

FLOORING MATERIALS–LIFE CYCLE COSTING FOR M.E. RINKER, SR.  
SCHOOL OF BUILDING CONSTRUCTION AT THE UNIVERSITY OF FLORIDA

By

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by

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This document is dedicated to my father, Celedonio M. Lozada Gentile, for been such a great fighter against difficult circumstances of life; because he became stronger in health and soul. Also this document is dedicated to my dear uncle, Elvio Waingart, a beautiful human being and a distinguished civil engineer who inspired me. Thank you for being an important part of our lives. We will always remember you with infinitely love and affection.

(Este documento esta dedicado a mi papa, el señor Celedonio M. Lozada Gentile, por que supero valientemente difíciles adversidades de la vida, por no dejarse vencer y por luchar siempre con valor, optimismo y sobretodo amor. Por que ahora es una persona más fuerte y saludable, tanto físicamente como espiritualmente. También dedico este logro a mí querido tío Elvio Waingart, un gran ser humano, un estupendo ingeniero civil y una gran inspiración para mí. Gracias por ser quien fuiste en nuestras vidas. Todos los que te conocimos te recordamos con mucho amor y cariño.)

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Abstract of Thesis Presented to the Graduate School  
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Major Department: Interior Design

A misguided perception of life cycle costing is that the longer something lasts, the less it costs over time. The purpose of this research is to examine flooring interior materials (linoleum, carpet, tiles, rubber, and sealed concrete) for the M.E. Rinker School of Building Construction at the University of Florida. The impact of the used substrate materials and the installation methods used for each alternative will be assessed for possible potential effects on the service life cycle cost. Using the service life cycle cost (SLCC) analysis, the true cost of each material will be computed projecting 100 years as the building service life and .03 as the inflation rate percentage.

## CHAPTER 1 INTRODUCTION

The proper selection of building materials contributes considerably to the overall life cycle cost<sup>1</sup> (LCC) of a building. However, the selection of materials is typically based on manufacturer's information, designers' professional or personal experiences, or the initial cost of the product and budget constraints.

Unfortunately this process of material selection contrasts with today's conscientious selection of materials required for attaining global sustainability. In the Brundtland Report (1999) sustainability is defined as “. . . meeting the needs of the present without compromising the ability of future generations to meet their needs . . .” (Kibert, 1999, p.1). The three fundamental principles of sustainability are: reduce, reuse, and recycle. In order to create an environmentally friendly atmosphere, as professional designers need to:

1. Be aware that every decision made, either big or small, will have a direct influence on our environment.
2. Attempt to reduce, with our decisions, environmental impact.
3. Make intelligent and sensible selections of green sustainable materials.

It is presume that a low initial cost of materials will result in a service life cycle cost<sup>2</sup> (SLLC) higher than the cost benefit of the initial purchase. The true cost of a

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<sup>1</sup> Life Cycle Cost is an economic/logistic procedure where the initial cost of a product is compared over its use life.

<sup>2</sup> When the life cycle cost only includes the period of time where the material is in use at the facility.

material includes the initial cost, installation cost, operation and maintenance cost<sup>3</sup>, and replacement cost. (Dell'Isola, & Kirk, 1981, p. 2)

The researcher recognizes that production and disposal issues are certainly very important in any life cycle assessment of materials. For the purpose of this research, however, it is the “use phase of the product that is most significant because of the relatively long lifetime over which building materials are in use” (Malin, 1999, p. 134). In order to assess the cost of flooring materials used at Rinker Hall, the product use phase and the life cycle cost will be analyzed.

### **Research Hypothesis**

The hypothesis of this research is that a low initial capital cost of a material will result in a service life cycle cost higher than the cost benefit of the initial purchase.

Using Net Present Worth (NPW), an evaluation tool that calculates all the cash flow associated with a specific flooring alternative to the present equivalent, as a ranking system it is expected that the material with the lowest initial cost will be the lowest cost alternative (lowest NPW) in the long run when maintenance, operational cost and replacements are considered.

### **Goals and Objectives**

The focus of the research is the creation of a decision making tool based on real life data that will facilitate practical evaluation of floor finishing materials. This tool will guide design professional in selecting materials for renovations or new constructions. A life cycle cost (LCC) analysis will be used as an economic evaluation tool. LCC quantifies incurring costs commonly overlooked (by facility managers and designers) as

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<sup>3</sup> Maintenance cost includes cleaning and repair expenses.

replacement and maintenance costs. The final result will be a comparison between alternatives given in term of a present value per square foot.

