods used to evaluate and select materials subject to analysis in this work come from (1) the Athena Institute based on the Life Cycle Assessment (LCA); (2) the U.S. Green Building Council (its rating system for constructions, the Leadership in Energy and Environmental Design (LEED)); and (3) a program presented for the U.S. National Institute for Standards and Technology, called Building for Environmental and Economic Sustainability.

The Athena Institute is a non-profit organization that helps professionals in the construction field to evaluate environmental impacts of building based on a Life Cycle Assessment (LCA). It offers a couple of tools that, applied together, serve to make a decision when selecting and analyzing materials for construction. The first is the Athena® Impact Estimator for Buildings, and the second the Athena® EcoCalculator for Assemblies (Athena, 2009).

Athena's definition for Life Cycle Assessment (Athena, 2009) is as it follows:

> *"a methodology for assessing the environmental performance of materials, assemblies and even whole structures over the course of their entire lives, from extraction through manufacturing, transportation, installation, use, maintenance and disposal or recycling."*

The Life Cycle Assessment is an internationally accepted strategy for contrasting and comparing specific products and the impact that they will have on the environment both as a component and, more importantly, as part of a complex system of construction

(Yudelson, 2007). Life Cycle Assessment goes beyond the analysis of indoor air quality as a component of the criteria. It reviews harmful emissions from the very beginning of the fabrication process. This means that the analysis of a material will be complex, and such a product will undergo testing at each stage of the life cycle: manufacturing, installation, maintenance, and disposal.

Complementary to this analysis of the construction materials themselves, there is the concept of the Life Cycle Cost (LCC). LCC focuses on economic issues arising throughout the life cycle of a material (Yudelson, 2007). It reviews all costs from fabrication through to disposal, and when combined with the LCA, offers a useful alternative to identify the best options for a project where there are environmental and economic concerns.

It has been established in recent years that new strategies are needed to stop the worsening of environmental conditions. Friedman (2007) states that governments, professional boards and non-governmental institutions have met to set standards and codes to regulate the negative impact in building practices: The U.S. Green Building Council giving Leadership in Energy and Environmental Design (LEED) certification demonstrates that the "building is environmentally responsible, profitable and a healthy place to live and work." (USGBC, n.d.). Among the advantages of LEED-certification, USGBC states that buildings constructed under their guidelines will "result in constructions that are healthier and safer for occupants".

By definition of the USGBC, the LEED system "was created to (1) define 'green building' by establishing a common standard of measurement; (2) promote integrated, whole-building design practices; (3) recognize environmental leadership in the building industry; (4) stimulate 'green' competition; (5) raise consumer awareness of 'green building' benefits; and (6) transform the building market" (USGBC, 2005).

This standard addresses concerns linked to the impact on the natural environmental as well as occupants' well-being through indoor environmental quality compositions and characteristics. From site selection to the physical properties of furniture, USGBC has developed a series of guidelines and recommendations for designers and developers to offer the most friendly solutions to the market (Haselbach, 2008).

Of particular interest is that the LEED rating system is especially concerned with low-emissions materials. It is beyond the scope of this study to detail the rating process itself; however, it is important to highlight the importance of this concern in this evaluation. As one of the eight credit categories, low-emitting materials become one of the major issues in the rating board (named as EQ Credit 4). Under this category one can find five subcategories that deal with three main aspects of materials (Haselbach, 2008).

- EQ Credit 4.1. Adhesives and Sealants
- EQ Credit 4.2. Paints and Coatings
- EQ Credit 4.3. Carpet System
- EQ Credit 4.4. Composite Woods and Agrifiber
- EQ Credit 4.5. Furniture and Seating

Each of these subcategories has a minimum requirement to achieve LEED evaluation. For each one of those parts or items, a mark or points will be made, and the resulting summation will locate the project in the appropriate category.

The LEED rating system has become the most complete and demanding accreditation board in North America, and has been a particularly lucrative asset to this study as a guide to select and evaluate products with regard to occupants' health, well-being and comfort.

For the consideration of economic issues and analyzing cost effectiveness, the Building for Environmental and Economic Sustainability (BEES) scale can help to identify significant economic implications in the selection process (Winchip, 2007).

The U.S. National Institute of Standards and Technology (NIST) has developed BEES as a tool for designers and engineers to set a criteria to contrast and compare construction products under sustainable issues with particular attention to the economics. Lippiatt (2002) states that "the purpose of BEES is to develop and implement a systematic methodology for selecting building products that achieve the most appropriate balance between environmental and economic performance based on the decision maker's values."

BEES will examine products in multiple life-cycle stages so that the results will give a broad idea of the true cost of the material in relation to other alternatives. It is important to introduce a multidimensional analysis for those products in order to avoid selections from simple concerns. According to Lippiatt (2002), basing the selection process on a single impact concern "may not be the most sustainable solution." The author cites an example in which she exposes that a "manufacturer might indicate that a product is 'green' because recycled content has been used or it has low-VOC emissions. These attributes might be accurate; however, the product's manufacturing process, or the means of transportation might have been very detrimental to the environment." From this example one can conclude that the notion of sustainability in the selection process might not receive great attention or present with a lot of options. While special attention to interior finishes that may affect indoor air quality and occupants' health is important, to introduce another series of ideas and requirements to make a best offer. In other words, while a selected material might very well meet all of the regulations about indoor air quality as established in North America, transporting said material for long distances (and consequently generating extra carbon dioxide emissions in the process) may nullify the environmental savings that were initially envisioned. For instance, it is well known that important reductions of formaldehyde have been undertaken in order to avoid harmful emissions to interior environments. While this low concentration in the final product could be safe for occupants, higher concentrations in the plant while fabricating the material may result in workers affectation.

Similarly, BEES will help to select materials that might result in a global sustainable pool of options in order to generate a complete outcome that will be healthy, and environmentally and economically sustainable for the market.

3.3 CHOSEN EVALUATION METHOD

As mentioned at the beginning of this paper, many studies have demonstrated the effects that are caused by harmful materials that are introduced in buildings' interiors. Much research has been presented and many new products have been developed to offer alternative solutions to the problem. However, the majority of homes are being constructed without regard to this concern, or at least with poor attention to the selection of interior components (Bass, 2004). Occupants' health remains on risk and Health Canada (2005) states that more that 2.2 million Canadians suffer from asthma, and more than 65% of the population exhibits high rates of allergies from several origins. This research will lead the discussion to understand the barriers that are affecting the introduction of safe alternatives in the building process, and the development of healthy strategies.

All the tools that were mentioned above will guide the selection process for materials that will be analyzed in the present study. The outcome will offer a list of high quality products offered in the market to be evaluated in order to identify their advantages and/or effectiveness as indoor air quality promoters. This work goes in depth to the properties and characteristics of the stated material to understand its advantages and disadvantages when used in indoor environments.

This chapter identifies the barriers that intervene in the market acceptance for the exposed products. This identification process will draw upon five criteria that evaluate the material and its participation in the market and building activity: availability, usability, variety, durability and cost.

With regard to *availability,* the author will study the ease by which a particular product may be attainable in common marketing outlets. This analysis will consider not only the final product accessibility, but also, and as a complementary outcome of this report, the availability of its ingredients and other raw materials. As Lippiatt (2007) argues, a product that has zero-VOC emissions but a manufacturing process that affects the environmental equilibrium might not be considered as a sustainable option.

For *usability* the author will evaluate the advantages and disadvantages of installing, maintaining, and replacing each product. Two subjects of analysis are incorporated in the study, as we look at the builder as the one responsible for the new construction; on the other hand the homeowner as a 'do-it-yourselfer'. This study will give an idea of whether or not the product feasibility attracts potential users.

Variety is directly related to marketing options. Here the author will address the possibilities that a consumer will have to select a particular healthy and sustainable material. Under this concern the author will analyze aesthetics characteristics of a given product that may affect architectonic conditions of spaces; *i.e.*: colors, textures, sizes, so on.

Once the product is locally available, does not require special conditions or skills to be incorporated in the building and gives a wide range of options, another question needs to be answered: will it last long? In *durability*, the author will rate whether or not the product lasts longer that its non-green counterparts. Additionally, the maintenance requirements to last for a long time are to be discussed in order to assess if it will need complex and expensive actions.

Finally, the author will undertake a *cost-analysis* study to identify if the product will be affordable and economically attractive. Two subjects of study will be addressed: the initial cost of the product by itself; and the cost of installation when it applies.

For the ease of the study, the selected materials are classified in three categories. These categories are set according to interior building systems and as a result of the author's interpretation of the EQ Credit 4 subcategories from the LEED-certification rating system. The first category is the floor, which includes included carpets, engineering, flooring and adhesives. The second building stage is to put up the walls, covering wallpaper and coating finishes. The third includes complementary materials that are required to include the two first systems. It is important to mention that all the products subject to evaluation produce zero- or low-VOCs and are safe for occupants' health. The product is recognized as a promoter of indoor air quality and certified by accredited organisms that regulate sustainable alternatives for the building market.

Its evaluation will consist in the comparison of its characteristics and the characteristics and properties of two other counterparts (one for complementary materials). One of them offers similar advantages to promote indoor air quality, and the other is chosen as a regular product that is offered in the market under standard regulations with disregard of indoor air quality.

The rating system is depicted in the following table, consisting of a mark that the author gives to every subject of study for each criterion. It is ranked on a scale from -3 to 3, where -3 represents the most negative opinion and 3 being the most positive, and where 0 is a neutral evaluation which means that the product in that specific subject does not have a negative effect, but does not have either a positive contribution to the interior environment and its occupants. An overall mark for each product will result in an indication of the author's evaluation for the given product compared with its control counterparts.

Mark	Meaning
3 and 2 (Positive)	The product contributes to the preservation of the environment, it offers several opportunities for the buyer to select from, does not require special skills or equipment to be included in the building system, is easily maintained, inexpensive, and so on.
1 and 0 (Neutral)	The product does not have any obvious negative qualities that would limit its selection. However, neither does it have positive contribution to the industry when analyzed under sustainability concerns, and more importantly, it does not contribute to promote indoor air quality.
-1 to -3 (Negative)	The product has some negative effects on the natural environment or on people's health, does not offer many choices for people to select from, usually requires special conditions to be installed and maintained, costs are high compared to similar products, etc..

3.4 MATERIALS EVALUATION.

3.4.1 Floor

3.4.1.1 *Marmoleum Click. Manufacturer: Forbo Flooring Systems.*

Marmoleum Click is a flooring product that is made from natural, renewable resources. It consists of a top layer of marmoleum which is pressed onto a jute panel that serves as a structure and a third cushion layer that provides a comfort underfoot[1]. Marmoleum is a product that primarily comes from linseed oil, an agrifiber product usually harvested in well-managed crops (Hubpages, 2009). As with its precursor, linoleum, it is usually used in sheets that are applied as a covering surface. One can state that Marmoleum Click is a hybrid flooring system. It has the environmentally friendly advantages of marmoleum and the installation convenience of laminate flooring systems (Fig. 3.1).

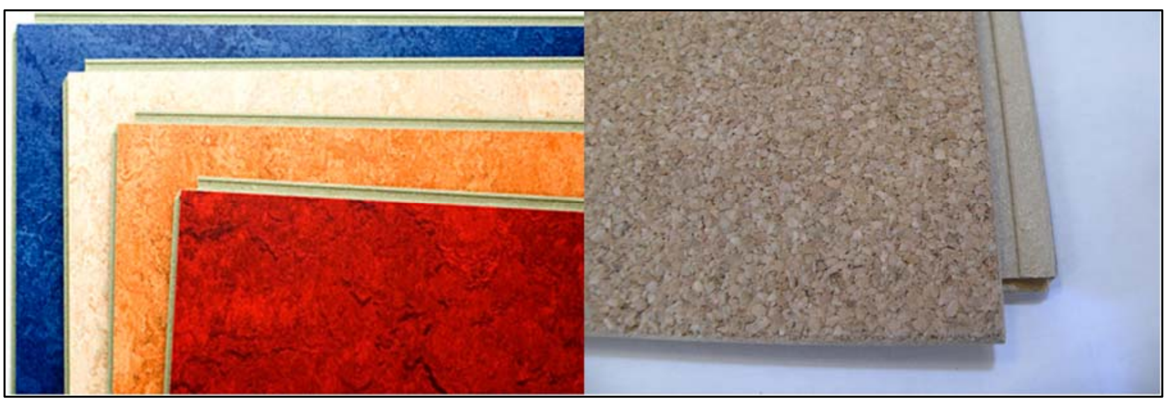

Figure 3.1. Marmoleum Click panels. Right: the top layer of marmoleum. Left: the bottom layer cushion. (Source: http://www.forboflooringna.com)

[1] The Oxford English Dictionary defines jute as "the fiber obtained from bark of the plants *Cochorus capsularis* and *C. olitorius* (family Titiaceæ), imported chiefly from Bengal, and used in the manufacture of gunny, canvas, bagging, cordage, etc." In addition, the Collins English Dictionary adds that this is a "natural strong fiber that is used in making sacks, rope, etc."

Forbo Flooring Systems has developed the product combining a layer of marmoleum with panels of composite wood free of formaldehyde and Isocyanate adhesives (BEES, 2007), which gives the material the possibility of being assembled instead of being glued. Additionally, it is biodegradable the company said.

Marmoleum click can be installed the same way that regular floating systems are. It comes in panels of 12 inches by 12 inches or inches by 36 inches, and it has a total thickness of 6.30/16 inches (Fig. 3.2). The manufacturer argues that "with a simple tongue and groove mechanism the panels simply click into place, and no glue is required, so the floor can be walked on immediately after installation" (Forbo Flooring Systems, n.d.).

An analysis of the physical properties of this product leads to the conclusion that certainly the product is elaborated from natural ingredients. The main compound for marmoleum is linseed oil which results "from pressing the seeds of the flax plant" (Forbo Flooring System, 2009). Additionally, pine rosins and wood flour obtained from controlled and FSC certified forestry industries and plantations are included to produce the structural panel[2]. For the pigments, the company sustains that ecologically friendly colors are added (Forbo Flooring Systems, n.d). From the specifications, one notices that these ingredients emit no VOC which gives another important element to the material. Finally, a layer of jute fiber (or cork) is added to provide a comfortable surface.

[2] According to Winchip (2007) the Forest Stewardship Council (FSC) "is a non-profit organization created to encourage the 'responsible management' of the world's forest". Its mission is to sponsor well managed forest through sustainable policies that permit to develop "environmentally responsible, socially accepted, and economically viable" forests around the world. (FSC, 2003).

This cushion is made from grown agrifiber that is generally produced in India and Bangladesh (Forbo Flooring Systems, n.d).

Element	Dimensions (mm)
Surface of Marmoleum	2.00
Structural Base (HDF)	6.80
Backing (Cushion surface)	1.00
Total Thickness	**9.80**

Figure 3.2. Structural dimensions for a panel of Marmoleum Click. (Source: Forbo Flooring Systems, n.d.)

Marmoleum Click contributes to the environment with a focus on achieving healthier interior environments. It has been certified by the Asthma and Allergy Foundation of America as asthma and allergy friendly[3]. The company reports that due to its natural ingredients, "Marmoleum Click is anti-static, so dust won't cling to it." Furthermore, results from independent lab testing demonstrated that it "inhibits the growth of many micro-organisms, including the MRSA strains of bacteria." (Forbo Flooring Systems, 2009). The selection of this product would be supported by all three assessment methods that have been presented to guide this study. A previous work directed by Gorrée *et al.* (2002), analyzes the LCA for linoleum (Fig. 3.3)[4].

[3] Since 2006, the certification program has been developed to promote products that have been tested by the not-to-profit union of medical and legal professionals in order to offer a documented option for the more than 60 million people in United States that have suffered from any sort of allergies and asthma. (http://www.asthmaandallergyfriendly.com/)

[4] The author considers that results and analysis of linoleum can be extrapolated to Marmoleum Click since this safe alternative is based the former material.

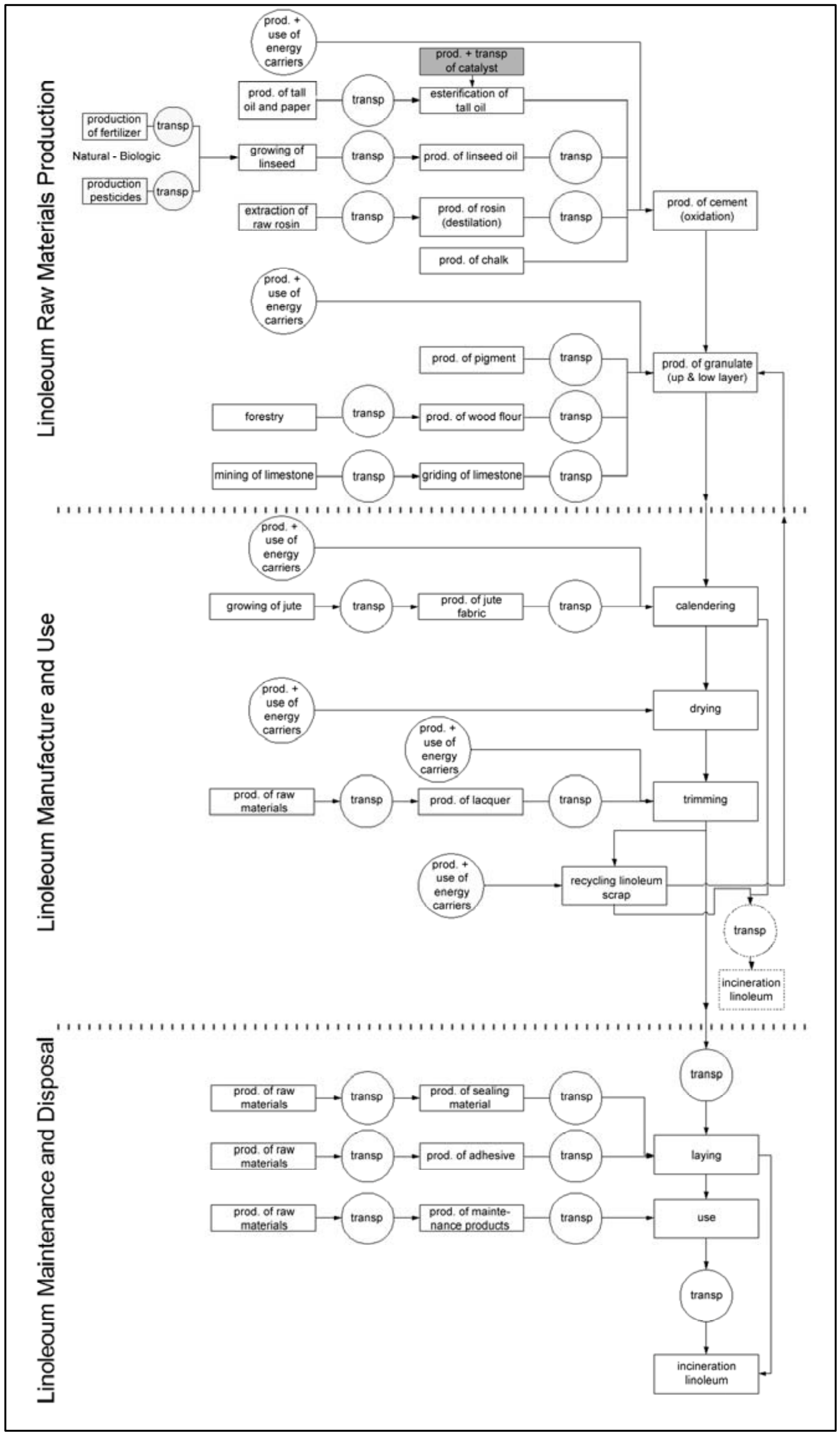

Figure 3.3. Diagram of the LCA analysis presented by Gorrée et al. (2002). The study was based on the analysis of the material from its production, use, and disposal. The gray areas show the stages where no accurate data was available. (Source: Gorrée et al., 2002)

The conclusion of the work supports the material as a safe option for indoor environments. Although there are some gaps in this study, particularly with respect to the global warming evaluation (due to the lack of precise information on the transportation of raw materials and final disposal), the main aim of this study is to evaluate materials that primarily promote healthy spaces through improving indoor air quality. Additionally, BEES results are low, which means that it contributes less (on average) of annual per capita environmental impacts compared to its counterparts (BEES, 2007). Finally, its zero-VOC components meet USGBC LEED-certification requirements for the EQ4 Credit category that rates and evaluates low-emitting materials for building materials.

After analyzing the commercial, physical and economical properties of the Marmoleum Click flooring system under the criteria selected for the purpose of this work, the following results are given in Figure 3.11. This results show a final overall assessment of how the author has rated the outcome of the research compared with standard products available on the market.

3.4.1.2 *EcoTimber Bamboo Flooring. Manufacturer: EcoTimber*

> *"Now there are affordable, durable, and rich-looking flooring options made from grasses and trees that mature in roughly half of the time that it takes hardwoods to reach market size."(www.toolbase.org)*

Bamboo flooring is a relatively new phenomenon, introduced less than ten years ago near the turn of the 21st century (www.sustainableflooring.com), and is an alternative to the traditional offerings of the North American flooring market: hardwood, regular laminates, carpets, ceramic tiles, stone, etc.

Solid Vertical-Grain Bamboo Flooring by EcoTimber consists of a single layer of natural material that is previously treated against moisture (Fig. 3.8). It is bonded with a formaldehyde-free and Isocyanate-free adhesive, and it is assembled from mature bamboo stalks (EcoTimber, 2009)[5].