### **Summary of Thesis**

The research objectives describe above will be described in detail in Chapter 2 through 8. Specifically, Chapter 3 presents background information regarding M.E. Rinker Hall School of Building Construction, life cycle cost analysis already completed for other facilities, and general information of commonly used flooring finishes in educational facilities, their structural properties, general specifications and cleaning and maintenance suggested procedures. Chapter 4 describes the methodology used to obtain and analyze the data. Chapter 5 describes the data collection tool used to obtain the data; Chapter 6 discusses the expected results and Chapter 7 presents and analyzes the obtained results. Conclusions about the analysis and the potential for future uses are discussed in Chapter 8.

## CHAPTER 2 SIGNIFICANCE

The study focuses on M.E. Rinker School of Building Construction at the University of Florida. This building uses carpet in the private offices, rubber in the atrium stairs, linoleum in the corridors, sealed concrete in the classrooms and ceramic tiles in the bathrooms. Because this building is awarded with a Gold LEED certificate it is of primary importance to know if the flooring materials used are the best alternatives when maintenance and operational costs are considered.

This research uses a life cycle cost analysis as a method of depicting the true overall cost of each floor covering over a predetermined period of time. Life cycle cost analysis can appear complicated and difficult to comprehend from the standpoint of establishing the real value of a floor covering expenditure. The initial purchase cost, installation charges, maintenance requirement and associated costs, plus the costs of cleaning chemicals must be factored into the analysis to yield the true expenditure of money over a period of time.

The result of the life cycle cost analysis is intended to be a quantitative decision-making tool that will allow design professionals and facility managers to make informed choices about facility flooring materials prior to incurring replacement restoration expenses.

For the purpose of this research, flooring material finishes are studied and compared. Floor surfaces are daily exposed to foot and equipment traffic, exposure to direct and indirect sunlight, and possible contamination of organic and chemical sources.

“As a finish material, it is often considered the most important specification in the interior design scheme. Floor finishes choices create an opportunity to expand a color palette and specify a product that is conducive to the type of activities and purpose of the building” (Harris, 2000, p.16).

Another important issue of flooring materials is associated with safety. “Floor surfaces are a crucial factor in preventing falls and need very careful consideration in relation to anticipated users and patterns of use and behavior . . . there is no such thing as a non-slip floor”(Berman, 1997, p.9).

## CHAPTER 3 BACKGROUND INFORMATION

### **Educational Facilities – Schools and Universities**

Universities and school facilities must be easy to clean and maintain. This is facilitated by (1) appropriate, durable finishes for each functional space, (2) careful detailing of such features as doorframes, casework, and finish transitions to avoid dirt-catching and hard-to-clean crevices and joints, and (3) adequate and appropriately located housekeeping spaces. A wide variety of traditional finishes for flooring materials are available for educational facilities. Choices include but are not limited to vinyl, linoleum, rubber, ceramic tiles, masonry, carpet, and exposed concrete. Each of these materials have different specifications, performance standards, aesthetics effects, and operational and maintenance procedures. But whichever flooring material is selected, facility managers will have to keep them clean, well-maintain and pleasant looking. “You have to have the resources available to maintain the surface,” says David Frank, president of the American Institute of Cleaning Services. “Whether it is carpet or tile, both require care. If you can’t maintain it, don’t buy it.” In educational facilities, aesthetics is of primarily importance because flooring is usually cleaned for appearance and not for hygiene or health (Kennedy, 2004, p. 2).

In educational facilities, high traffic areas, such as corridors and cafeterias, are covered with resilient non-slip surfaces such as vinyl, rubber or linoleum. Concrete flooring is also a suitable alternative for high traffic areas. For private space such as offices, carpet is preferred because its acoustical properties and the wide selection of

colors available. For wet areas as bathrooms and kitchens, ceramic tiles are commonly used (Kennedy, 2004, p. 1).

Like other buildings, educational facilities must follow the local and the state general building codes. Ideally, the facility design process incorporates direct input from the owner and staff early in the process. The designer also has to consider the needs of the users, faculty, students, visitors, and support staff that generally do not have direct input into the design. A good design integrates functional requirements with the human needs of its users.

### **M.E. Rinker School of Building Construction**

The School of Building Construction (SBC) began at the University of Florida (UF) in 1935 and is the oldest Building Construction Program in continuous operation in the United States. This school operates as part of the College of Design, Construction and Planning (DCP) at the University of Florida. This College is one of the most extensive design colleges in the nation and the only college nationwide that combine under one college the disciplines of architecture, interior design, landscape architecture, urban and regional planning and building construction.