Figure 3.8. Solid Vertical-Grain Bamboo. (Source: http://www.ecotimber.com)

The company reports that the products have received the FSC certification and meet the E1 and 2012 CARB standards for indoor air quality[6]. These characteristics enable the product to be included in the evaluation since it meets the author's requirements for

[5] The website www.toolbase.org which is specialized in flooring products reviews reports that the two most common specie to fabricate flooring matures in about three years (*Phyllostachys pubescens* known as "moso" in Japan, and "mao zhu" in China), however the same source argues that some companies "claim to use only five- or six-year-old culms or sprouts.

[6] California Air Resources Board that will be on effect on 2012. This regulation undertakes stringent criteria to sponsor indoor air quality. (http://www.arb.ca.gov)

VOC emissions. Another positive characteristic that has been found when reviewing the product properties is the hardness. According to the Janka Scale, one can identify that the hardness of the product is higher than many traditional woods used in the flooring market (Fig. 3.9)[7]. Additionally, when analyzing its physical properties, it is clear that bamboo is on the top of the list for Dimensional Stability evaluation[8]. After studying these two physical characteristics, one can ascertain that bamboo is a high quality material that could be incorporated in interior spaces, and thus selection of this product represents a valid alternative to be evaluated (Fig. 3.10a – 3.10b).

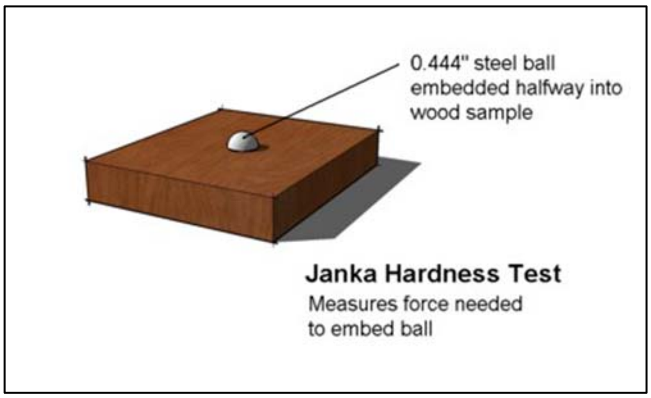

Figure 3.9. Janka Test as a tool to measure the hardness of determinated specie of wood. The results are given by the force that is applied to a steel to be embedded. The harder the wood the stronger the force. (Source: http://www.silicontraption.com/414pope)

[7] The Janka Hardness Rating developed by the National Wood Flooring Association is a test that measures the pounds of force per square inch that is needed "to embed a steel ball in a piece of wood" (Formisano, 2009). This means that the higher the number resulted from the test, the hardest the tested wood. For instance, Natural Bamboo has received 1380 which is higher than Red Oak (1290), White Oak (1360), and Yellow Birch (1260).

[8] Dimensional Stability list is prepared by the United States Department of Agriculture to evaluate wood species ability to maintain its size and shape based on the changes of the environment where it is used. For instance, its capacity to resist humidity and temperature. (http://agclass.nal.usda.gov)

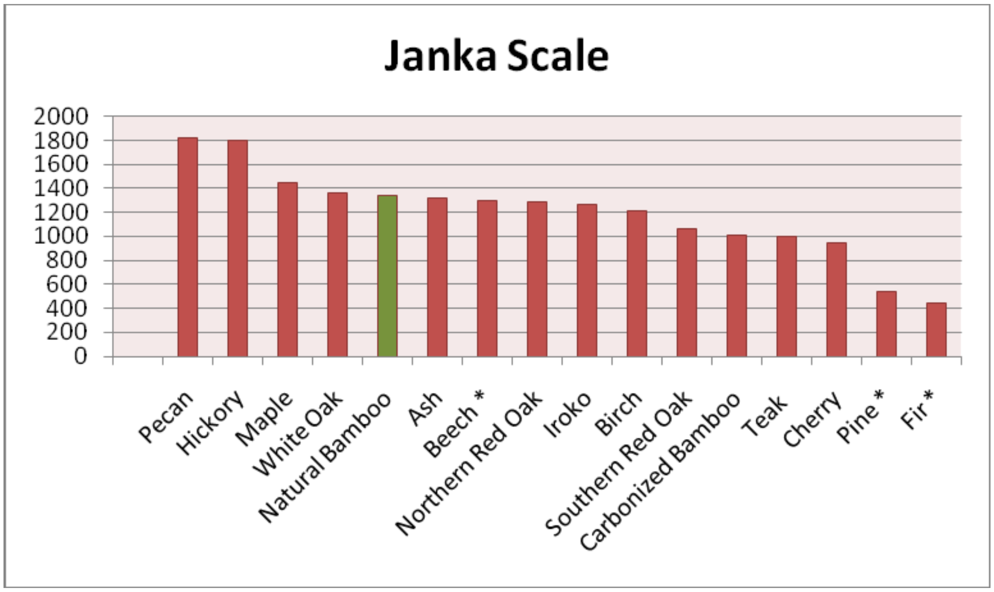

Figure 3.10a. The chart shows Natural Bamboo among the hardest wood species. *Average for species. (Source: http://www.fudeli.ca/documents/Hardness)

Wood Species	Dimensional Stability
Natural Bamboo	0.00129
Teak	0.00186
Cherry	0.00248
Pine *	0.00264
Fir *	0.00267
Pecan	0.00315
Birch	0.00338
Maple	0.00353
White Oak	0.00365
Northern Red Oak	0.00369
Hickory	0.00411
Beech *	0.00431
* Indicates average of species group	

Figure 3.10b. The table shows Natural Bamboo as the wood specie with best performance for Dimensional Stability. (Source: United States Department of Agriculture. http://www.usda.gov)

Due to its recent appearance in the building market, there is no life cycle assessment (LCA) study for bamboo or similar flooring alternatives. In fact, Bowyer (2009) states that "to date, there have been no LCA studies of bamboo flooring published." However, given the level of acceptance that this material has had in the market, it can be fully expected that comprehensives studies will be undertaken to assess the environmental and economic advantages and disadvantages. Bowyer exposes that "neither bamboo nor solid wood flooring are included in the BEES database, a situation that will hopefully change in the near future."

Notwithstanding the lack of research data, the author has considered bamboo as an alternative solution for indoor spaces because of the lack of chemicals in plantations and the use of safe alternatives to bind it. Moreover, one considers that EcoTimber bamboo flooring products have been developed with special regard to occupants' health and the surrounding environment. Finally, based on manufacturer information and the analysis of its awarded certifications, this product would qualify for LEED-certification credits in two categories (the EQ4 for evaluating low-VOC emissions, and the MR6 for rating rapidly renewable materials). Figure 3.11 summarizes the conclusion of these evaluations. As mentioned before a comparison has been made to analyze different flooring products made from wood. In the table the author has rated Marmoelum Click, EcoTimber Bamboo Flooring and a third control option to give context in the regular market. This third option was selected because it does not offer any special consideration for indoor air quality. As mentioned in the introduction, the author's aim is to contrast healthy materials to regular ones to understand the marketing differences.

		Evaluation					
Criteria	**Subject of study**	**Marmoleum Click**	**Mark**	**EcoTimber Bamboo**	**Mark**	Revolution Floating floor	Mark
Availability (a)	Final Product	Local stores	**3**	Local stores	**3**	Local stores	3
	Raw Materials	From different Countries	**-3**	China	**-3**	U.S.	1
	Manufacture	U.S. / Europe	**-3**	U.S.	**1**	U.S.	1
Variety (b)	Colors	Several options	**3**	Wood colors	**0**	Few wood colors	-2
	Textures	Several options	**3**	Only wood	**0**	Only wood	0
	Sizes	Two sizes of panel	**2**	Different lengths	**1**	One size	-2
Usability (c)	Installation	Ease to install	**3**	Ease to install	**2**	Ease to install	3
		No special skills for installer	**3**	No special skills for installer	**3**	No special skills for installer	3
		Easy for D-I-Y	**3**	Easy for D-I-Y	**3**	Easy for D-I-Y	3
		No special tools	**3**	Nailing tools	**1**	No special tools	3
	Maintenance	No specialized actions	**3**	Nailing actions needed	**1**	No specialized actions	3
	Replacement	Ease to remove	**3**	Ease to remove	**3**	Ease to remove	3
Durability (d)	Warranty	25 years	**3**	Lifetime	**3**	25 years	3
	Life-cycle	30 years normal use	**3**	50 years and + normal use	**3**	Not apply	n/r
	Maintenance	Easy to clean	**3**	Easy to clean	**3**	Easy to clean	3
		Not compatible with humidity	**0**	Resistant to humidity	**2**	Not compatible with humidity	0
		Scratch resistant	**2**	Scratch resistant	**1**	Easily scratched	-2
Cost (per sq. ft.) (d)	Material	High prices from $ 4.99 to $ 5.99 (no underlay.)**	**0**	High prices from $ 4.29 to $ 5.49 (no underlay.)**	**0**	Low prices from $ 1.29 to $ 3.49 (+ underlayment)	2
	Installation	Low prices from $ 1.99 to $ 3.99	**3**	Low prices from $ 1.99 to $ 3.99	**3**	Low prices from $ 1.99 to $ 3.99	3
		Overall	**37**	**Overall**	**30**	Overall	28

(a) Data come from manufacturer website and brochures as well as from specialized websites. See references list
(b) Data obtained from the manufacturer website: http://www.ecotimber.com/bamboo-flooring.php; www.forboflooring.com; www.revolutionflooring.com
(c) Information gathered from data sheets available on the product website. Complementary Information compiled from electronic magazines specialized in flooring products reviews. Please see reference list.
(d) See 14
(e) Prices obtained from author's field visit, and may vary depending on the store (Home Depot, Reno Depot, Rona and Pavillion du Design
** The system may be installed without need of underlayment which will reduce costs and time. n/r = not rated

Figure 3.11. Comparison for Flooring laminates

Evaluation comments

Under the author's evaluation criteria, Marmoleum Click showed the highest outcome (37) followed by EcoTimer Bamboo (30). The control option did not offer major quality characteristics (28). After reviewing the evaluation outcome, one can identify the strengths and weakness for each product.

Marmoleum Click scored outstandingly for most evaluation items, receiving negative marks only for the origin of raw materials and manufacturing. For EcoTimber Bamboo, satisfactory results were obtained for most criterion of evaluation; however, the product showed limited options for costumers' choices, which reduced its final mark. Revolution Floating Floor, the control product, presented an acceptable final overall mark, but demonstrated clearly negative behaviors in some scoring centers. On the other hand, the product sported the lowest price, a major concern for people's decision making process.

3.4.1.3 ***Ecoworx Broadloom Carpet. Manufacturer: Shaw Contractor Group***.

As previously mentioned, research has clearly demonstrated that carpets are one of the main sources of VOC emissions in indoor environments. Recent research has devised specific ingredients that meet international regulations to control negative impacts on occupants' health as well as on the natural environment.

Ecoworx Broadloom by Shaw is a flooring product that is made from 'avant-garde' components designed to increase its general performance. Bertilson *et al*. (2004) exposes that the backing (Ecoworx) and the fiber (Eco Solution Q) developed by William McDonough and Michael Baungart for Shaw's product fulfill what they called, in their book, a 'cradle-to-cradle life span'[9]. In effect, both the backing and the fiber that Shaw has used in this flooring product are 100 percent recyclable. This property gives the product an environmentally friendly extra-mark.

The Ecoworx backing is based on polyolefin which has been approved as food safe. That means that the ingredient is completely safe for people's health (Bertilson et al., 2004). Although the fact that the company accepts that the nylon may be a off-gas component, its modern version (Eco Solution Q) has been tested and certified as having very low toxicity (Bertilson et al., 2004). The same researcher states that "due to the lack of PVCs and phthalates used in the backing, as it is traditional, there are significantly fewer emissions". Moreover, Ecoworx Broadloom Carpet has received a

[9] 'Cradle-to-cradle' means that the fabrication process of a product is undertaken in what McDonough (2002) called a "closed-loop" system in which "every output ingredient is safe and beneficial" (BCorporation Resources Guide, 2008). Additionally, the Environmental Protection Encouragement Agency (2008) states that cradle-to-cradle aims to eliminate the concept of waste.

CRI Green Label and Green Label Plus for its efficient performance in interior environments[10].

The product is structured in two main stages. The Eco Solution Q fiber that comes in more than 200 color options, offering a wide range of choices. The Ecoworx backing which is comprised of three other layers (Fig. 3.12). The company indicates that this is a "3-step process": (1) the high performance precoat for maximum tuft bind; (2) a thermoplastic laminate for superior delamination strength; and (3) a woven reinforced layer for stability (Shaw Contractor Group, 2009).

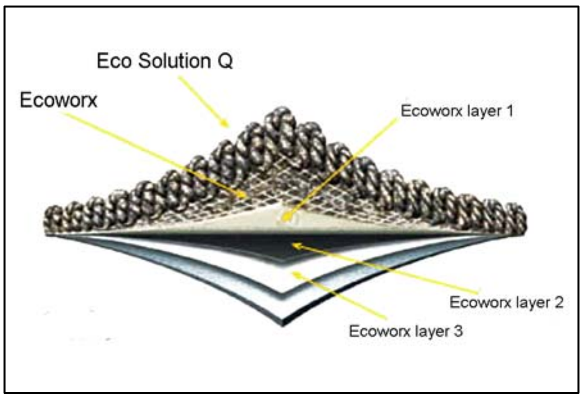

Figure 3.12. Ecoworx Broadloom layering. (Source: http://www.shawcontractgroup.com)

[10] Green Label and Green Label Plus are testing and certification programs developed by the Carpet and Rug Institute (CRI) which is an independent laboratory that examines carpets, adhesives and cushion products to evaluate chemical emissions (Winchip, 2007). Formaldehyde, styrene and 4-PC (Phenylcyclohexene) are tested to evaluate whether these VOCs are released from the product. Winchip reports that the Green Label program also tests vacuum cleaners and cleaning products "to ensure continuous compliance with the standards".

The selection of this floor covering for this work as a promoter of indoor air quality is based on a previous consultation of the three assessment methods explained above. Baker (2009) argues that McDonough has developed a comprehensive evaluation of materials drawing upon LCA analysis. This gives additional support to the conception of Ecoworx and Eco Solution Q that have been designed by McDonough and Baungart and that were based on those previous LCA studies (McDonough and Baungart, 2002). A diagram for a BEES study of a generic nylon broadloom serves as a means of reference to understand the phases that are analyzed (Fig. 3.13).

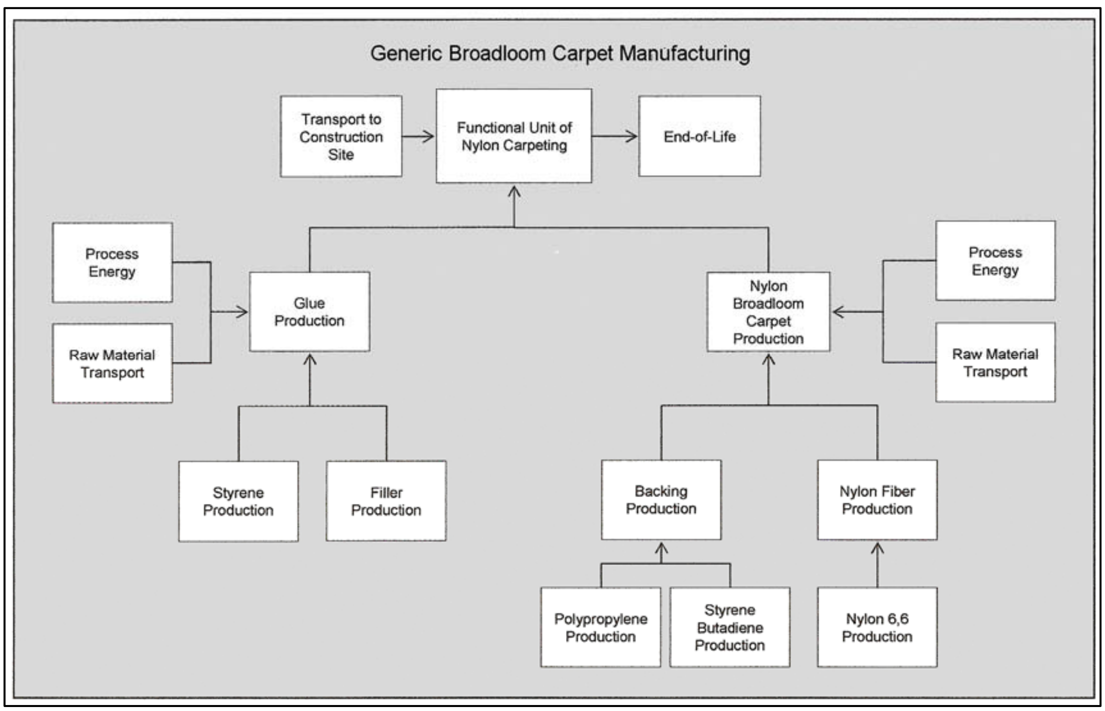

Figure 3.13. A diagram that shows the manufacturing process for a generic nylon broadloom. It serves as a means of reference for the LCA study that have been undertaken by the U.S. National Institute of Standards and Technology (NIST) while developing BEES 2007. (Source: BEES, 2007)

BEES (2007) has also studied new generation nylon carpets, yielding a satisfactory opinion about their environmental performance and cost-effectiveness. Finally, the product is a candidate for LEED credits not only for its low-VOCs emissions, but also for its recycled content and for the possibility of being 100% recyclable (Bertilson et al., 2004).

3.4.1.4 *Nature's Carpet. Manufacturer: Colin Campbell*

The manufacturer argues that Nature's Carpet is a 100% natural product made "entirely from wool" which is a "rapidly renewable resource". It also has the particularity that the wool "is clipped from sheep raised where no herbicides or pesticides are used" (Thomas, 2005) (Fig. 3.14) Thomas indicates that Nature's Carpet is bound based on a natural latex to join the wool facing to a natural jute backing[11]. Additionally, the colors available are those reproducible with non-metallic dyes or "naturally occurring" in the wool the company argued. They also report that due to its natural ingredients, the carpet is completely biodegradable and 'ultra-low-toxicity' (Fig. 3.15).

Figure 3.14. Sheep from where the New Zealand melino wool is taken to produce Nature's Carpet. (Source: http://www.naturescarpet.com)

[11] The same author agrees with the manufacturer when they report that the natural backing is a layer made form vegetable fibers grown in Bangladesh controlled under biological conditions.

Figure 3.15. Natural occurring colors from the original wool. It can be used either in living room or bedroom. (Source: htpp://www.naturescarpet.com)

The installation of the carpet is similar to regular carpets; however, the manufacturer recommends a 100% natural jute and animal hair underlayment to keep the environmentally friendly properties untouched. Taking into account that this additional layer may increase costs, the author suggests including an alternative zero-VOC underlayment. Maintenance of this carpet does no differ from its regular counterparts. Nature's Carpet insists that the product can be vacuumed and cleaned with the same specialized liquids as for regular carpets.

The selection for Nature's Carpet draws upon the analysis of its properties. The author has found that the natural components and the means of production promote sustainable strategies. In addition, the lack of chemical ingredients and complex factory processes permit the product to become a sponsor of indoor air quality. Furthermore, the BEES (2007) study for natural wool carpets concludes that the covering option does not have negative implications on the environment and its relative cost-effectiveness can be successfully managed (Fig. 3.16). Another point of interest for its selection is the fact that the product would achieve credits for LEED-certification under the EQ4 Credit category that the author has utilized as a main reference for the method, as well as earning credits for the Rapidly Renewable Materials category (MR6).

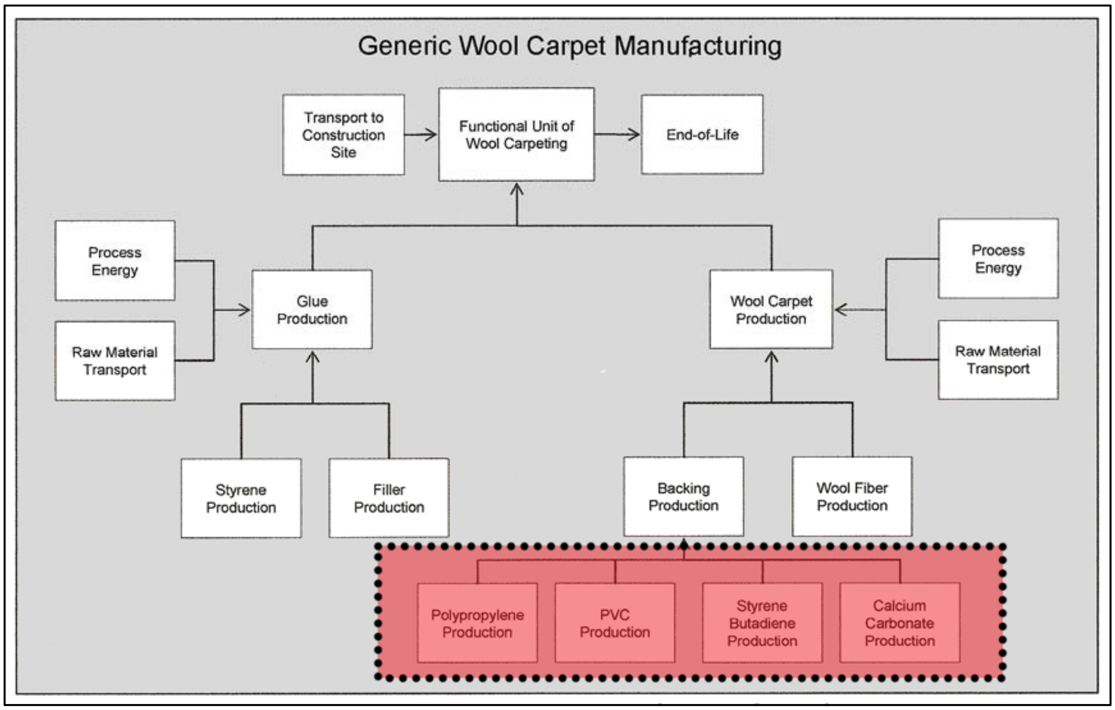

Figure 3.16. Diagram of a generic wool carpet production. In the red area it can be seen the backing fabrication methods which are based on chemical components. This is a major difference between Nature’s Carpets and regular wool carpets. (Source: BEES, 2007)

Two LCA studies of wool carpet performance with respect to sustainable principles and healthy effectiveness have been reviewed, one in the UK in 2009[12]; and the other in New Zealand in 2006 (Fig. 3.17) [13]. The second one gives more accurate data for the purpose of this work due to the fact that Nature's Carpet is made from wool produced in New Zealand. Barber and Pellow (2006) concluded that wool is in some cases five times less harmful to the natural environment and to humans' health than other synthetic compounds.