In 1975 the Department of Building Construction was accredited by the American Council for Construction Education. That same year the College of Architecture & Fine Arts was divided into two colleges, with Building Construction going into the College of Architecture. One year later Building Construction became the School of Building Construction at the University of Florida. In 1989 the SBC was renamed the “M.E. Rinker Sr. School of Building Construction” after M.E. Rinker, Sr. and the CSR/Rinker Materials Corporation who pledged a \$5 million endowment to the School of Building Construction.

M.E. Rinker, Sr. School of Building Construction (Rinker Hall) is the first high performance green building on the University of Florida campus. Rinker Hall is one of only 26 in the world with a Leadership in Energy and Environmental Design (LEED) Gold Certification by the U.S. Green Building Council. LEED is a green building standard that measures environmental sustainability (Figures 3-1 -- Figure 3-6).



Figure 3-1: Rinker Hall Entrance Sign (Source: C.M. Lozada)



Figure 3-2: Rinker Hall Façade (Source: C.M. Lozada)

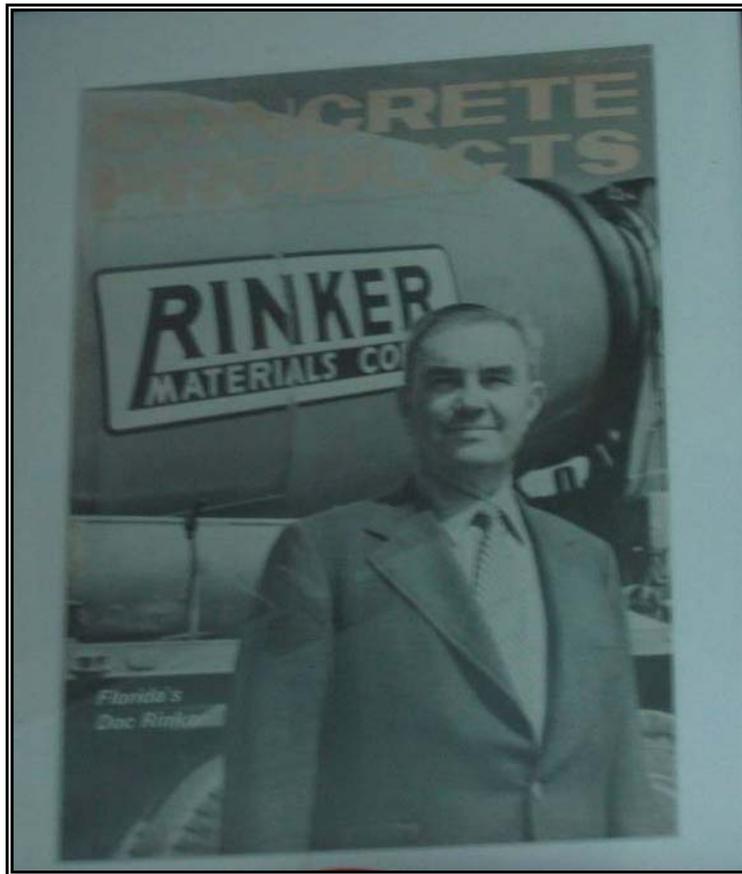


Figure 3-3: Sr. M.E. Rinker (Source: C.M. Lozada)



Figure 3-4: Rinker Hall (Source C.M. Lozada)



Figure 3-5: LEED Gold Award for Rinker Hall (Source: C.M. Lozada)

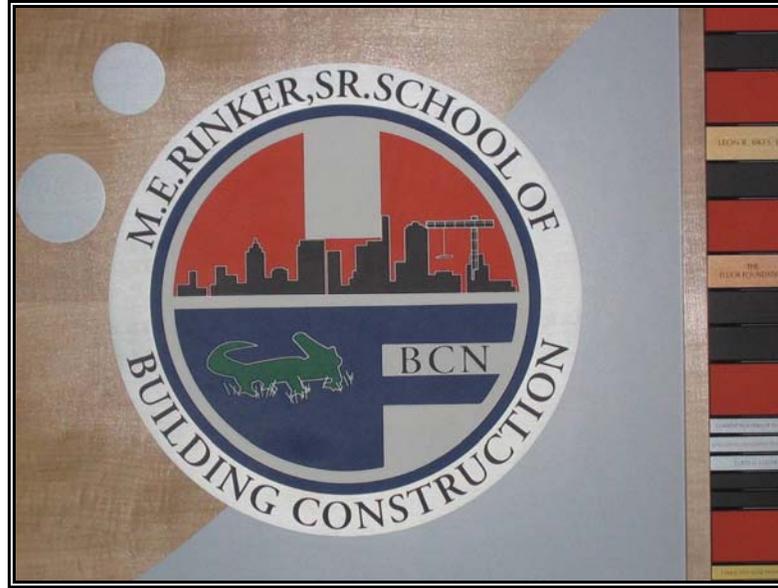


Figure 3-6: M.E. Rinker, Sr. School of Building Construction Logo (Source: C.M. Lozada)

### **Advantages of Life Cycle Costing**

In the past, the “emphasis have been toward improving the reliability of early price forecasting and the cost planning of the design process rather than toward the evaluation of the whole life cycle cost” (Bull, 1993, p. 122). Facility owners usually want the lowest possible first cost without considering the long run costs like maintenance (cleaning and repairs) operation, and replacement. Life cycle cost analysis help designers determine if the owners can afford not only the initial cost, but the long term cost of a facility. Life cycle cost procedures is an “attempt to evaluate projects on the basis of combination of initial and future costs” (Bull, 1993, p. 123). Life cycle costing should not be confused with Life Cycle Assessment which includes the whole life of the material including environmental accounting; life cycle cost includes only the economic values used to compare the cost of different material alternatives over the serviceable or useful life span (Dell’Isola, & Kirk, 1981, p. 11).

Ashworth (1993) stated that a life cycle cost approach . . . is essential to effective decision making in the following ways (as cited in Flanagan et al., 1993):

1. Life cycle costing is a total cost approach undertaken in the acquisition of any capital cost project or asset, rather than merely concentrating on the initial capital cost alone.
2. Life cycle costing allows for an effective choice to be made between competing proposals of a stated objective. The method will take into account the capital, repairs, running and replacement costs, and express these in consistent and comparable terms. It can allow for different solutions of the different variables involved and set up hypotheses to test the confidence of the results achieved.
3. Life cycle costing is an asset management tool that will allow the operating costs of premises to evaluate at frequent intervals.
4. Life cycle costing will enable those areas of buildings to be identified as a result of changes in working practices, such as hours of operation, introduction of new plant or machineries, use of maintenance analysis.  
(p. 123)

#### **Life Cycle Costing Applications**

Life cycle costing has several different applications associated with development and construction projects: 1) as part of the investment appraisal; 2) at the design stage; 3) at the construction stage; 4) during the project use and occupation; 5) at procurement; and 6) for energy conservation applications (Bull, 1993, p. 126). For the purpose of this research, only the project use and occupation stage will be considered.

During the occupation phase of a facility, the highest cost impact item from the owners' standpoint is the maintenance expenditures. These costs do not remain constant over the facility useful time; therefore they need to be evaluated frequently. Also changes in facility functionality or hours of occupancy need to be monitored over time to maintain an economic life cycle cost of a facility. It is known that "the maintenance category alone averages in a typical office building approximately \$1.50 - \$2.50 per gross square foot per year" (Dell'Isola, & Kirk, 1981, p. 49). The authors defined maintenance cost as that one that includes regular custodial care and repair, annual maintenance

contracts, and salaries of facility staff performing maintenance tasks; including replacement items of less than \$5,000 in value or having a life of less than 5 years (p. 50).

In order to positively impact the maintenance cost of a facility designers and owners should: 1) select high quality exterior and interior surfaces that do not require recurrent maintenance such as painting or waxing; 2) select floor covering materials with minimum routine repair and replacement requirements; 3) plan a preventative maintenance program; 4) decide where to do the maintenance as a full time staff or to contract for the service; and 5) have complete knowledge of the proper maintenance procedure for each type of material.

### **Life Cycle Cost Analysis Method**

In order to help with the decision making process several approaches have been developed to determine a building material's environmental quality. The most commonly accepted process is the life cycle assessment (LCA). "The LCA process is based on a lifecycle inventory, in which a researcher identifies and quantifies all of the raw materials and energy consumed in the production, use and disposal of the product, as well as pollutants and by-products generated" (Wilson, 1997, p.1). This complete life cycle of a material is often referred to as "cradle to cradle" assessment. After the initial inventory of a material is complete the LCA examines the environmental impact of each of the materials and energy flows (Figure 3-7). Unfortunately, the complexity associated with LCA makes it very difficult to use. Furthermore, the lack of accurate data on products and processes and the almost impossible task of tracking ecological impact of materials make the assessment more difficult (Wilson, 1997, p. 10). Despite the difficulties of life cycle assessments they can still provide a very good starting point for comparing materials.