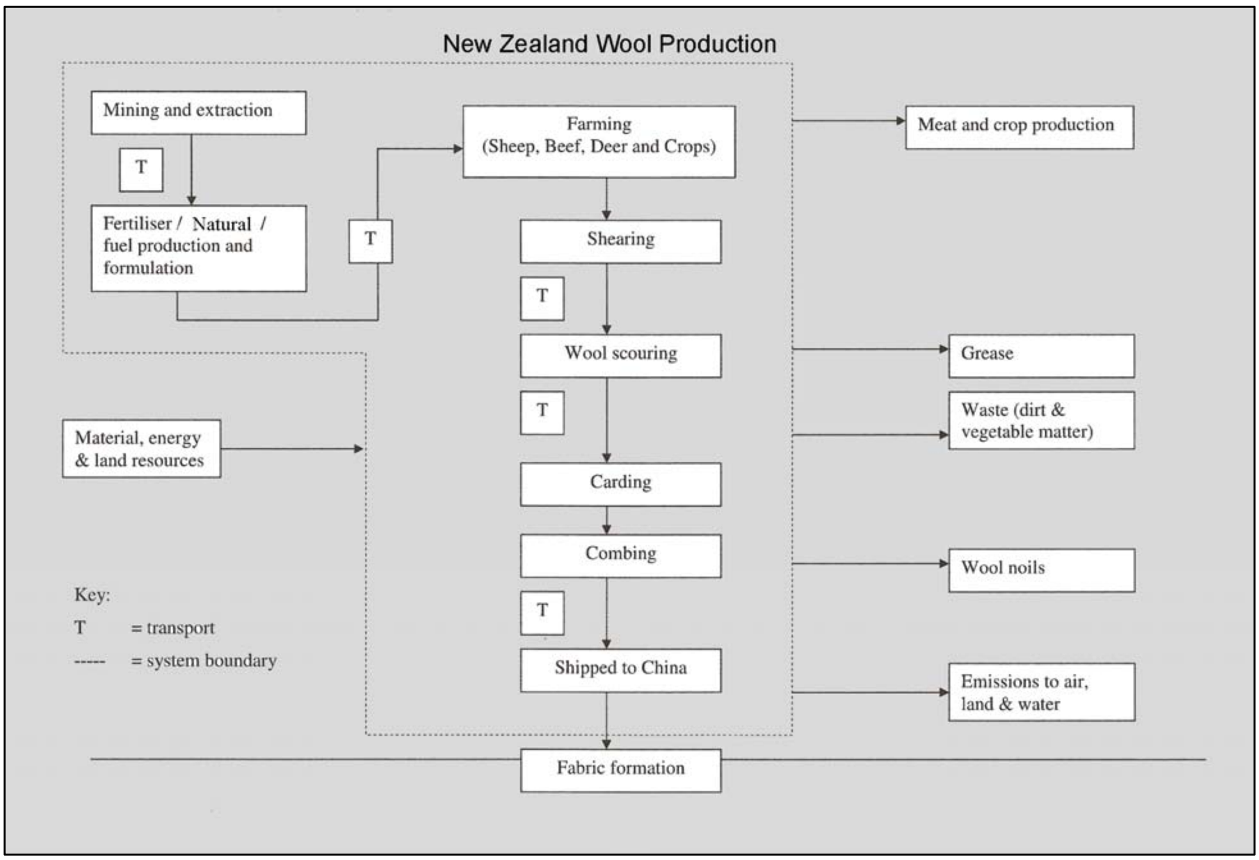

Figure 3.17. Diagram from the Life Cycle Assessment (LCA) study developed to analyze the New Zealand merino wool production. (Source: Barber and Pellow, 2006)

[12] Study led by M. Poole a Business Manager at the British Wool Marketing Board (BWMB), August, 2009
[13] Study led by A. Barber and G. Pellow for The AgriBusiness Group, March 2006.

A concluding evaluation for both described carpet options is presented in Figure 3.18. The same method used to evaluate laminates flooring options serves to rate these alternatives. A third control option has been selected to compare the healthy choices to, in an attempt to assess the advantages or disadvantages that affect costumer selection. In the next part of the chapter the author presents a brief comment that will summarize both evaluations and offer an introduction to the final discussion of the work.

		Evaluation					
Criteria	**Subject of study**	**Ecoworx Broadloom**	**Mark**	**Nature's Carpet**	**Mark**	Milliken Carpet	Mark
Availability	Final Product	Local stores	**3**	Local stores	**0**	Local stores	3
(a)	Raw Materials	U.S. produced (40 % recycled)	**3**	New Zealand	**-3**	U.S.	1
	Manufacture	U.S.	**1**	Denmark/Australia	**-3**	U.S.	1
Variety	Colors	More than 200	**3**	Many Natural Colors	**2**	20 colors	2
(b)	Textures	Several options	**3**	Several options	**3**	18 patterns	2
	Sizes	also in squares	**3**	n/a		also in squares	3
Usability	Installation	Ease to install	**0**	Ease to install	**0**	Ease to install	0
(c)		No special skills for installer	**0**	No special skills for installer	**0**	No special skills for installer	0
		Ease for D-I-Y	**-1**	Ease for D-I-Y	**-1**	Ease for D-I-Y	-1
		No special tools	**3**	No special tools	**3**	No special tools	3
	Maintenance	No specialized actions	**3**	No specialized actions	**3**	No specialized actions	3
	Replacement	Ease to remove	**1**	Ease to remove	**1**	Ease to remove	1
Durability	Warranty	Lifetime	**3**	10 Years	**1**	10 Years limited	-2
(d)	Life-cycle	5 to 7 years use	**0**	5 to 10 years use	**2**	5 to 7 years use	0
	Maintenance	Ease to clean	**2**	Ease to clean	**3**	Ease to clean	2
		Not compatible with humidity	**0**	Resistant to humidity	**2**	Not compatible with humidity	0
		Scratch resistant	**n/a**	Scratch resistant	**n/a**	Easily scratched	n/a
Cost (per sq. yd.)* (per sq. ft.)**	Material	Low prices from $ 21.99 to $ 29.99 $ 2.44 to $ 3.33	**3**	High prices from $ 50.99 to $ 62.99 $ 5.66 to $ 6.99	**1**	Low prices from $ 21.99 to $ 29.99 $ 2.44 to $ 3.33	**3**
(e) (per sq. yd.)* (per sq. ft.)**	Installation	Low prices from $ 12.00 to $ 19.00 $ 1.33 to $ 2.10	**3**	Low prices from $ 12.00 to $ 19.00 $ 1.33 to $ 2.10	**3**	Low prices from $ 12.00 to $ 19.00 $ 1.33 to $ 2.10	3
		Overall	**33**	**Overall**	**17**	Overall	24

(a) Data come from manufacturer website and brochures as well as from specialized websites. See references list
(b) Data obtained from the manufacturer website: http://www.shawcontractgroup.com; www.naturescarpet.com www.millikencarpet.com
(c) Information gathered from data sheets available on the product website. Complementary Information compiled from electronic magazines specialized in flooring products reviews. Please see reference list.
(d) Aaron Winer in - http://greenhaven.wordpress.com/2009/03/25
(e) Prices obtainded from author's field visit to Home Depot for Milliken Carpets. For Shaw Contract Group and Nature's Carpet see reference list.
* Retail prices commonly given in sq. yards for carpets. ** Prices converted by the author to sq. foot for the ease of the study
n/a = subject of study does not apply

Figure 3.18. Comparison and evaluation for carpets

Evaluation comments

The evaluation of carpeting options produced quite varied results. Ecoworx Broadloom earned the highest overall mark (33), followed by the control alternative (24). Nature's Carpet, a product put forward as a 'healthy' alternative, scored only 17, the lowest outcome mark of the three.

While analyzing the results from the table, one can easily see that Ecoworx Broadloom offers a wide variety of options for people to select from, outstanding durability, and sports a number of features that make it a healthy and economic alternative. The control product was limited under the *variety* criterion because it offered a limited palette of options for designers/homeowners; additionally, the company does not claim a long lasting durability for the product compared to the counterparts. Finally, while Nature's Carpet has demonstrated a very healthy and environmentally friendly performance from a theoretical perspective, at first glance it seems that its limited market availability and high prices make it an unpopular option.

3.4.1.5 *Final analysis of the flooring system evaluation*

As a result of the analysis and evaluation of flooring options, the author has found interesting results that leave the door open to further research. Successful improvements have been introduced in the flooring industry, drawing upon applied research that has been focused on reducing health affectations and developing environmentally friendly components. Laminate and wood options rise as the most convenient alternative for developers and homeowners looking to improve indoor air quality. The carpet industry still needs to develop materials and ingredients that satisfy not only environmental and health concerns, but also needs to meet market economic reality. Finally, it was found that affordability continues to be an important issue while selecting building materials.

Through the evaluation it was found that laminates can be bound with 100 percent safe adhesives that will, additionally, remove harmful emissions from interior environments. Marmoleum is a natural product based on vegetable fibers that rises as an interesting option due to its wide range of options for designers and homeowners. Bamboo has been demonstrated as a developing option that based on actual tests becomes one of the most promissory alternatives. It is ultimately processed under controlled actions, harvested in certified plantations and treated with safe ingredients that make it a sponsor for indoor air quality.

Finally, the evaluation outcome for the flooring system has shown that affordability is still a determinant factor in the decision making process to select a building component. Economic strategies should be undertaken to provide an incentive for builders to accept these alternative and safe products. They may never be truly competitive with regular products because many of them require special processes and phases that increase the short-term installation costs; however, promotion strategies might help to present healthy products as an extra-value option that, unlike their counterparts, help to achieve and promote indoor air quality which will result in an improvement for occupants' quality of life.

3.4.2 Walls

3.4.2.1 *Natura Paint. Manufacturer: Benjamin Moore*

Natura is a coating product that has been developed by Benjamin Moore in another attempt to offer a healthy option for interior finishes. The company had started with Aura, which was the first low-VOC paint that Benjamin Moore introduced in the market. Later, as a result of years of research, the manufacturer says that a new color system has been developed. It fulfills MPI and GS-11 requirements for such certifications for indoor air quality[14]. The company also argues that this component allows it to offer an endless list of color options to select from.

Gennex is a zero-VOC waterborne colorant that serves as the base for Natural line paints. Burt (2009) indicates that the most important contribution of Natura draws upon it truly being a zero-VOC emissions paint. As paints are required to have fewer than 150 grams per liter VOC to pass regulatory guidelines for indoor air quality, he says that

[14] Master Painters Institutes (MPI) certification and Green Seal certification that seeks to rate and approve products that have passed rigorous processes of evaluation including plant visit to verify its environmentally friendly and healthy conditions. "We utilize a life-cycle approach" the organization reports as a means of study and product method of analysis. (http://www.greenseal.org/about/whatwedo.cfm)

Natura successfully achieve zero-VOC emissions from its ingredients. The manufacturer presents Natura as a healthy option "ideally suited" for residential applications because it does not emit the conventional odor that conventional paints – including low-VOC paints – release. When interviewed for the website www.examiner.com, Carl Minchew (a representative from Benjamin Moore) explains that this difference is an important concern because most low-VOC paints are tinted with non controlled colorants that may increase harmful emissions. On the other hand, Nartura's base, which is zero-VOC itself, is colored with this ultimate additive for color that also fulfills zero-VOC requirements (Fig. 3.19).

Figure 3.19. Benjamin Moore's Natura.
(Source: http://www.benajminmoore.com)

Benjamin Moore's Natura is a new product that has not been studied by itself under LCA methods; however, for the purpose of this work, one can take similar studies as guides to support its selection. As an acrylic latex base, Natura can be compared with generic acrylic latex bases that have been analyzed by LCA professionals. Scott and Farrow (2001), compiled a series of work from researchers that treated regulation systems for environment, health and safety. As a part of that work, Nadaï (n.d.), presents a comprehensive reference of how LCA studies for acrylic bases and varnishes were successfully accepted by the E.U. Commission for the Eco-labeling regulation 880/92. At that moment, two bases were analyzed: (1) glycerophthalic (oil solvent-based); and (2) acrylic (water-based). The results from that work demonstrated that the water-based versions represented the healthiest alternative (Fig. 3.20). The lack of complementary studies and guidelines about the topic did not permit the author to compare whether or not those results were good indicators. However, Nadaï reports that it gave the thrust to start developing such studies to achieve more verified data that later permitted to launch controls in that matter. The same author reports that from 1991 to 1994, based on LCA assessments, France undertook new criteria to regulate VOCs from paints and varnishes. They noticed not only that acrylic bases were safer, but that lowering TiO_2 (Titanium Dioxide) concentrations will generate better outcomes for achieving healthier spaces.

	VOC emissions in grams/liter	
	Acrylic	**Glycerophthalic**
Average	250	450
Amplitudes	0 - 450	400 - 600
Satin/Flat	≤ 200	
Shiny	≤ 450	

Figure 3.20. Volatile organic Compounds of paints and varnishes in Europe in 1992. (Source: Scott and Farrow, 2001)

The discussion above serves as a theoretical framework for modern acrylic alternatives that, in cases like Natura, have eliminated TiO_2 as an ingredient. Additionally, one can notice that BEES (2007) has included the promotion for acrylic latex based paints, and it has presented a generic analysis for it (Fig. 3.21). Besides its Green Seal and MPI accreditation, it is important to note that the possibility of earning LEED-credits for the USGBC certification gives an extra support for the selection given its already explained property of being zero-VOC emissions product.

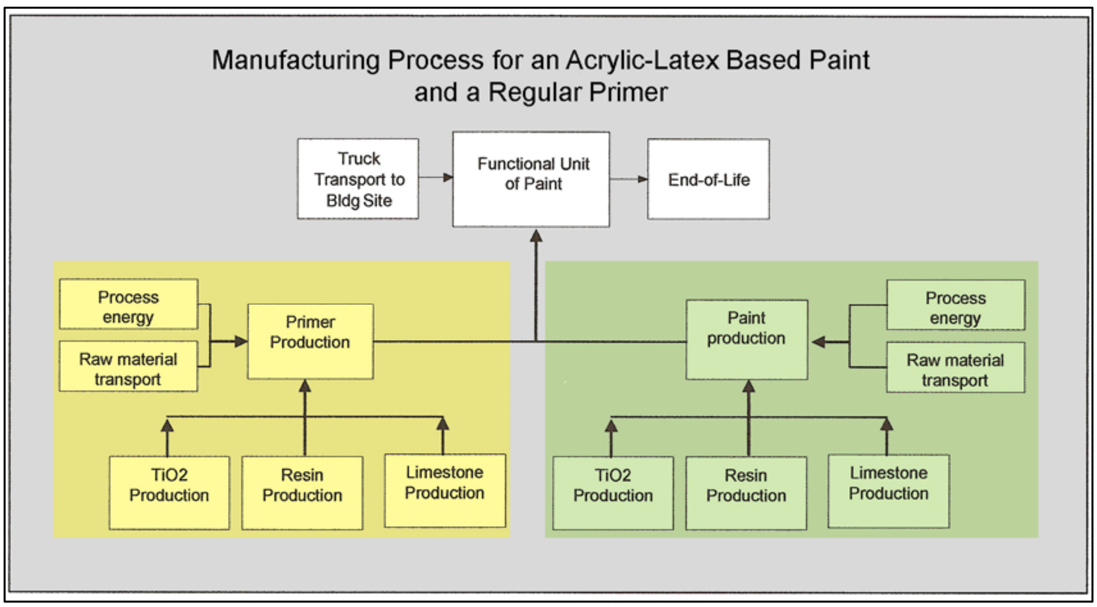

Figure 3.21. Diagram of a LCA study where the authors combined the two elements for a fished surface: primer (yeallow) and paint (green). It is remarkable the use of TiO_2 as an ingredient. Natura's based has eliminated this component to add a natural and sefe resin. (Source: BEES, 2007)

3.4.2.2 *Collagen Natural Interior Paint. Manufacturer: ECOtrend*

ECOtrend's offering is, without question, a totally new concept for interior finishes. After reviewing the market options to select products for this study, the author did not find a product with similar characteristics. ECOtrend introduced a new coating line that is primarily based on natural collagen extracted from egg shells (Fig. 3.22)[15]. The Oxford dictionary defines collagen as:

> *"a protein which Is present in the form of fibers as a major constituent of bone, tendons, and other connective tissue and which yields gelatin on boiling and leather on tanning."*

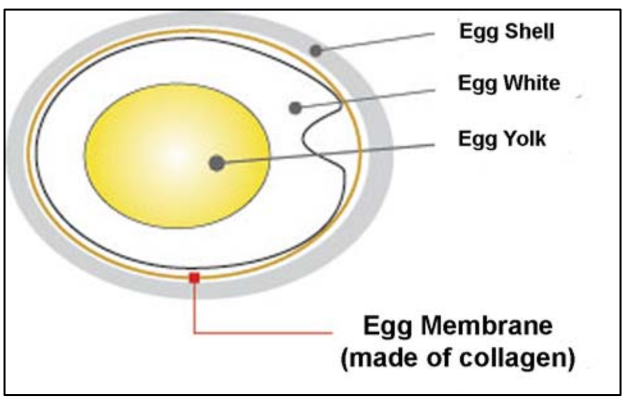

Figure 3.22. Section of an egg that shows its phisycal components. The main ingredient for the Natural Interior Paint is covering the internal face of the shell. (Source: http://www.ecotrendlife.com)

[15] "Aside from finding use for the egg shells in fuel cells, Fan also developed an organic acid that removes the membrane from the egg shells that contain collagen". N. Sod (2007) Scientists develop a method to extract collagen from egg shells. (http://www.associatedcontent.com)

ECOtrend has taken this 100 percent natural ingredient from egg shell membrane to convert it into a "binding agent that produce an environmentally friendly paint" the company argued. The manufacturer reports that the product does not have any VOCs or harmful components compared to oil- or water-based products (Fig. 3.23). The company explains that they mixed collagen with a paint binder because (1) it has a high binding energy since collagen "synthesizes at very high molecular weight"; and (2) prevents deterioration since collagen may be added to metals avoiding fading. ECOtrend has indicated that the product is in the waiting list to obtain its certification GS-11[16]. The manufacturer claims that the product "totally exceeds Green seal standards" for such accreditation.

Types of paints	Volatile Organic Compounds (Units per billion)			Formaldehyde*	Environmental Hormones*
	Benzene	Toulene	Xylene		
Ecotrend Collagen	None	None	None	None	None
Oil-Based	n/a	2000 - 5000	10000 - 30000	200 - 500	n/a
Water-Based	30 - 100	500 - 3000	30 - 100	20 - 80	30 - 100

* units per billion

Figure 3.23. The table shows the comparison among three paints. ECOtrend shows its healthy performance due to the natural origin of the base ingredients. Oil- and Water-based paints data is taken in average of generic products. (Source: Ecotrend, n.d.)

[16] The company informs that when the application was submitted for the certification, Green Seal had stopped receiving new requests for that period (Fall 2007). Since Green Seal is currently reviewing their certification process, ECOtrend remains on hold for its evaluation.

The paint has a special advantage, as it has an "outstanding durability and water resistance" due to collagen's elastic properties compared to regular paints that may "crack and split" if applied on damp surfaces (ECOtrend, 2009). In contrast, color choices with this paint are, admittedly, quite limited, with only 40 color options that may reduce designing alternatives in comparison to the regular market (Fig. 3.24).

Figure 3.24. ECOtrend collagen Interior Paint.
(Source: htpp://www.buildinggreen.com/cgi-bin)

Due to its novelty and particular ingredient characteristics, the author could not find a comprehensive study or scientific approach to lend life cycle assessment (LCA) support to the selection. As mentioned before, LCA studies have been undertaken to assess environmental concerns about the material's life-cycle. In that matter, one notices that there is data for such studies for traditional bases and some modern alternatives. In fact, for the previous selected product, references can be taken as a means background and support for new developed alternatives always under the same structural components. ECOtrend Collagen Natural Interior Paint cannot be associated to any other former study.