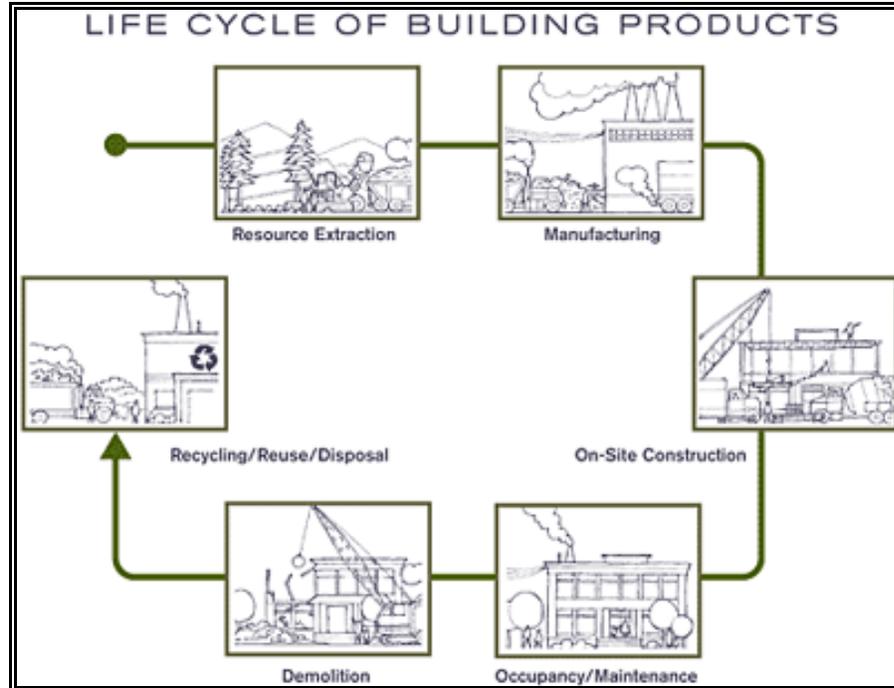


Figure 3-7: Life Cycle Cost of Building Products (Source: <http://www.wbdg.org/design/resource.php?cn=0&cx=0&rp=6>)

Life cycle cost analysis is a comparison of costs for different material alternatives over the serviceable or useful life span of the facility. In this process, the net cost for each material alternative is examined and compared. It provides quantitative results based on specific assumptions, such as the building service life, inflation rate, discount factor, the material service life, and the salvage value, if any. Of this list of factors, the most important for the researcher is the building service life. It is very common to see how buildings intended purposes are modified over time because of changes in population or technologies. That means that the functional purpose through their useful life change. If educational facilities are intended to be reused and adapted to other activities then the complete useful life of the building is probably longer than the useful life of the educational facility. If this is the case then the approach to use for analysis is the Service Life Cycle Costing (SLCC). The SLCC analysis only uses the service life of

the building's original intended use. For this research, this method will calculate the cost of a material (during its service life in the facility), including replacement and maintenance costs. Then, the best alternative for flooring will be determined and recommendations will be made for the use of new, more sustainable materials.

There are many methods available to calculate specific economic performance measures. Used appropriately, these methods allow the planning and design team to evaluate the economic consequences of particular design decisions. The various economic analysis methods include:

Life-Cycle Cost Analysis (LCCA)

Net Benefits (NB) and Net Savings (NS)

Benefit-to-cost ratio (BCR) and Savings-to-investment ratio (SIR)

Internal rate of return (IRR)

Overall rate of return (ORR)

Discounted payback (DPB) and Simple payback (SPB)

For the purpose of this research, the Life Cycle Cost Analysis (LCCA) will be used because it is the basic method recommended by the United States Federal Government (e.g. WBDG Cost-Effective Committee, <http://www.wbdg.com>, Retrieved August 2003).