For the purpose of this work, the author supports the evaluation of the product due to its environmentally friendly characteristics. Moreover, data regarding VOCs emissions exposed by the manufacturer is promising, given the previously reviewed list of products. Once the paint receives its GS-11 certification as an indoor air quality promoter, it is a fact that it will also sponsor LEED-Credits due to its zero-VOC emissions. In addition, the product is about to receive the Greenguard certification, which is a complementary asset that gives accreditation for indoor air quality standards[17].

In Figure 3.25 the author has developed a comparison of both painting options based on the evaluation of its characteristics. The same criteria have been used; however the author has adapted some subjects of evaluation to make them more suitable for this type of product. For instance, in *variety*, finishes has been included to replace textures, and surfaces to cover has replaced sizes. In *usability*, drying times and coverage has been included in order to assess whether or not the product offers a convenient economic alternative. Once again a third product presents a control option that serves as a reference for the analysis of the healthy selections.

[17] The Greenguard Environmental Institute is a non-profit organization that establishes acceptable indoor air standards for interior products. "GEI's mission is to improve public health and quality of life through programs that improve indoor air." (www.greenguard.org)

		Evaluation					
Criteria	**Subject of study**	**Benjamin Moore Natura**	**Mark**	**ECOtrend Collagen Paint**	**Mark**	Behr Premium Plus	Mark
Availability	Final Product	Local stores	**3**	Local stores	**3**	Local stores	3
(a)	Raw Materials	Locally produced	**3**	Locally produced	**3**	locally produced	3
	Manufacture	Canada	**3**	Canada	**3**	U.S.	1
Variety	Colors	Wide range colors	**3**	40 colors	**0**	Wide range colors	3
(b)	Finishes	Flat, eggshell, semi-gloss	**2**	Flat, eggshell, semi-gloss	**2**	Flat, enamel, satin eggshell, semi-gloss, hi-gloss and ceiling	3
	Surfaces that covers	Wallboard, plaster wood, metal, plastic	3	Wallboard, plaster wood, metal, plastic	3	Drywall, plaster, stucco, wood	3
Usability	Application	Ease to apply	**3**	Ease to apply	**3**	Ease to install	3
		Easy for D-I-Y	**3**	Easy for D-I-Y	**3**	Easy for D-I-Y	3
(c)	Dry to touch	30 min.	**3**	30 min.	**3**	2 hours	0
	Dry to repaint	1 - 2 hours	**3**	3 - 4 hours	**0**	4 hours	0
(per gallon)	Coverage	374 - 425 sq.ft.	**3**	300 - 400 sq. ft.	**3**	250 - 400 sq.ft.	2
Durability	Warranty	Lifetime	**3**	Lifetime	**3**	Lifetime	3
(d)	Water Resistance	n/a	**n/r**	High performance due to collagen	**3**	n/a	n/r
	Clean up	Soap and water	**3**	Soap and water	**3**	Soap and water	3
	Binding properties	n/a	**n/r**	High performance due to collagen	**3**	n/a	**n/r**
Cost (e)	Per Gallon	$49.99	**-2**	$54.95	**-3**	$31.97	3
		Overall	**36**	**Overall**	**35**	Overall	33

(a) Data come from manufacturer website and brochures as well as from specialized websites. See references list
(b) Data obtained from the manufacturer website: http://www.benjaminmoore.ca; http://www.naturalinteriorpaint.com http://www.homedepot.ca; http://www.behr.com
(c) Information gathered from data sheets available on the product website. Complementary Information from the American Painting Contractor, May 2009. Please see reference list.
(d) See 14
(e) Prices obtained from author's field visit, and may vary depending on the store (Home Depot and Reno Depot) as well as from online stores from manufacturers websites
n/a = no information available; n/r = Not rated

Figure 3.25. Comparison and evaluation for zero-VOC paints.

Evaluation comments

The evaluation results present an interesting conundrum: all three products finished with a similar overall mark. No option showed any significant difference from the other. The highest mark was obtained by Benjamin Moore Natura (36) with a gap of one point over Ecotrend Collagen Interior Paint (35) and a three point difference from the control Behr Premium Plus Interior (33).

Natura showed weakness in the price section, being 56 percent more expensive than the control option. Ecotrend Collagen showed special durability characteristics that makes the product particularly unique; however, it registered the lowest mark due to its high cost (72 percent more expensive than the control and 10 percent more expensive than Benjamin Moore Natura); additionally, Ecotrend Collagen offers a limited color palette for costumer/designers selection. Behr Premium Plus, as a control product, represented an attractive alternative for economic concerns and presents the widest variety of choices. On the other hand, it also demonstrated the longest drying times, which may affect application times and, as a result, this may increase final project costs.

3.4.2.3 *Innvironmental Line of Wall coverings: Manufacturer Innovations in Wall Coverings Inc.*

Innvironment Line of wall coverings is a totally reinvented alternative offered by Innovations in Wall Coverings Inc. The company argues that this is an eco-friendly line "composed of natural, renewable and recyclable materials, using water-based inks". While researching the selection process for wall coverings for this evaluation, the author noticed that most products were based on vinyl, a known source of VOC emissions. In fact, the company reports that before Innvironment Line "was launched", the industry was dominated by PVC (Polyvinyl Chloride) products (Fig. 3.26). After reviewing the specifications from the manufacturer, one can state that Innvironment Line developed organic wall coverings based on natural materials (coffee, adzuki bean, green tea, and charcoal) that are applied to a structural backing made from cellulose[18].

Particular physical properties can be depicted from the products due to the natural raw materials, the company states that "these fibers are deposited at random ensuring a non-geometric fibrous profile". These characteristic gives the wall covering the advantage of being breathable and biodegradable. According to Curwell (2002), most wall covering products create conditions conducive to mold growth because they permit moisture to collect between the product and the covered surface itself. In contrast, the manufacturer reports that due to the fiber weaving technique used, products from Innvironment Line aid to reduce mold and mildew which are causes for the sick building

[18] The Oxford English Dictionary defines cellulose as "an insoluble carbohydrate which is the main structural constituent of the cell walls of plants, and one of the most abundant organic compounds on the earth." It states the use of this component as the main ingredient for products made from natural fibers like cotton and paper.

syndrome. In addition, no PVC and plasticizer ingredients have been incorporated to the line, and only water colors and minerals have been added to achieve color and sheen (Innovations in Wall Covering, n.d.).

Company	Line / Product
Arc / Com	Paladin Tangiers Stripe Torino
Innovations	Abingdom
Knoll Textile	Leda Pause
Luxe Surfaces	Koda Molli Stripe Spoomdamask Via Xing
Seltex	Argus Vine Heavenly Marble 101 Sakai Leaf
Tela	Delac 1 Pigeons Play
Vescom	Hauki Kivu Malawi Monar Roxen Sagra Tessera Trinity
Vycon Contract Wallcovering	Cassimere Cordoba Intaglio stripe Mirage Neela

Figure 3.26. A wide offer of vinyl and PVC wall covering can be found in the market. (Source: Information gathered from companies websites. See reference list)

One can realize that this eco-friendly line offers different alternative choices based on the same characteristics of manufacturing. For instance, Kyoto, Sapporo and Valencia are wall coverings of the same type. Each one of these products comes in different colors and textures which gives the customer/designer a wide range of alternatives to select from (Fig. 3.27). The manufacturer also states that these natural products "may exhibit variations in color, weave and texture" due to its handcrafted organic material.

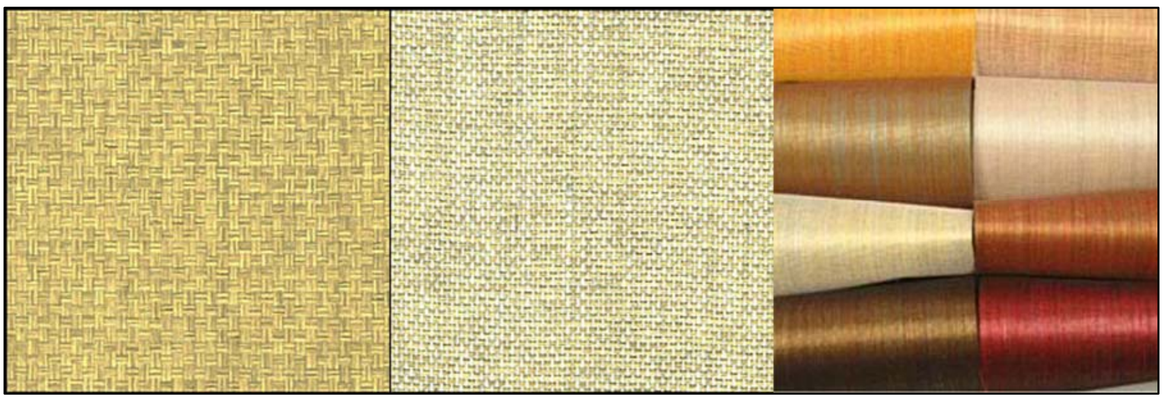

Figure 3.27. Kyoto, Sapporo and Valentia products form Invironment Line offer different alternatives for colors and textures. (http://www.innovationsusa.com)

The wall covering Innvironment Line is a fairly new alternative that comes to offer one of the few healthy options for interior finishes, other than paints. The author has found that most wallpaper contributed negatively to achieving improved indoor air quality. This line is one of those modern alternatives that has not been incorporated in specialized assessment methods, due to its novelty in the market. However, the company has received ASTM certifications according with specific quality conditions[19]. Although they have not received particular eco-friendly certifications (the company reports that the line is in the waiting list for the Green Seal certification for 2009), Innvironment products do help to earn LEED-credits toward USGBC certification in both the MR6 and EQ4-Credit categories which makes these products part of this work as such promoter of indoor air quality and sustainable building material.

3.4.2.4 *Japanese Wall. Manufacturer: Mardero LLC.*

Mardero's mission is to create cleaner air, promote healthy living and enhance working spaces (Green Source, 2009). One can expose that the Japanese Wall has been developed an alternative line of products that may replace the use of regular paints and wallpapers. It is not a paint, and neither is it a traditional wallpaper. A Japanese Wall is a product based on a mixture of natural clay, sand, straw and water[20]. This produces a sort of stucco that the company has named Jurako after the neighborhood around Kyoto that hosts the history of the warrior and commander Hideyoshi Toyotomi (Fig. 3.28) [21].

[19] ASTM E84 Standard Test Method for Surface Burning. This certification aim is to give a comparison between wall and ceiling building materials to asset burning resistance performance. (http://www.astm.org/standards)

[20] In Japanese Wara means straw which is mainly obtained from rice and grain stalks. The company states that Wara is often used to traditionally fabricate hats, mats, and bags. Mardero has included this natural element as a building material giving Japanese Wall particular properties. (Mardero, n.d.)

[21] The company has supported that the use of a natural earth from that place as a building component gave particular richness to the construction. Mardero describes the place as "…the oldest city in Japan, where a special kind of clayish soil was found. It was used by the most significant figure in Japanese history, warrior and commander Hideyoshi Toyotomi to build his residence…" (http://www.japanesewall.com/about/TheMisteryOfJuraku)

As a particular component, the product uses a very unique ingredient which is called Diatomite Earth. The Collins English Dictionary defines the material as it follows:

> *"A soft very fine-grained whitish rock consisting of the siliceous remains of diatoms deposited in small ponds or lakes. It is used as an absorbent, filtering medium, insulator, filler, etc."*

Figure 3.28. Juraku-Dai. The palace was built by Hideyoshi Toyotomi. The color is given by the local earth that was used as the base for the stucco. (Source: http://www.japanesewall.com)

Diatomic Earth is also known as DE and it has many natural properties that give the product special advantages. The manufacturer exposes that the granules contain millions of microscopic "perforated cylindrical shells, resulting in an inert, light-weight, highly porous, and powerful absorbent material" (Fig. 3.29). That physical property makes the product a natural absorbent of harmful emissions. Another physical characteristic can be found in the Oxford Dictionary when it describes diatomite as "an excellent non-conductor of heat" which supports the company's claims that, among other beneficial assets, diatomite earth makes the Japanese Wall resistant to fire and a good insulator to weather conditions. Several research studies support the use of this natural component in many developing building materials. Degirmenci and Yilmaz (2008) developed a comprehensive study to analyze the use of diatomite as a partial replacement for cement when making cement mortar[22]. In addition, Pimraksa and Chindaprasirt (2008) concluded that the use of diatomaceous earth on bricks might reduce the product's weight. Theses researchers have found alternative uses for the fossil that improve materials outcome. As a result, Mardero states that "the raw materials used in Japanese Wall had been extensively researched and scientifically analyzed" to improve environmental conditions for wellbeing of people.

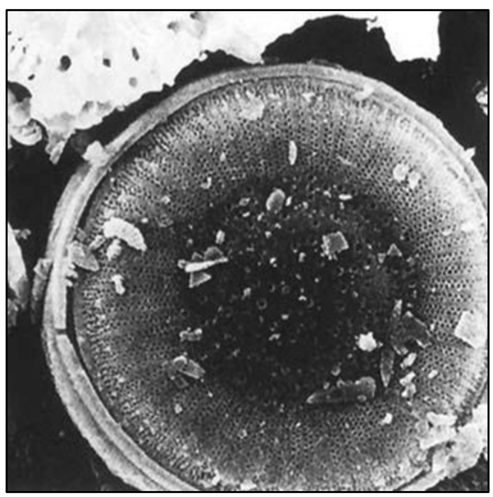

Figure 3.29. A granule of diatomite.
(Source: Pimraksa and Chindaprasirt, 2008)

[22] N. Degirmenci. Balikesir University. Engineering and Architecture Faculty. Department of Architecture. Balikesir, Turkey. And A. Yilmaz. Balikesir University, Engineering and Architecture Faculty. Department of Civil Engineering. Balikesir, Turkey.

The author realized that the manufacturer has shown a particular interest in indoor air quality issues. In fact, the company reports that the Japanese Wall represents a different option to traditional paints and wall coverings that often contribute to the worsening of interior environments. More importantly, they remark that the product is "made-up of non-VOC, and non formaldehyde water based materials" that not only promote and clean indoor air quality, but also donates a great insulation performance. Based on this additional data one can infer that the product may help to reduce energy consumption for heating-cooling requirements.

The Japanese Wall is available in a limited palette of earthy colors and textures choices mainly made from natural components the company states (Fig. 3.30). This interior sand-based material comes as a dry powder that needs to be mixed with water to obtain the desired consistency to apply on the surface. Different textures may be achieved depending on the application technique that is implemented. In addition, it is presented as an attractive alternative for 'do-it-yourselfers' (Mardero, LLC, n.d.).

This alternative finishing product has been selected for consideration drawing upon its natural raw materials and the demonstrated physical properties of diatomaceous earth of purifying air. Although no life cycle assessment studies have been published due to its relatively new introduction in the market, scientific research has resulted in positive conclusions of this natural fossil that serves as the base for the Japanese Wall production. Additionally, the other ingredients like sand, water and straw are naturally available and the author did not find any negative element that would affect its inclusion. Once again the author has considered that this material will contribute to achieve LEED-

Credits for the projects that use it. Moreover, its demonstrated natural ingredients not only promote indoor air quality, but also help to clean the interior environment which is a major concern in this study. Finally, the natural components are easily renewable and will allow for extra points under the MR6 category for such certification.

Figure 3.30. Japanese Wall may be installed in any interior space of a house. Earthy colors give a warm sensation for the spaces. Alternative textures may be achieved depending on product's consistency and technique of application. (Source: http://www.japanesewall.com)

Evaluation comments

This comparison revealed that the control product earned the highest mark among all (37) followed by the Japanese Wall (21) and Invironment Line (19). After analyzing the behavior of each material, the author has realized the marketing weakness of both healthy alternatives: although Design by Color Wallpaper did not show indoor air quality concerns, the product appears as an attractive option under the criteria that was selected for this work. On the other hand the Japanese Wall and Innvironmental Line presented with several deficiencies to compete in the wall covering market.

The Japanese Wall demonstrated high performance for usability due to the ease of application and maintenance; however, the product is not easily available in the regional market and it does not offer several color and texture options. Additionally, no warranty is offered by the manufacturer which may affect marketing opportunities compared with its counterparts. The lack of information for prices did not allow the evaluation for the products under that section.

Innvironmental Line resulted with the lowest mark due to the high level of difficulty to install the product. In fact, the need for an installer has affected the final outcome of the product. The company insists in recommending a professional hanger that may support the limited warranty. Unlike this negative side, the product can be described as one of the healthiest options in this work based on the gathered information.

Criteria	Subject of study	Evaluation: Innovations Innvironment Line	Mark	Mardero Japanese Wall	Mark	Design by Color Wallpaper	Mark
Availability	Final Product	Local stores	**3**	Need to be ordered	**0**	Local stores	3
(a)	Raw Materials	Locally produced	**3**	Some from Japan	**1**	Locally produced	3
	Manufacture	U.S.	**1**	Canada	**3**	U.S.	1
Variety	Colors	Limited options	**1**	Limited options	**1**	Several options	2
(b)	Textures	Several options	2	Limited options	**1**	Several options	2
	Sizes	Two options 36" and 56"	3	Not Apply	**/**	One option 20.5"	0
Usability	Installation	Ease to apply	**0**	Ease to apply	**3**	Ease to apply	3
(c)		Easy for D-I-Y	**-2**	Easy for D-I-Y	**3**	Easy for D-I-Y * (easy-up system)	3
		Need for Installer	-2	No need for Installer	**3**	No need for Installer	3
	Maintenance	Wet cloth and mild soap	**3**	Wet cloth and mild soap	**3**	Wet cloth and mild soap	3
	Replacement	n/a	**n/r**	Not apply	**/**	Easy to remove (easy-down) *	3
Durability	Warranty	Limited 3 years	**-2**	No warranty	**-3**	n/a	n/r
(d)	Life Cycle	Lifetime properly installed	**3**	Lifetime properly applied	**3**	Lifetime properly installed	3
	Maintenance	Ease to maintain	**3**	Ease to maintain	**3**	Ease to maintain	3
Cost	Material	n/a	**n/r**	n/a	**n/r**	$ 0.75 to $ 1.15	2
(e)	Installations	$ 0.99 - $1.29	**3**	n/a	**n/r**	$ 0.99 - $1.29	3
		Overall	**19**	**Overall**	**21**	**Overall**	37

(a). Data come from manufacturer website and brochures as well as from specialized websites. See references list
(b). Data obtained from the manufacturer website: http://www.innovationsusa.com; http://www.japanesewall.com http://www.homedepot.ca; http://www.designbycolor.net
(c). Information gathered from data sheets available on the product website. Please see reference list
(d). See 14
(e). Prices obtained from author's field visit to Home Depot from Design by Color Wallpaper material. The price is given by roll and the author has made the conversions for the purpose of this evaluation. (Roll duplet from $ 20.99 - $ 31.49 for a total coverage of 56 sq.ft.
* Easy-up Easy-down system is a property method that the company offers to make the installation easier. The wallpaper contains an adhesive on the back that permits the installer to apply the covering. It is also easy to remove from walls
n/a = no available information; n/r = not rated

Figure 3.31. Comparison and evaluation for wall coverings

3.4.2.5 Final analysis of the wall system evaluation

As a general outcome of the healthy wall finishes evaluation, the author has noticed that applied research has given some incentive for paints to become more environmentally friendly. In fact, nowadays, alternatives like Ecotrend Collagen Interior Paint offer an 'avant guard' choice, not only for the wellbeing of occupants, but also for the natural environment because its disposal does not generate water pollution (Ecotrend, 2009).

Interesting advances have incorporated safe ingredients as a replacement for harmful chemical components. During this study, the author found that several pollutant constituents had been removed from paints and wall coverings to reduce or eliminate the noxious effect on people's health.

The wallpaper industry has also been influenced by the introduction of these natural ingredients that has modified products performance. However, after reviewing the final results of the work, one notices that more improvements need to be developed in order to transform those safe emergent alternatives into effective marketing competitors. All these strategies will be discussed in the following chapter of the work.

3.4.3 Complementary Materials

3.4.3.1 ADHESIVE: *Vapor Master VM-808. Manufacturer: All Purpose Adhesive Company (APAC)*

The VM-808 adhesive is a product developed by All Purpose Adhesive Company (APAC). The company states that the selections of high quality raw materials and years of research and tests have resulted in a successful line of low-VOC adhesives. The two options of the line offer different characteristics for similar uses. One of them is the VM-618 adhesive which is designed for vinyl and PVC backing carpets. The other is the VM-808 multipurpose adhesive for broadloom. Since the aim of this work is to evaluate products that help to improve indoor air quality, and the first product of the line although is a low-VOC certified it is used to glue sources of harmful emissions like petroleum based carpets, the author has selected the second one VM-808 which is made for broadloom made of natural backing like the ones that were already described and analyzed in the previous part of this chapter.

This material is a solvent free and low-VOC adhesive that is part of the ecological series of environmentally friendly products for floor coverings. The product has shown in tests "a very aggressive water resistant bond that ages exceptionally well", which has permitted the company to offer a lifetime bond warranty (APAC, 2008). According to Curwell et al. (2002) as a non-solvent adhesive, this product has "no significant risk foreseen for occupants". In fact, the company reports in the material safety data sheet (MSDS) that there is no need for special protection for the installer when applying the product, and also reports that the tests for the Carpet Rug Institute (CRI) certification has demonstrated that VM-808 exceeds its regulations giving a total of 0 grams per liter VOC (Fig. 3.32)[23].

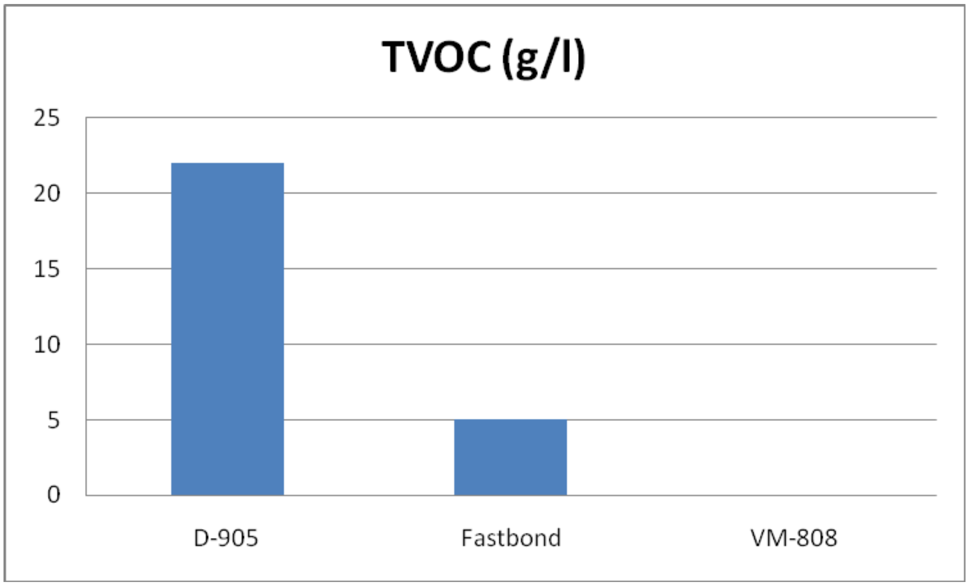

Figure 3.32. The chart shows three multipurpose adhesives that meet low-VOC guidelines from the Carpet Rug Institute. D-905 by Durabond (22 grams per liter TVOC); Fastbond by 3m (5 grams per liter TVOC); and VM-808 by APAC (0 grams per liter TVOC). (Source: http://www.durabond.com; htpp://www. products3.3m.com/catalog; http://www.apacadhesives.com)

For installation purposes APAC exposes the advantages of VM-808. The company says that the "wet installation methods" allows the installer to lay the carpeting immediately the adhesive has been spread on either porous or non-porous surfaces. One can easily infer that this method will reduce installation times and overall project costs.

[23] The carpet Rug Institute guidelines (CRI) in a third-party independent laboratory test ask for as low as 25 gram per liter Total Volatile Organic Compounds (TVOC) for carpet and multipurpose adhesives. Products meeting this requirements will achieve Green Label Plus certification from the institution.

Additionally, it is important to mention that VM-808 has received a CRI Green Label Plus certification due to its environmentally friendly properties and remarkable indoor air quality performance. Moreover, the product has successfully passed a "perform testing for moisture vapor emissions per the anhydrous calcium chloride test method" which has given the adhesive ASTM 1869 certification[24]. Another interesting characteristic that can be found in VM-808 is that APAC has included Ecoprotek as an ingredient of the adhesive which is a property component that the manufacturer has created for its ecological line that adds "biocides that protect the adhesive in both the wet state and dry state, from attack by mold, mildew and bacteria" (APAC, 2008).

The selection of VM-808 for this study is based on its zero-VOC performance. In addition, the author has found valuable approaches to LCA analysis that will sponsor the introduction of these types of adhesives on the assessment methods (BEES, 2007). As 0 grams per liter VOC emitter, VM-808 is a product that will help to achieve LEED-credits for the USGBC certification under the EQ4-Credit category. This advantage gives the adhesive enough qualifications to be included in the rating work.

In Figure 3.33 the author has evaluated this product with a second alternative option that does not represent any healthy alternative for the improvement of interior environments.

[24] The test aims to evaluate and measure moisture vapor emissions from concrete surfaces that may be release and generate negative environmental conditions for interior spaces. (http://www.astm.org)

		Evaluation			
Criteria	**Subject of study**	**APAC VM-808**	**Mark**	3m Fastbond	Mark
Availability	Final Product	Local stores	**3**	Local stores	3
(a)	Raw Materials	Locally produced	**3**	Locally produced	3
	Manufacture	U.S.	**1**	Canada	3
Variety	Colors	Not apply	**n/r**	Not Apply	1
(b)	Textures	Not Apply	**n/r**	Not Apply	1
	Sizes	4-Gallons pails	1	4-gallons pail, gallon & quart	3
Usability	Installation	Ease to apply	**2**	Ease to apply	2
(c)		Ease for D-I-Y	**2**	Easy for D-I-Y	2
		No need for Installer	3	No need for Installer	3
	Maintenance	Not apply	**n/r**	Not Apply	n/r
	Replacement	Not apply	**n/r**	Not apply	n/r
Durability	Warranty	Limited lifetime	**2**	Limited	0
(d)	Life Cycle	Lifetime properly applied	**3**	Lifetime properly applied	n/a
	Maintenance	Not apply	**n/r**	Not Apply	n/r
Cost	Material	Pail= $ 149.69	**3**	Pail= $ 252.49	-3
(e)	Installations	Not apply	**n/r**	Not apply	n/r
		Overall	**23**	**Overall**	**18**

(a). Data come from manufacturer website and brochures as well as from specialized websites.
(b). Data from the manufacturer website: http://www.apacadhesives.com;
and http://www.products3.3m.com. See reference list
(c). Information gathered from data sheets available on the product website. See reference list
(d). See 14
(e). Prices obtained from author's field visit to Home Depot and Reno Depot
n/a = not available information; n/r = not rated

Figure 3.33. Comparison and evaluation of an adhesive

Evaluation comments

The VM -808 adhesive finished with an outstanding overall mark compared with its counterpart. The safe adhesive earned a total mark of 23 points versus the 3m Fastbond adhesive that obtained a final mark of 19.

The healthy alternative demonstrated interesting quality properties that gave it extra points to differentiate it from the regular option. In addition, one can see that with regard of the price, VM-808 presents an attractive alternative. All this results will be deeply analyzed in the next chapter when the author develops the final stage of this work.

3.4.3.2 PRIMER: *Ultra Grip Multipurpose Primer. Manufacturer: Dunn-Edwards*

Dunn-Edwards has introduced a waterborne primer designed for interior and exterior use. The primer can be applied with very good performance either on unpainted surfaces like fiberglass, anodized aluminum and plastics or rough materials like wood and masonry (Green Source, 2009). The company exposes that the product has demonstrated outstanding stain backing properties and that it is specially formulated to be compatible with acrylic-latex and natural paints.

Ultra-Grip is considered a low-VOC primer as it contains 45 grams per liter VOC[25]. In addition, the manufacturer reports that it does not contain ethylene-glycol or any other harmful resins, and it is based on a 100 percent acrylic resin that allows the product to applied with no negative affectations on people's health (Curwell et al., 2002). According to this data, Dunn-Edwards has been accredited for the Master Painter Institute's Green Performance Standard as well as for the California's Collaborative for High Performance Schools (CHPS)[26]. Moreover, Ultra-Grip Primer has met FDA

[25] After the analysis of all the information gathered for this work, one may notice that most international guidelines and assessment methods agrees in setting limits for VOC emission in paints and primers less than 150 grams per liter. In fact, one of the most stringent limits comes from Green Seal GS-11 accreditation which certifies products under this limit. (http://www.greenseal.org)

[26] "MPI is dedicated to the establishment of quality standards and quality assurance in the architectural painting and coating application industries" (http://www.paintinfo.com/mpi). The Collaborative for High Performance School is a United States national movement that encourages the improvement of the student performance as well as the academic experience while developing the best possible scholar ambiance. (http://www.chps.net)

guidelines for direct food contact surfaces[27]. As a primer, it does not contain any tint that affects its chemical composition; however, the author found that in many cases it has been used as a base adding up to 2 oz of water based colorant (www.archithings.com, 2009). Although these colorants are water based, one may say that this addition might modify VOC emissions and must be tested before its application in order to maintain indoor air quality standards because no information has been offered by the manufacturer about color modifications on the primer.

The selection of this product for the evaluation of materials that improve indoor air quality will complement the wall finishes section. Before covering the wall with the desired finishing product, it is often necessary to apply a primer base to ensure the quality of the final outcome, in this case, the author considered, after reviewing market options for primers, that Ultra-Grip by Dunn-Edwards represented the best alternative when achieving healthy interior environments. The amount of VOC emissions are the lowest found for a primer[28] (Fig 3.34).

Additionally, the previous LCA study, already exposed for latex-acrylic paints by BEES, represents an extra reason for its consideration. Finally, with regard of LEED accreditation, this product represents a good opportunity to earn the necessary credits for the category of low-VOC emissions that has been consulted along this work.

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[27] United States Food and Drugs Administration (FDA) has developed guidelines to regulate the physical properties of surfaces that may be in contact with aliments in order to reduce risk of food contamination. (http://www.fda.gov)

[28] Three similar low-VOC primers were reviewed by the author in order to compare Ultra-Grip's performance as one of the lowest emitters in the market.

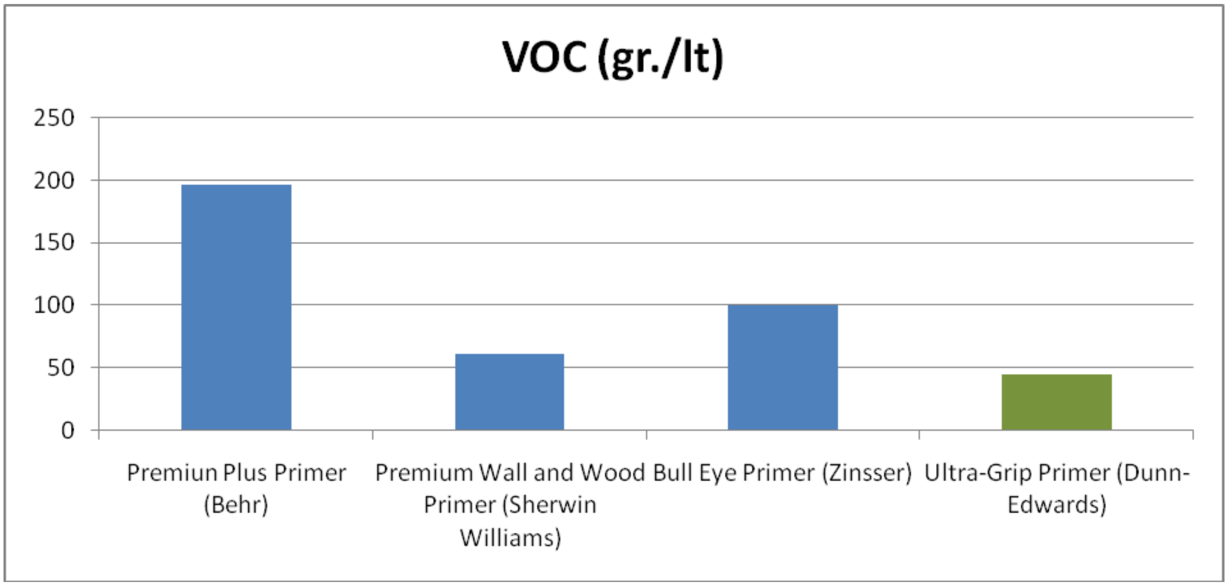

Figure 3.34. Chart that shows the comparison among four different low-VOC primers. Limits for VOC emissions for primers and paints have been internationally set under 150 grams per liter. Here it can be seen Ultra-Grip performance to achieve GS-11 certification. (Source: Material Safety Data Sheet for primer obtained from manufacturers websites: http://www.behr.com; http://www.sherwin-williams.com; http://www.zinsser.com; http://www.dunnedwards.com)

The author's evaluation for this primer is available in Figure 3.35. The product is compared with another option for interior walls, and, as well as the previous control alternatives does, not offer any healthy feature when achieving indoor air quality.

		Evaluation			
Criteria	**Subject of study**	**Dunn-Edwards Ultra-Grip**	**Mark**	Zinsser Bull Eye	Mark
Availability	Final Product	Western U.S.	**1**	Local stores	3
(a)	Raw Materials	Locally produced	**3**	Locally produced	3
	Manufacture	U.S.	**1**	Canada	3
Variety	Colors	Not apply	**n/r**	Not apply	n/r
(b)	Finishes	Not apply	**n/r**	Not apply	n/r
	Sizes	4-gallons pail, gallon & quart	**3**	Gallon	1
Usability	Application	Ease to apply	**3**	Ease to apply	3
		Easy for D-I-Y	**3**	Easy for D-I-Y	3
(c)	Dry to touch	45min. - 1 hour	**2**	30 min.	3
	Dry to repaint	4 - 6 hours	**1**	1 hour	3
(per gallon)	Coverage	400 sq.ft.	**3**	450 sq. ft.	2
Durability	Warranty	Lifetime	**3**	Limited Lifetime	2
(d)	Water Resistance	n/a	**n/r**	n/a	n/r
	Clean up	Water	**3**	detergent and water	2
	Binding properties	n/a	**n/r**	n/a	n/r
Cost (e)	Per Gallon	$25.99	**3**	$27.66	0
		Overall	**29**	Overall	28

(a) Data come from manufacturer website and brochures as well as from specialized websites. Please see reference list.
(b) Data obtained from the manufacturer website: http://www.dunnedwards.com and http://www.zinsser.com
(c) Information gathered from data sheets available on the product website. For complementary information please see reference list.
(d) See 14
(e) Prices obtained from author's field visit to Home Depot and online stores from manufacturer
n/a = no information available; n/r = not rated

Figure 3.35. Comparison and evaluation of primers

Evaluation comments

The results of the evaluation for the primer show that Ultra-Grip offers a very good behavior for most criterions. The weakness of the product can be seen in two subjects of evaluation: it showed longer drying time for repainting purposes compared to its counterpart. In addition, the author found that the product is not readily available on the eastern coast, which has reduced its final mark for the availability section. However, the company offers, through its big stores network, the possibility to ship the product wherever in North America. Finally, when analyzing cost, one can realize that Ultra-Grip has the lowest price which coverts it in an attractive option regarding its safe condition for interior environments.

CHAPTER 4

Evaluation Analysis, Conclusions and Recommendations

4.1 INTRODUCTION

It has been demonstrated that the construction industry has been highly influenced by the growing interest in improving wellbeing while taking care of the environment. The rising interest in developing sustainable strategies over the past few years has been driving the production of alternatives that offer safe performance not only for people's health, but also for the care of the surrounding natural environment.

Based on the fact that North American houses will always need to be insulated for a significant part of the year due to weather conditions, it is particularly necessary to eliminate sources of harmful pollutants. In the first part of the study, the author exposed the significance of efficient ventilation to clean spaces; however, the limited ventilation typically available during cold months will not be enough to purify interior environments. That means that reducing the sources of indoor contaminations is necessary to facilitate ventilation efficiency.

The evaluation conducted by the author helped to identify possible causes that affect the choice to incorporate healthy alternatives in interior spaces. The author found that some alternatives represent valuable options when achieving indoor air quality. Nevertheless, there is a gap in the market that may still be covered by new, additional options. From the author's point of view, this industry is still in process of flourishing, and needs to be supported and regulated by all stakeholders.

In this chapter, a final description of the importance of promoting indoor air quality as the axis of the study is presented. In addition, the author will present a detailed analysis of the results of the evaluation for every criterion. A comprehensive description of the evaluation of every system and product is presented in order to offer an accurate discussion about the evaluation. Finally, the reader will find the final discussion about the findings where the author states the conclusions and recommendations from the study.

4.2 INDOOR AIR QUALITY AS A GOAL

Since indoor air quality remains an important concern while analyzing health issues, government and non-profit institutions around the world have developed guidelines and standards regulating the minimal conditions necessary to control safe interior environments. However, the author considers that these standards need to be applied with more stringent criteria, as he found some inconsistency between what companies say and what they really offer. After studying the evaluation analysis, the author presents a series of comments and recommendations to encourage further research into strategies that will help to improve the achievement of healthier indoor environments.

Health Canada (2005) reports that interior environments are five times more polluted than outdoor environments. The organization has concluded that both biological and chemical compounds are responsible for such unsanitary conditions. The author found California as the most dedicated and demanding place where indoor air quality has become part of the rigorous environmental regulations. The Air Resources Board from the California Environmental Protection Agency and the South Coast Air Quality Management District (SCAQMD) developed guidelines that, in many cases, serve as references for non-profit institutions and provincial governments to develop their own regulations. (Winchip, 2007)

The use of adhesives and sealants that release VOCs has been an ongoing issue with respect to indoor air quality. Formaldehyde and Isocyanate, among other mentioned pollutants, are known to be negative ingredients that were needed to produce many construction materials. Nowadays, low- and zero-VOC products are available to be incorporated. Natural ingredients have been developed and introduced to the industry, and materials like linoleum have been reinvented to fulfill modern requirements and now offer sustainable and safe options to the field.

Nevertheless, when analyzing the selection of products to be added to the evaluation, the author found that information given by companies about hazards and risks is not controlled and verified by governmental organizations. The Material Safety Data Sheet (MSDS), the document through which a manufacturer reports a product's physical properties, toxicity levels and VOC calculations, should be evaluated and approved by a specialized entity to ensure truthfulness for consumers. This is not currently done, and as a result, in many cases the author could not find scientific and/or technical supporting documentation of companies' claims in their promotional brochures or these data sheets. For instance, a primer from "Zinsser" which is marketed in the zero-VOC segment did not, in fact, show satisfactory data when they exposed that the product met regulations for this category. Another sample of this was found by the author when reviewing the "Illmond 600" sealant which was offered by "Tremco" as a zero-VOC alternative; however, when studying the physical properties of the product, the author realized that this sealant was made from polyurethane which is a synthetic compound based on isocyanate, a well-known source of VOC emissions. For this reason, the author encourages further research about the use of plastics in interior environments, as each year more and more of this material is being incorporated into new building projects. In fact, Uffelen (2008) reports that since 1984, the production of plastic "surpassed that of steel for the first time." Uffelen exposes that the amount of plastic production has, in fact, multiplied in the last 70 years (Fig. 4.1).

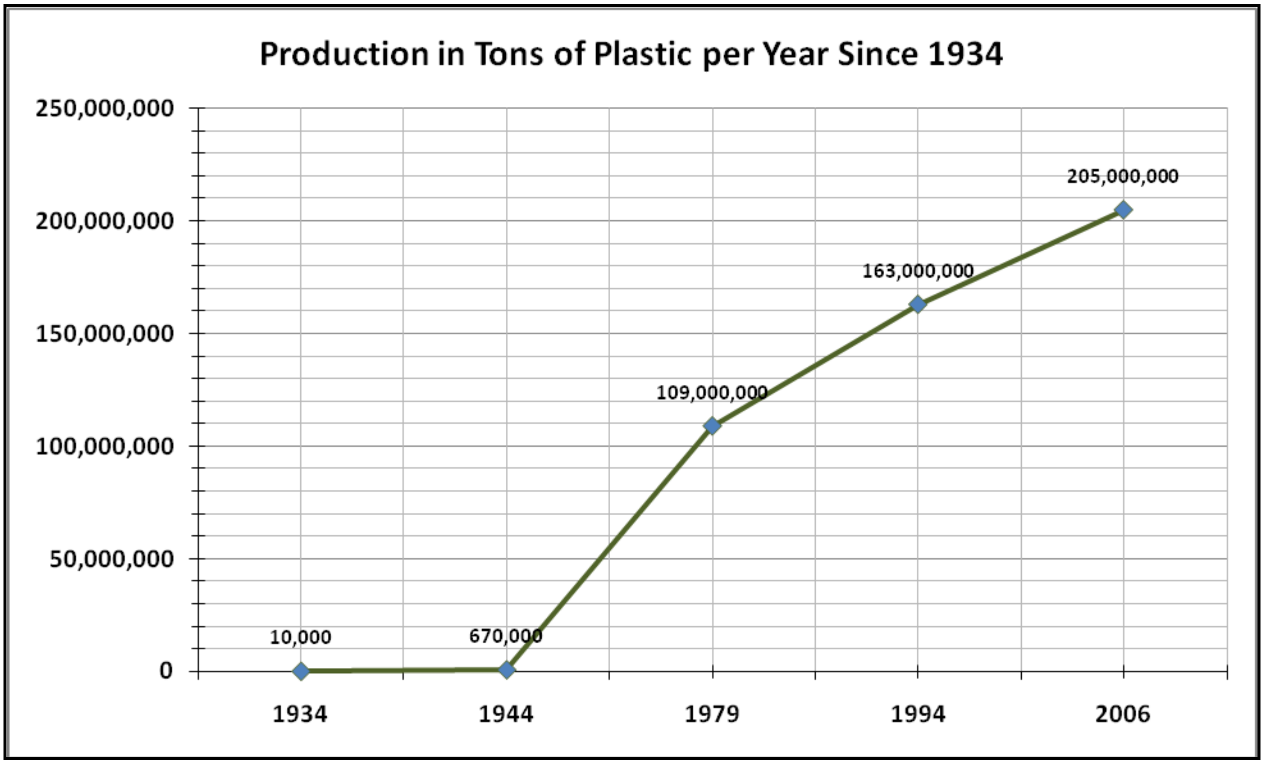

Figure 4.1. Production of plastic since 1934. (Source: Uffelen, 2006)

After analyzing all the compiled data about the noxious effects of VOC emissions on people's health in the first part of this work, and after reviewing the comprehensive work of authors like Uffelen (2008) that states that "architecture can no longer be imagined without plastic-floor coating, wall paper, dome light, façade elements." And Fernandez (2006) who includes polymers in the list of emergent materials for innovative buildings, the author poses the following questions: Are human beings damned to inhabit harmful spaces? And is it true that plastics will dominate the architectural industry in years to come, even in a concerned world about contaminated environments?

At the beginning of the work the author expected it to be easy to find safe interior products that help to improve indoor air quality to be evaluated alongside conventional options. It quickly became apparent that there are, in fact, few trustworthy alternatives that fulfill indoor air quality guidelines due to the lack of verified data by the company. On the other hand, the author found that the rising influence of non-profit organizations and institutions is giving an important thrust to balance the marketing of healthy options to achieve the best conditions for safe interior air.

4.3 THE EVALUATION AFTERMATHS

As a result of the selection process, the author found that few options may be available in the North American market for interior finishings; however, each system showed at least one category that presented more alternatives to be studied. The flooring system was divided into (1) laminated-hardwood; and (2) carpeting products. In the first division the opportunity to select the product was less limited than for the second one. The options for carpet that fulfill indoor air quality requirements were notably very limited, compared to the floating floor alternatives. Accordingly, the wall finishing system showed how the paint industry has produced several options that may be incorporated for the achievement of healthy interior environments, but with respect to wall covering options, the list of safe options was truly reduced. Finally, the search for complementary materials was characterized by the lack of substantial safe products. The options ultimately included in this work are those for which verifiable technical information could be obtained. Although in many cases this information was not certified by institutional or governmental offices, the author valued the fact that concerned companies have shown the commitment to improve environmentally friendly and healthy alternative products through technical and scientific research.

Since the evaluation was designed to be applied by independent criterion and subject of study, the author will present a detailed analysis of each product under these rating patterns.

4.3.1 Conclusions of the flooring system evaluation

The overall result in this system showed that Marmoleum Click and Ecoworx Broadloom obtained the highest mark in their categories. The first demonstrated an outstanding behavior in every criterion receiving a negative review only with respect to cost and the origin of components. The evaluation ruled that the product may be described as a very good alternative that not only promotes indoor air quality, but that also offers a wide range of options for the designer/homeowner. The second product attained the highest ranking in the carpeting evaluation. The product was, overall, satisfactory, and is described as a safe alternative to be considered. When compared with the control options (in this case, a very popular product offered in one of the most popular stores in North America: Home Depot), Ecoworx scored an outstanding final mark indeed.

Ecotimber Bamboo received the second highest grade in its category. The major difference between Ecotimber and the first place contender has to do with variety. While Marmoleum Click offers several options for color, textures and sizes, Bamboo as a hardwood product is limited to wood colors and textures. Nevertheless, the product achieved, for most criteria, higher overall marks than the control floating floor. This makes Ecotimber a nice, suitable, sustainable and healthy alternative to be considered for interior finishing purposes. Similar limitations (with respect to variety) apply to Nature’s Carpet. While it is one of the most natural products in the evaluation (due to the origin of its raw materials and production process), the use of natural wool limits the possibility of color variations. Moreover, the high cost of wool production derives a high final cost for the product which might intervene in the market acceptance compared with the other two carpeting alternatives.

This work also concludes that the carpet industry has presented several advances, as safe natural fibers and improved synthetic materials have been introduced to the manufacturing process. Cited research has demonstrated that VOCs emissions have been dramatically reduced to minimal levels. However, two important issues remain negatives. Environmental concerns are still unsolved. Bowyer (2009) reports that compared to wood and natural cork, nylon and wool have relatively more environmental impacts. In addition, those technological improvements have come with economic implications resulting in high costs for these safe alternatives. Indeed, after evaluating the products one can say that this fact has influenced its acceptability in the market.

4.3.1.1 *Availability*

Ecoworx Broadloom scored the highest mark among the reviewed products in this category, as it is produced in North America, the raw materials are easily available in the region, and the final product can be locally sourced. The runner ups for this criterion included both the laminate and carpeting control option, which are easily available in local markets and produced within the region. Ecotimber Bamoo ranked fourth, on account of the fact that bamboo species do not grow in North America; nevertheless, in the author's view, this element might not affect the fact that the bamboo represents a sustainable and safe option due to its fast growth and environmentally friendly qualities. Finally, one may see how the nature's carpet and Marmoleum Click availability does not represent a very convenient alternative. Figure 4.2 shows the global outcome for flooring system under the first criterion of evaluation.

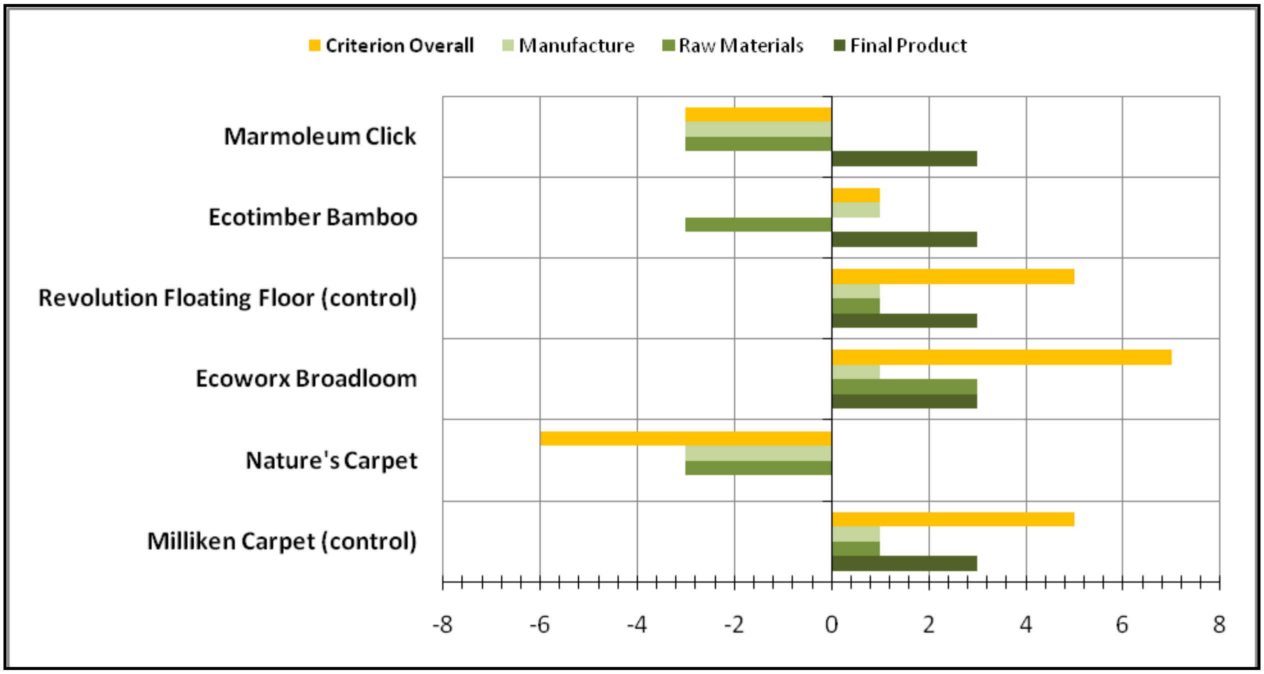

Figure 4.2. Results of Availability for the flooring systems

The chart illustrates how with respect to market availability, Ecoworx offered the best option. The author did not find any indicator under this criterion for it to be affected in the market. On the other hand, Nature's Carpet was negatively influenced by a number of factors while competing as an effective option to achieve indoor air quality.

4.3.1.2 *Variety*

In this criterion, the author found that Ecoworx and Marmoleum Click offer the best variety of options for design purposes among all evaluated products. The interesting outcome is that Nature's Carpet offers an important range of design options, limited only by the possibility of being flexible in sizes. Modern carpeting options can be found in squares (tiles) that give additional opportunities to vary the final image of the finished design. In that sense, the control product for carpets does offer this advantage, which may result in extra marketing benefits. It is important to notice that for wood flooring, bamboo achieved a higher mark than the popular control option. Bamboo offers more color options and sizes that may enrich the final architectural outcome.

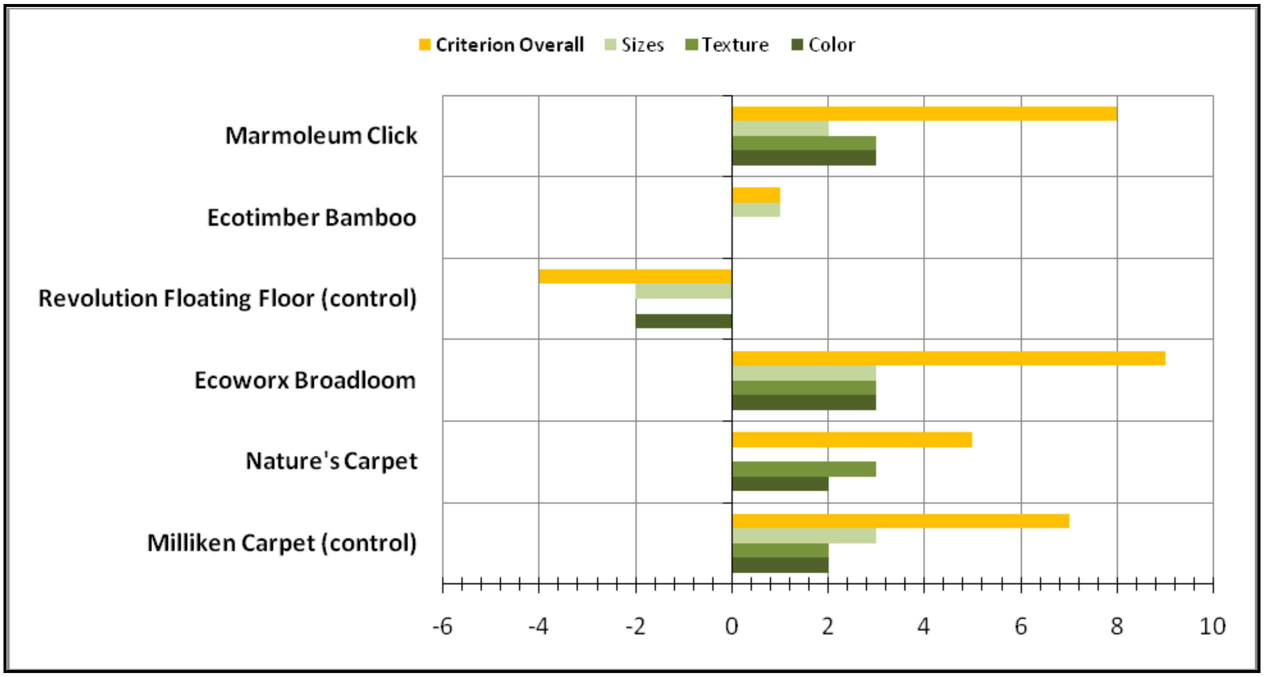

Figure 4.3 Results of Variety for the flooring system

In the summary chart, it is noteworthy that none of the healthy alternatives resulted with a negative ranking on this criterion (Fig. 4.3). Once again, Ecoworx offered the most varieties and options for people to select from. Several color options, textures and panel sizes make the product an alternative and safe option that should be taken in to account in interior designs. Marmoleum Click is atop the list for its category, as the mixture of natural linoleum and zero-VOC structural laminate offers a wide range of designing possibilities. The Milliken Carpet (as a control product) has demonstrated its marketing success with a wide variety of design options as well. In this respect, Nature's Carpet showed good performance, as the natural colors of wool and the added natural inks to complement the offer represent a nice alternative. In the case of bamboo, the author notes that bamboo affords more alternatives than regular floating floors. Finally, the author concludes that for a variety of purposes, all of the selected healthy products represent a valid and efficient alternative that could reasonably be included as a means for ensuring healthier interior environments.

4.3.1.3 *Usability*

This criterion was one of the most balanced in the evaluation. For wood products, only one difference can be found in the marks. For carpets, the three evaluated products earned the same overall mark.

Ecotimber Bamboo, depending on the style and model, sometimes needs to be nailed down. This requirement reduced its mark in this category compared with the other products; however, it does not truly affect the other subjects of study, even when evaluating the ease of installation and maintenance: nailing does not represent a major technical skill that would particularly increase the difficulty level of installing or using this product. On the other hand, with respect to carpets, all the three products have the same characteristics, though they resulted with the same final marks (Fig. 4.4).

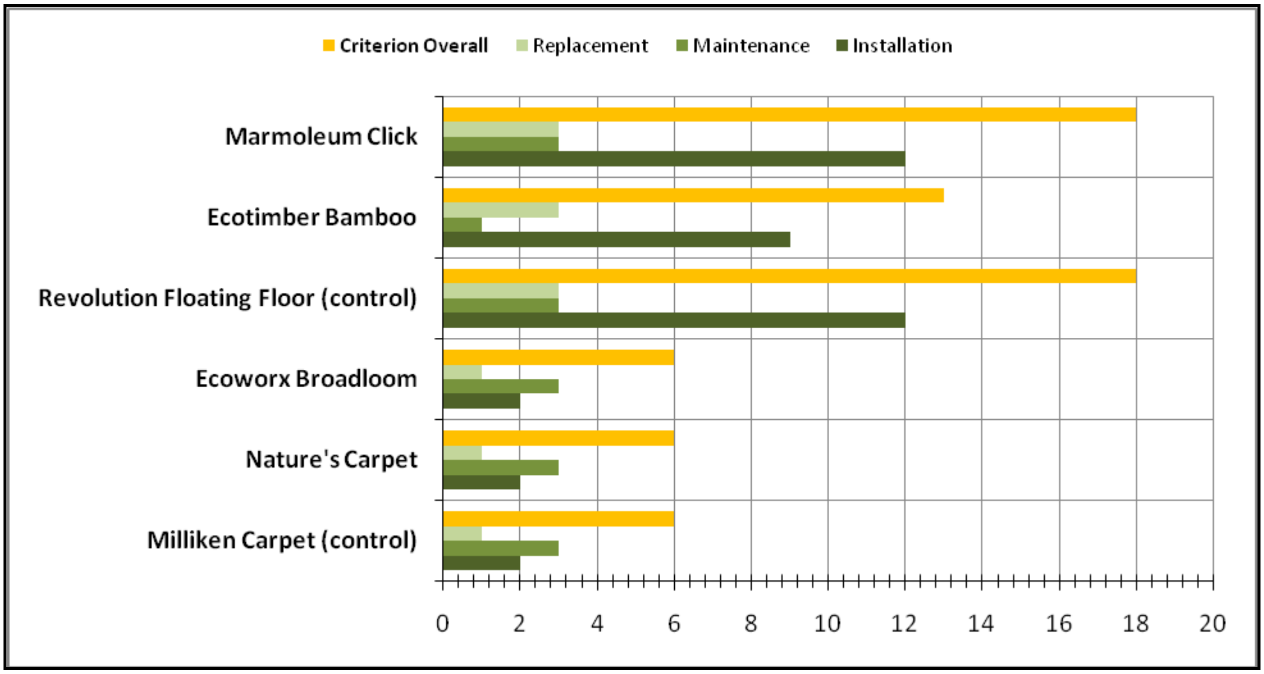

Figure 4.4. Results of Usability for the flooring system

The summary chart shows how although the safe products did not receive a higher mark than the control products, these control alternatives do not offer better performance than the healthy options. All else being equal, the author would rather select safe alternatives that will help to improve indoor air quality and environmental conditions.

4.3.1.4 *Durability*

This criterion offers different results from the others. The author found that wood products obtained the highest mark for durability. Even more interesting is the fact that the evaluation shows that Ecotimber Bamboo offers the best performance because it includes the advantage of being resistant to humidity. No other option in this work offers this interesting quality. The wood products, Marmoleum Click and Ecotimber Bamboo, also have the property of being scratch resistant, a characteristic that its counterparts in the same category do not meet. Furthermore, with respect to the carpets classification, Nature's Carpet offers the highest quality in the market options, attributing to the product very important characteristics and competitive advantages. Ecoworx received the lowest mark among the safe alternatives due to the short life-cycle given by the company which may reduce replacement times (Fig. 4.5).

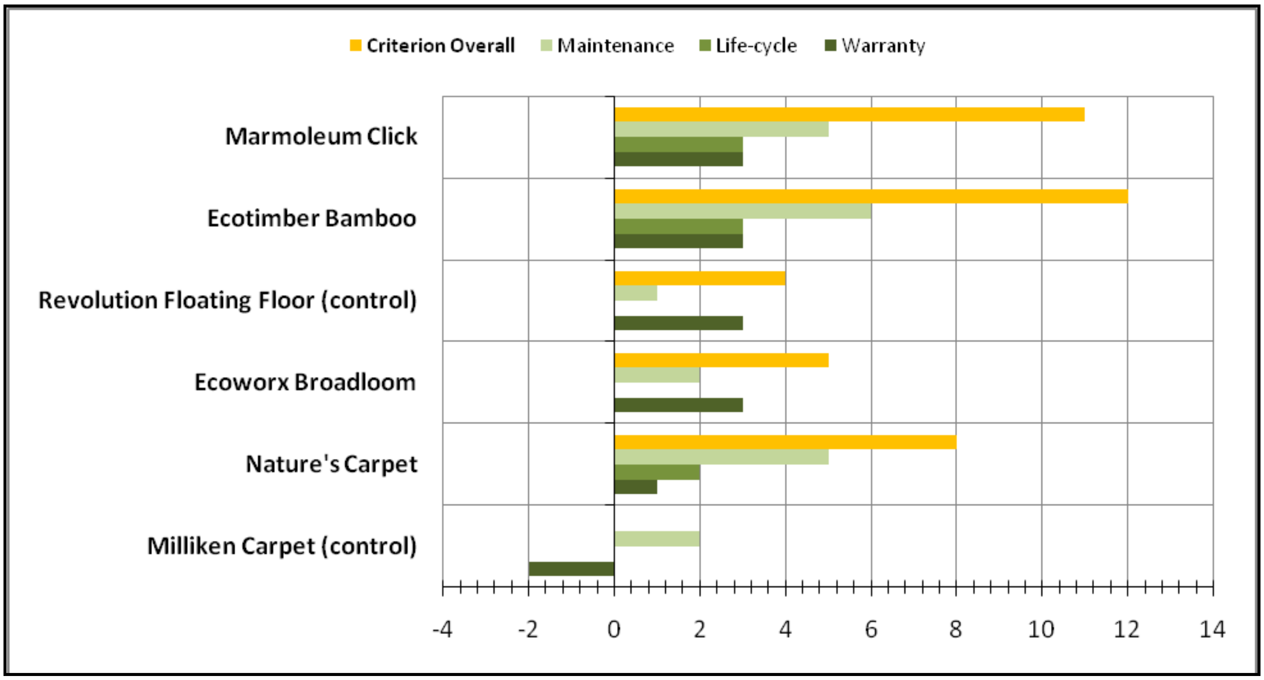

Figure 4.5. Results of Durability for the flooring system

Finally, the chart demonstrates how the weak products from the previous criteria earned the top three places for this segment, which may balance the overall outcome and increase the debate or discussion about which is the most appropriate option. Once again, the popular options did not offer major advantages, and their poor durability evaluation may make them an unprofitable choice.

4.3.1.5 *Cost*

This analysis shows that carpets generally have better results than wood products. Ecoworx earned the title as presenting the cheapest option among all the products evaluated. The carpet control alternative also offers a very affordable selection compared with the other evaluated products. The regular floating floor has also presented a cheap choice – though this might well be its only positive characteristic. The rest of the products are relatively balanced, as Marmoleum Click, Ecotimber Bamboo and Natrure's Carpet are relatively expensive products compared with their counterparts (Fig. 4.6). Nevertheless, the author has found that durability and quality properties may add extra value to this option to become more effective in the market. In the chart it is evident that Ecoworx was the product with the lowest price in the evaluation, matched only by the control carpet alternative.

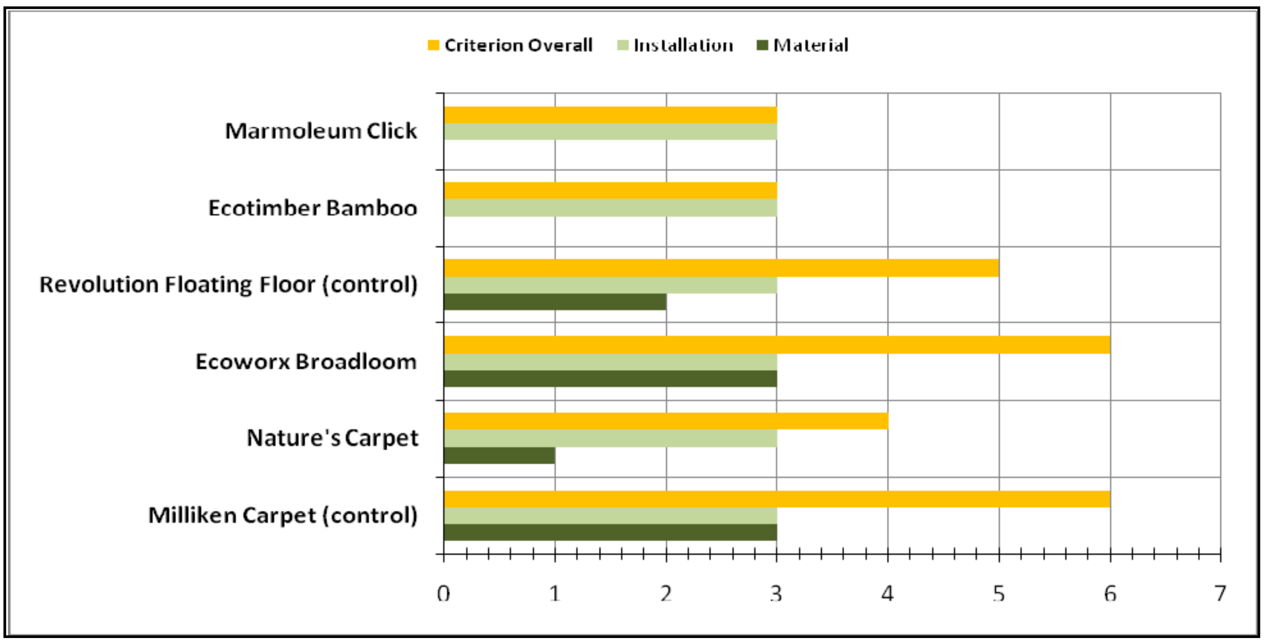

Figure 4.6. Results of Cost for the flooring system

4.3.1 Conclusions from the wall finishing evaluation

The evaluation of wall finishings highlighted two different trends in both categories (paints and wall coverings). While reviewing paints, the author found that all products behaved similarly. On contrary, for the wall covering category, the control group obtained the highest mark compared with the two healthy selections. From this category, the control product earned an overall grade of 37 points followed by Benjamin Moore Natura from the paint category with a total of 36 points. Both products demonstrated outstanding performance on most criteria. Only one subject of study resulted with a negative grade between these two products. For Benjamin Moore Natura, the cost per gallon was found to be high when compared with its control alternative, which may reduce success possibilities in the given market.

Ecotrend Collagen Paint placed third after Natura with an outstanding 35 points. The product revealed a very interesting behavior in the durability criterion thanks to the particular performance of collagen that has introduced special and unique properties to the product. The paint price is the highest among the options (and perhaps the most expensive in the market for such a finishing product), but the unique qualities that the product has introduced in the market as an environmentally friendly alternative provides it with an extra value that might be taken into account.

The other two safe products included in this work (Japanese Wall and Innvironmental Line of wall coverings) did not present with satisfactory overall performance. The lack of consistency during the evaluation process turned two healthy and safe alternatives into rather unmarketable options. Moreover, the author could not gain access to cost information, which impeded the possibility of comparing and rating the products under this criterion.

4.3.2.1 *Availability*

This criterion was the one that gave the most balanced behavior for all products, except for Japanese Wall which showed deficiencies due to the fact that the product needs to be ordered. The other three products promoting their indoor air quality benefits are easily available in the local market and demonstrated the advantage of being produced within the region (Fig. 4.7).

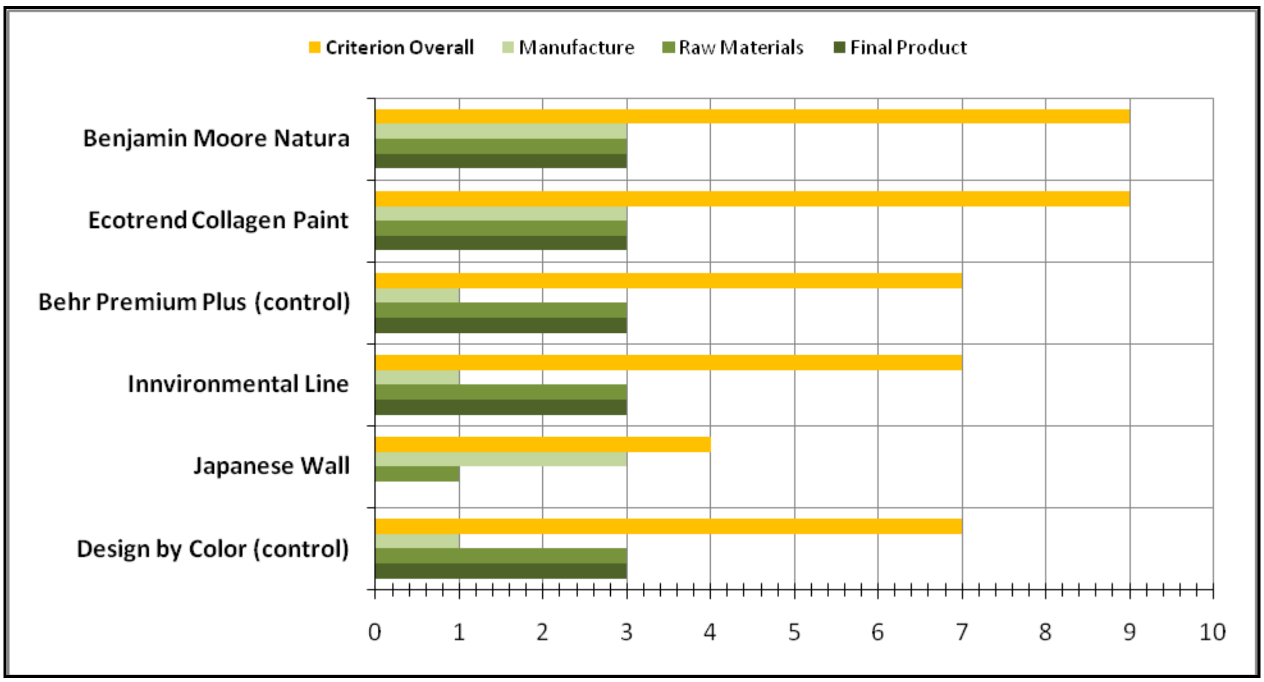

Figure 4.7. Results of Availability for the wall finishing system

After analyzing these results, one could argue that, other than Japanese Wall, this partial evaluation offers no additional decision-making information for any of the safe products. All of them compete under the same conditions with regular products.

4.3.2.2 *Variety*

The evaluation of variety produced as many results as products evaluated. Each alternative obtained a different mark, shows the 'variety' of choices that these materials may present. The highest mark was achieved by Behr, depicting the product as the more flexible alternative with several options for colors, finishes and surface to be applied. Next is Benjamin Moore Natura that represents the best healthy election in this criterion. Natura would need to increase the offering of finishes in order to reach the highest place. Innvironment Line ranks as the third alternative thanks to its multiple possibilities for textures and sizes. Ecotrend's limited color options placed it in the bottom three followed by the control wallpaper. Finally, Japanese Wall's limitations put the product in last place, rendering it the least attractive finishing selection (Fig. 4.8).

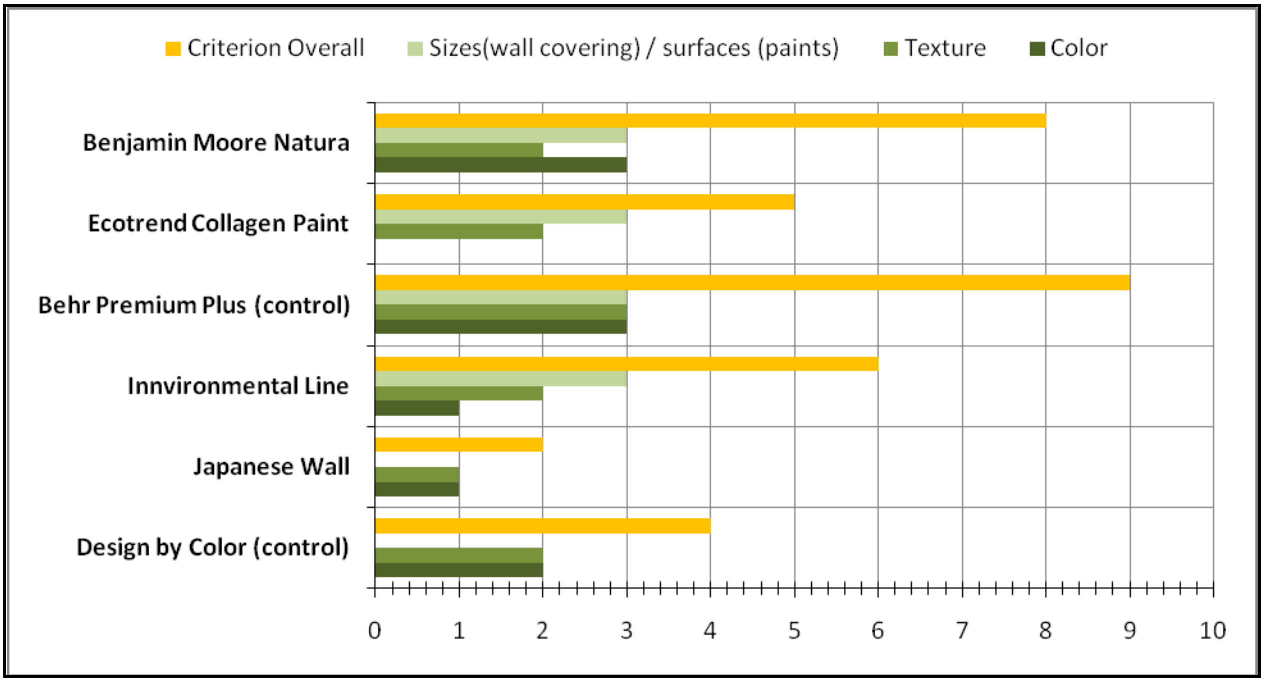

Figure 4.8. Results of Variety for the wall finishing system

The above clearly spells out that the Japanese Wall and Innvironmental Line do not represent popular options in the market. In contrast, the control line of wallpaper from Design by Color might well remain as the main alternative, which sadly affects the achievement of indoor air quality. For paints, the author did not find any reason to prefer regular (harmful) products when options like Benjamin Moore Natura and Ecotrend Collagen offer a high quality, environmentally friendly and safe election.

4.3.2.3 *Usability*

This segment shows two different behaviors; (1) for paints; and (2) for wall coverings. In the first, the three options achieved similar outcomes; however, Benjamin Moore Natura offers reducing drying times – as much as 50 percent less – compared with the rest of the options. On the other hand, the control shows the longest drying time to touch which has reduced its final mark for this criterion. In contrast, the wall covering category finished with a more varied result. The three products obtained uneven marks that demonstrated their dissimilarity. Color by Design earned the highest mark among all evaluates due to the ease of its installation, replacement and maintenance; while Innvironment Line obtained the lowest ranking thanks to the high level of difficulty to install the products (Fig. 4.9).

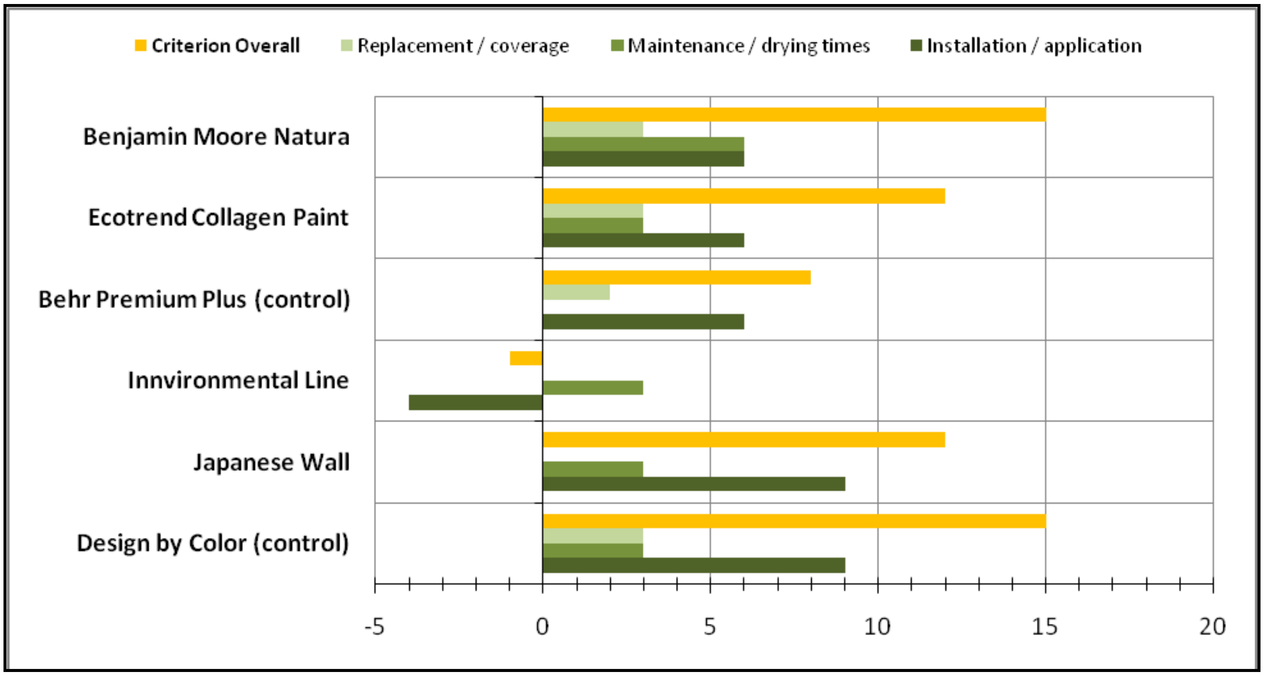

Figure 4.9. Results of Usability for the wall finishing system

The chart shows that Benjamin Moore and Design by Color present the best selections for usability. This means that for paints, the possibility of introducing an indoor air quality promoter does not represent a major concern under this criterion; nevertheless, none of the safe alternatives for wall coverings are supported by high usability qualities.

4.3.2.4 *Durability*

The analysis of durability depicts three levels of quality. In the first, the author finds Ecotrend as the best choice. The collagen paint presents 'avant guard' properties thanks to its natural component that has given the product special qualities. This product earned the highest mark possible – more than double the score obtained by the next option in line. In the second level, the author finds Natura and the two control products offering an acceptable standard performance. The interesting finding can be seen in the third level where the two healthy alternatives for wall covering do not expose attractive characteristics that encourage its satisfactory performance in this criterion (Fig. 4.10).

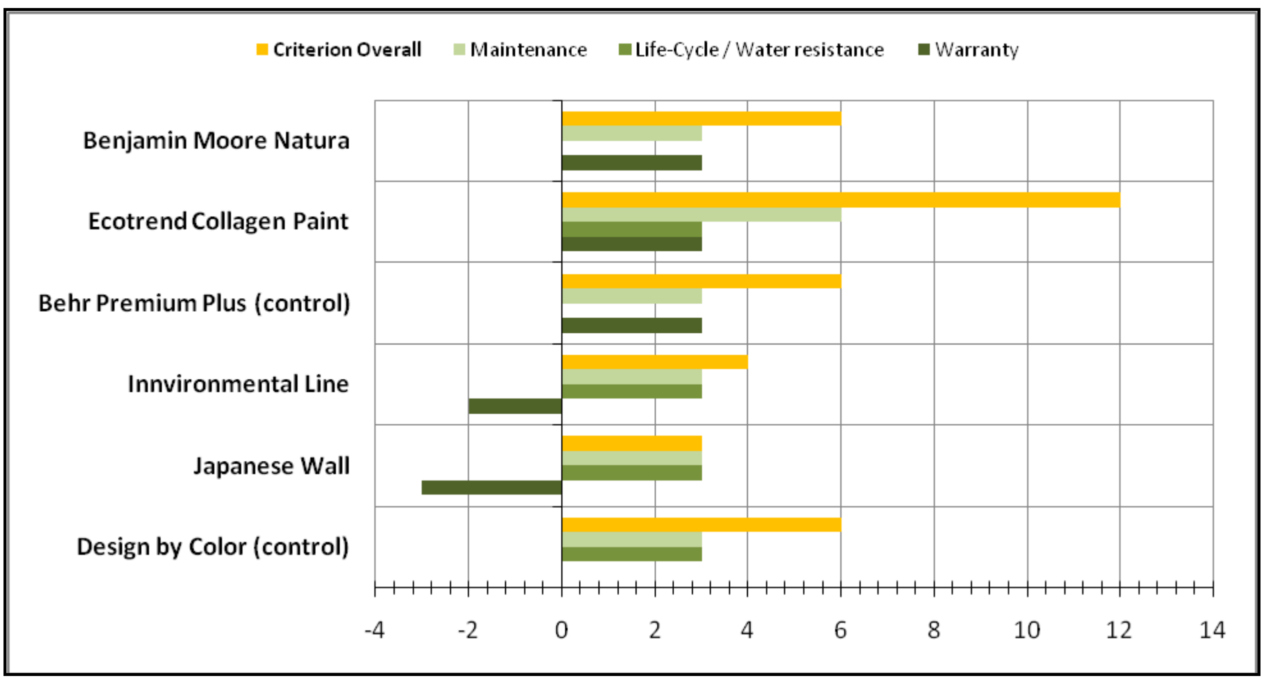

Figure 4.10. Results of Durability for the wall finishing system

If one needs to select a product based on its qualities for durability, one can easily see that Ecotrend will be the best selection. On the contrary, once again the indoor quality promoters for wall covering do not represent a viable option for this partial evaluation.

4.3.2.5 *Cost*

While analyzing the gathered information for paints, the author noticed that Ecotrend was the most expensive product, followed by Benjamin Moore Natura. The control product showed a competitive price that might become one of its mains strengths. It is important to mention that the author did not succeed in obtaining pricing information for the two healthy alternatives for wall coverings. This lack of data prevents the author from accurately completing the evaluation of these products (Fig. 4.11).

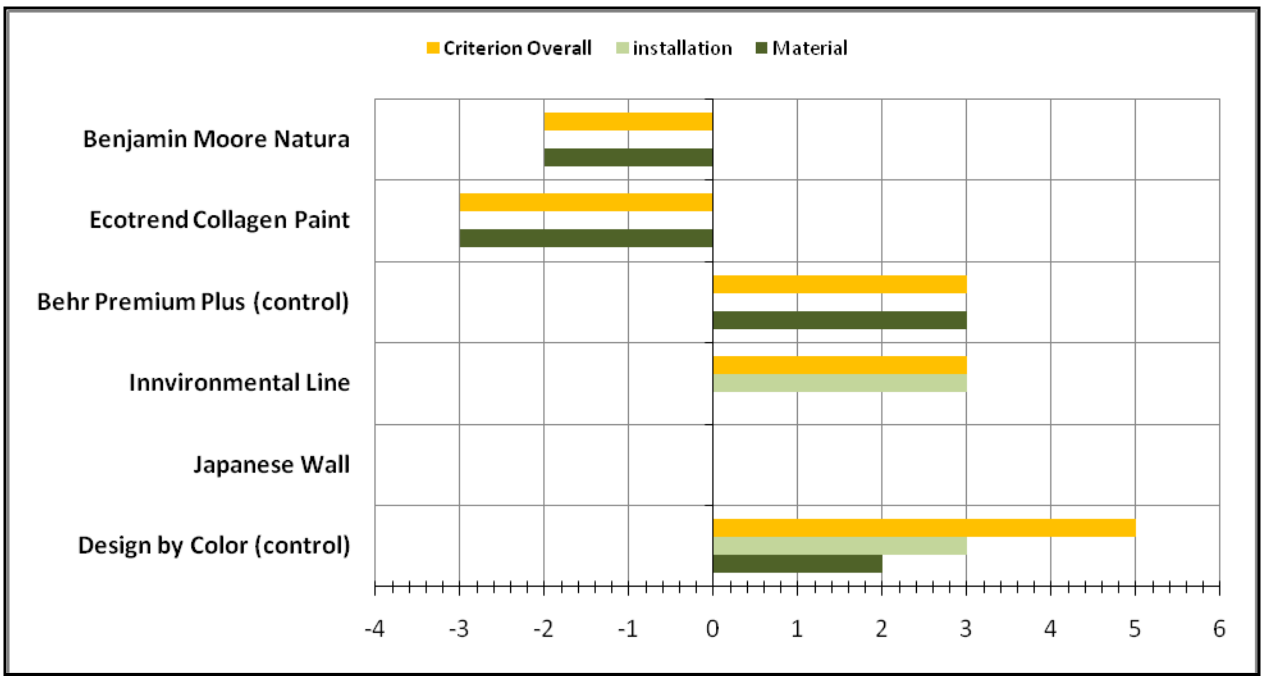

Figure 4.11. Results of Cost for the wall finishing system

Unlike in the last criterion where Ecotrend offered the most convenient option, in this case, the results show the opposite. The author states that with regard to price, none of the environmentally friendly alternatives represent an attractive choice.

4.3.1 Conclusions from the complementary materials evaluation

After the final analysis of these two categories (adhesives and primers), the author found data which is encouraging for the purposes of achieving improved indoor air quality: the environmentally friendly products selected for evaluation not only promoted healthier indoor environments, but were found to be better options than their conventional counterparts in general terms. In contrast with the other systems, the healthy products were always cheaper than the control options. The author found that high quality conditions are similar to one another. Since this category does not contain a finishing material, the variety evaluation was limited to packing presentations for costumers.

4.3.3.1 *Availability*

In this criterion, both regular products offered the best behavior since they obtained the highest mark possible. VM-808 adhesive earned the second highest, only missing a mark because of the place of manufacture. As mentioned in the description of the product, Ultra-Grip's absence in local stores reduces its success in the market (Fig. 4.12).

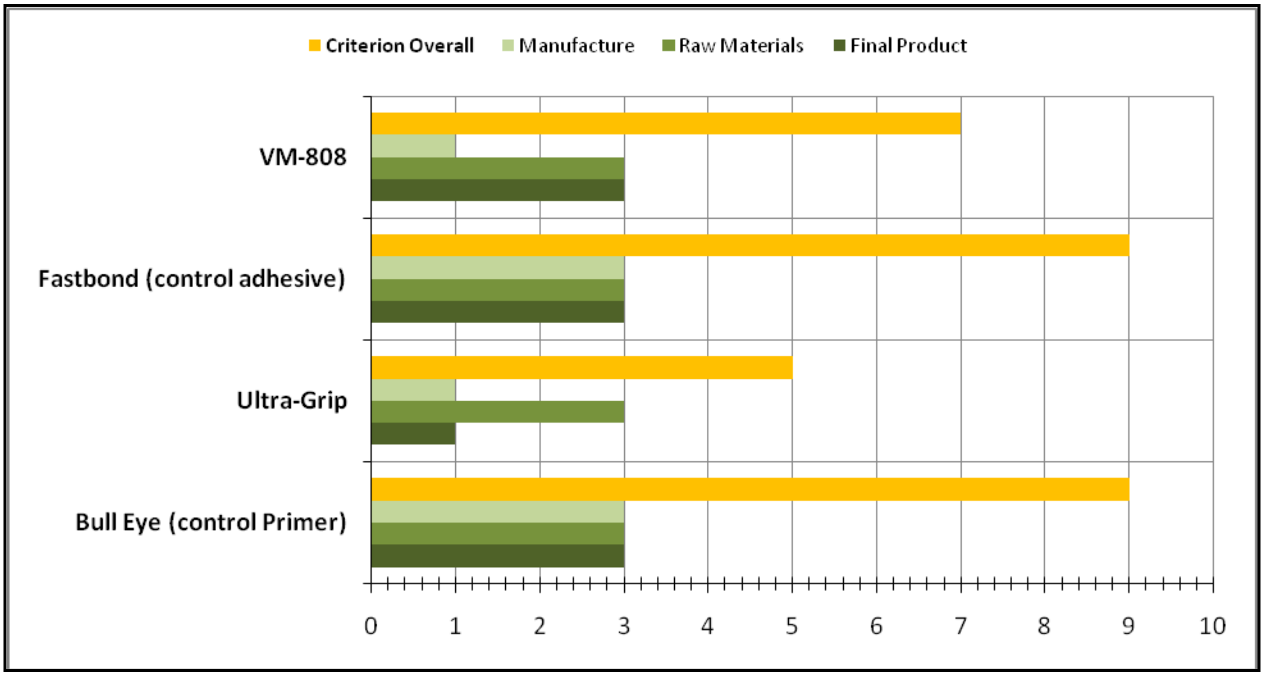

Figure 4.12. Results of Availability for the complementary materials system

Finally, the author reports that the ease of market access might be a concern when selecting one of these eco-products. Regular options are well introduced in the market and appear as stronger choices due its availability.

4.3.3.2 *Variety*

For this criterion, the author found mixed results. For the evaluation of adhesives, the zero-VOC option is only sold in a one-gallon size. On the contrary, the regular adhesive by 3M can be found in three convenient presentations. For the primers, the situation is inverted, with the low-VOC alternative by Dunn-Edwards offering as many options as the regular paint industry does for paints. In contrast, the control option for primers by Zinsser only presents one gallon size. As mentioned above, color and texture as subject of study did not apply for this category since these products are not finishing materials (Fig. 4.13).

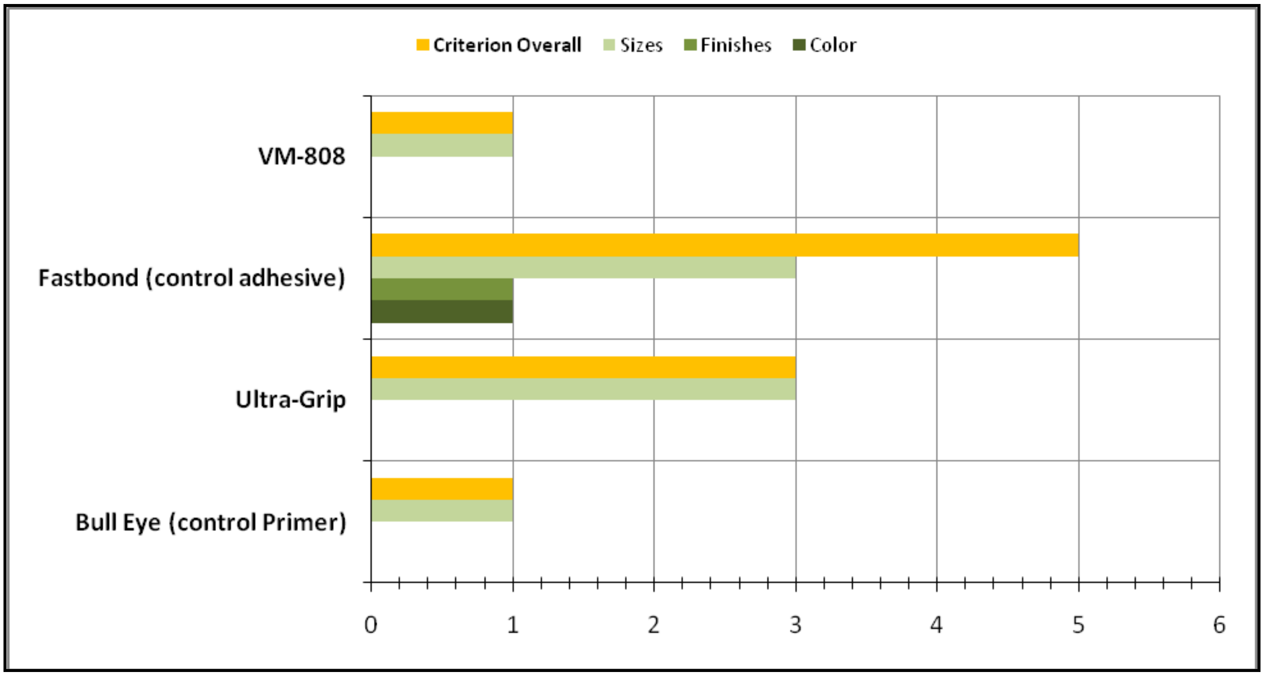

Figure 4.13. Results of Variety for the complementary materials system

4.3.3.3 *Usability*

This criterion demonstrates a balanced outcome for most choices. For adhesives, the author did not find any difference that made one of these options particularly unique. In fact, both got the same mark. For the primers, the control option received the same mark as the eco-friendly options, while Ultra-Grip earned the lowest mark due to longer waiting times for drying (Fig. 4.14).

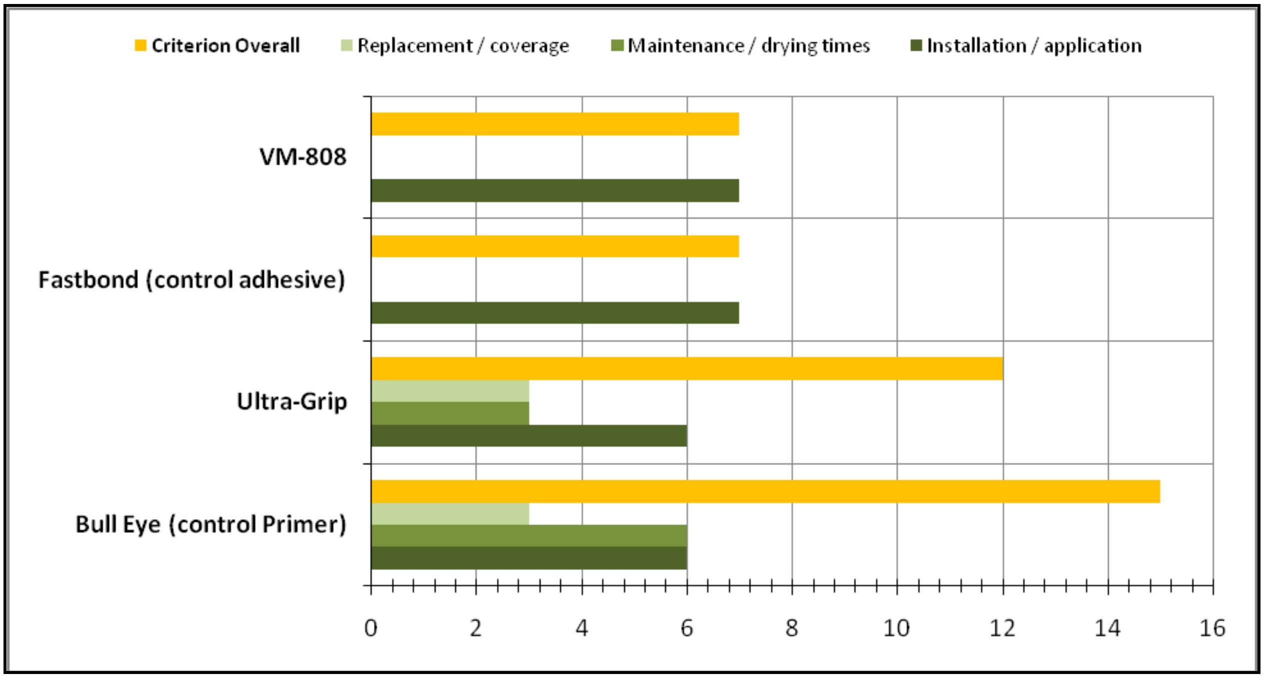

Figure 4.14. Results of Usability for the complementary materials system

The author considers that no product surpasses another in this instance. All of them are used the same way; in fact, for Dunn-Edwards primer, the author posits that the qualities and healthy properties might well balance the small gap for waiting time.

4.3.3.4 *Durability*

The evaluation shows that both safe alternatives provide a more durable finish than the control option. The lifetime claimed by APAC for its adhesive clearly surpasses its counterpart. For Ultra-Grip, its lifetime warranty and ease of cleaning gave it the highest place. In contrast, the control for primer offered a limited guarantee that reduces its final behavior (Fig 4.15).

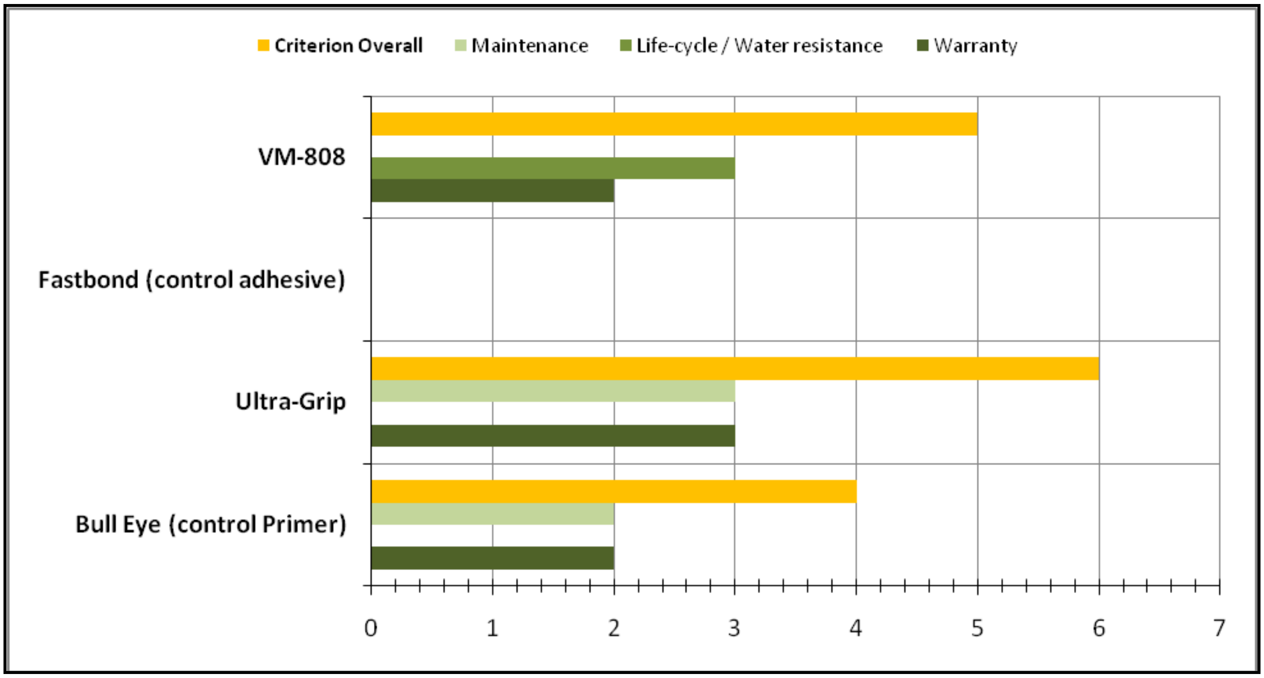

Figure 4.15. Results of Durability for the complementary materials system

4.3.3.5 *Cost*

As mentioned above, both healthy elections are sold at accessible prices that enable the products to be attractive choices while looking for indoor air quality promoters. In Figure 4.16, it can be seen that both control options do not represent an economically viable alternative. In addition to the fact that these options do not offer opportunities to improve interior environments, it is the author's opinion that no reason exists to support the continued use of these negative materials in interior designs.

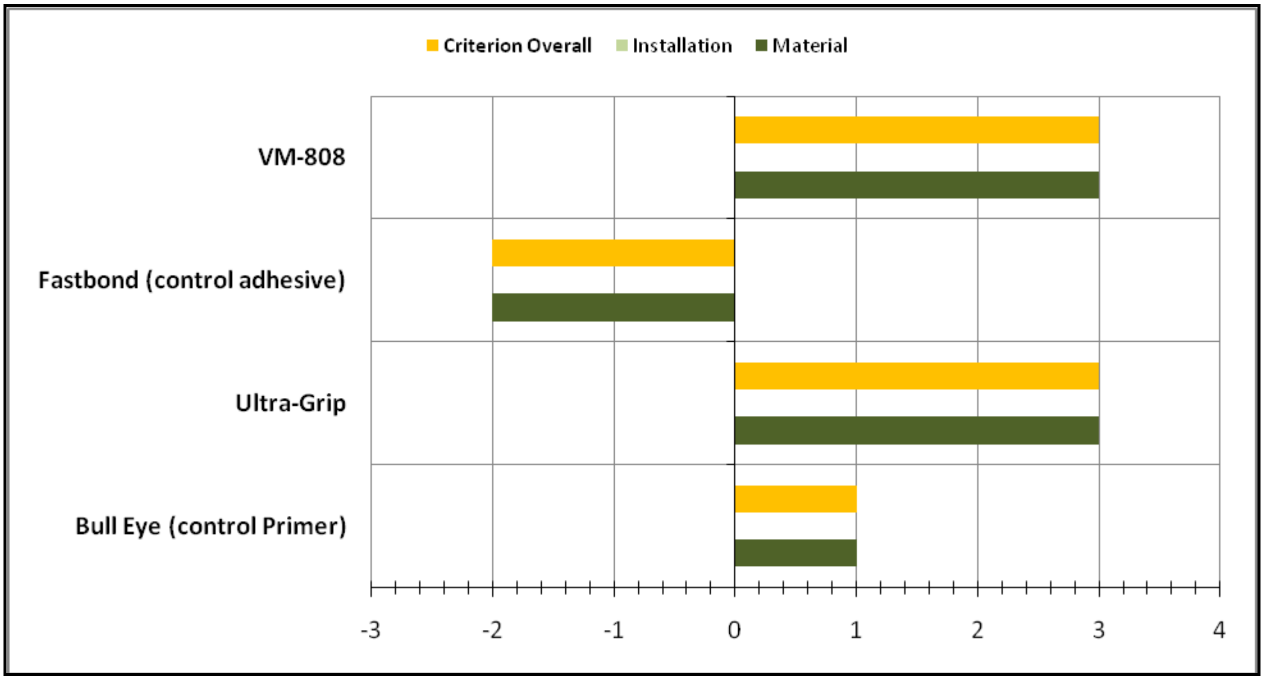

Figure 4.16. Results of Cost for the complementary materials system

4.4 CONCLUSIONS AND RECOMMENDATIONS

After the selection process in the second part of the work, it quickly became apparent that the industry still needs to develop more alternative products, because not many materials meet the guidelines for achieving healthy interior environments. The author found it necessary to work and evaluate with few alternatives that met the requirements for this work. In addition, the author realized that on several occasions when a product was offered to the market as zero- or low-VOC emissions, no scientific or technical data was available to support that claim. This fact led the author to reject those products and seek other possibilities. The lack of reliable supporting documentation raises doubts about whether or not a given product truly represents a trustworthy choice to be included with regard of indoor air quality goals.

In this matter, the author deeply encourages further research to produce information that not only backs up marketing options, but that also generates the sense of trust that people seek in healthy materials. Additionally, government and non-profit organizations need to watch for the fulfilling of guidelines. The presentation of a reliable Material Safety Data Sheet (MSDS) should be mandatory for all products under this segment; and people should be informed about how to read them in order to obtain the required knowledge about a given product. That means that as much information as possible should be given so that people may become aware and convinced about the advantages of such options for their healthy leaving.

To this end, the author found that the assessment methods served as a valuable tool to become informed about the advantages and disadvantages of particular materials. The Building for Environmental and Economic Sustainability (BEES) and Athena standards (based on Life Cycle Assessment (LCA) studies) yield accurate data on products' environmental impact at every level of production, use and disposal. Nevertheless, the author found that due to the complexity of those analyses, several new products are still waiting to be included in such methods. In addition, the application of these systems required particular attention because the high level of difficulty, and the fact that cannot be easily understood. The author thinks that the possibility of developing a method similar to LCA can be mass-introduced in the field. Such a method could serve as a popular tool that may contribute to people's education about selecting and evaluating their own alternatives. The wide availability of understandable assessment methods in the mass market will allow more people to be involved and concerned about indoor air quality, and will afford them the tools to decide the real conditions in which they want to live in.

The author's first aim was to study three systems of interior environments: Flooring, wall finishes, and furnishing. For the first two systems, two subcategories were included to cover the most popular techniques. For flooring, wood products and carpeting were evaluated, with the second element having fewer safe alternatives in the market for indoor air quality concerns. In fact, in some cases, the author could not find different options that accomplished the assessment method's goals. For the wall coverings, the author found that paints became the best options for interior finishes, as the paint industry has developed a wide range of options that demonstrated competitiveness and environmental friendliness. On the contrary, wall coverings are still lacking in development, and once again few options could be processed. Indeed, both options for wall coverings resulted with low overall marks, showing several gaps among the subjects of study. For furnishing, the author could not even find options to analyze. The industry of furnishing in general is lacking in technical and scientific data that supports indoor air quality achievements. Several manufacturers suggested that their products meet guidelines and regulations for such purposes; however, the author was not successful in certifying this information. From the author's point of view, this represents an important gap in the study, as furniture represents a major element in the interior environment that will influence the condition of the air people breath. Wood products, textiles and plastics are well known components of the furnishings that complement homes, and as for flooring and wall finishes these elements serve as a source of harmful pollutants that must be removed in order to maintain healthy conditions. Indeed, it makes little sense to introduce safe alternatives for flooring and wall finishes if the interior environment will ultimately be filled with uncontrolled materials as part of the furniture. As an alternative, the author opted to work with complementary materials that are used for installation purposes of the studied divisions. In this additional system, the author found interesting data that demonstrated that adhesives and primers can be introduced with no risk for occupants' health. Finally, one can conclude that although few options rise as indoor air quality promoters, the industry is still developing ideas that later will complement the palette of choices. It is nevertheless necessary to encourage greater development and research in the furnishing field in a way that no doubts surround the selection of a given product.

Another important consideration that the author found is the fact that in many cases, products that help to improve the interior environmental conditions offered limited options for people to achieve different designs. Compared with the mainstream regular options, safe selections tend to offer fewer selections for such purposes, which may affect their market acceptance. In the author's view, this concern can be solved in the coming years due to the fact that industry has shown particular interest in developing healthy materials.

When evaluating and discussing the data obtained from the cost analysis, the author found that safe products may compete in many cases with regular options. At the beginning of the work, the author had contemplated that high costs might negatively affect the selection and acceptance of 'safe' materials in the marketplace; nevertheless, one can see that in some instances these indoor air quality sponsors offer a good economic alternative. On the other hand, the author believes that in cases where healthy options resulted with higher prices, that product demonstrated particular properties that gave it extra value. In that sense, one may say that more promotion could help to spread the advantages of these choices that at the end of the day will pay off the possible added cost.

Finally, the author concludes that government, industry and non-profit organizations must work together in order to develop strategies that promote materials and products that help to improve indoor air quality. It has been established that in many cases these healthy materials represent a reliable choice for customers. Moreover, one can state that more information should be given to most people (homeowners, professionals, etc.) to finally accept and understand indoor air quality concerns in order to adopt strategies that may improve it in their direct interior spaces. Given the fact that few products are offered, the need for more production remains an issue to be solved. An increased demand for these products would, of course, provide a greater incentive for the industry to launch further research that will ultimately create new possibilities and provide verifiable quantitative properties data for the utilized materials.

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