LCCA is a method for assessing the total cost of facility ownership. It is a method proposed by many as the best for evaluating building-related options (Bull, 1993, p.6). It takes into account all costs of acquiring, owning, and disposing of a building or building system. For the purpose of the design professional, life cycle costing can be defined as “an economic assessment of competing design alternatives, considering all significant costs of ownership over the economic life of each alternative, expressed in equivalent

dollars”(Dell’Isola, & Kirk, 1981, p. 1). The Newsletter Periodical (Spring 2000) states that life cycle costing is the best measuring stick for making investment decisions . . . because it takes into account the time value of money, varying cash flows, cost of capital, project life, and different magnitudes of the competing investment decisions; and more important the outcome of this analysis is in current dollars.

LCCA is especially useful when project alternatives fulfill the same performance requirements, but differ with respect to initial costs and maintaining and operating costs. Alternatives have to be compared to select the one that maximizes net savings.

Lowest life-cycle cost is the most straightforward and easy-to-interpret measure of economic evaluation. Other commonly used measures as Net Savings (or Net Benefits) and Savings-to-Investment Ratio (or Savings-to-Cost Ratio) are consistent with the LCCA measure of evaluation if they use the same parameters and length of study period.

### **Purpose of a Life Cycle Cost Analysis Method**

The purpose of the LCCA method is to estimate the overall costs of project alternatives and to select the design that ensures the facility will provide the lowest overall cost in the long run. It is better for the owner if the LCCA is done early in the design process, while there is still a chance to modify the design without having to incur in changing expenses during the construction phase.

### **Costs to Assess**

The first and most challenging task of an LCCA is to determine the economic effects of alternative designs of buildings and building systems and to quantify these effects and express them in present dollar amounts. Building-related costs fall into four major categories: 1) initial cost; 2) operation and maintenance cost (O&M); 3) replacement costs; 4) personal salaries.

**Initial Costs**

The purchase, acquisition, construction costs, and loan payments which may include capital investment costs for land acquisition, construction, or renovation and for the equipment needed to operate a facility.

**Operation and Maintenance Cost**

Maintenance costs, which includes cleaning and repair, are often more difficult to estimate than other building expenditures because they vary from building to building. Operating schedules, employees' methodologies, and facility managers maintenance protocols are different. For this reason there is great variation in these costs even for buildings of the same type and age.

**Replacement Cost**

The number of times a material will need replacement depends upon the life cycle of that material and the expected life cycle of the building. For example: if a life of a carpet is 10 years and the building life cycle is 50 years then the carpet will be replaced 4 times during the useful life of the building. The replacements will occur at time  $T=10$ , 20, 30, and 40.

**Personnel Salaries**

Dell'Isola and Kirk (1981) state that maintenance labor costs amount up to 90 percent of the total maintenance cost of a building; from that total 19 percent is assigned to maintenance of interior finishes.

### Parameters for Present-Value Analysis

When using the LCCA, only those costs that are relevant<sup>1</sup> to the decision and significant<sup>2</sup> in amount are needed to make a valid investment decision. In order to compare design alternatives, present, future, and recurrent costs for each alternative must be brought to a common point in time. This can be accomplished using any one of these methods:

- **Present worth factor:** This formula converts all future annual expenditures to today's costs.

$$P = A * \frac{(1+i)^n - 1}{i(1+i)^n}, \quad \text{where}$$

P = present value

A = annual payment

i = interest rate in decimal format, minimum rate of attractive return

n = period of years expressed in the same units as the interest rate

- **Capital recovery factor method:** “If an amount of money (P) is invested today at an interest I, what sum (A) can be secure at the end of each year for n years, such that the initial investment (P) is just depleted?” (Khisty, & Lall, 1998, p.700). Converts present cost to annual series of payments.

$$A = P * \frac{i(1+i)^n}{(1+i)^n - 1}, \quad \text{where}$$

A= annualized cost or series annual payments

P = present value

---

<sup>1</sup> Costs are relevant when they are different for one alternative compared with another

<sup>2</sup> Costs are significant when they are large enough to make a credible difference in the life-cycle cost (LCC) of a project alternative

$i$  = interest rate in decimal format, minimum rate of attractive return

$n$  = period of years

- **Compound interest method:** Converts an initial sum ( $P$ ) to a future equivalent amount when invested at an interest rate,  $i$ , over a period of  $n$  years.

$$F = P (1+i)^n, \text{ where}$$

$F$  = future value

$P$  = initial or capital investment

$i$  = interest rate

$n$  = period of years

or

$$P = F/(1+i)^n, \text{ where}$$

$F$  = future value

$P$  = initial or capital investment

$i$  = interest rate

$n$  = period of years

- **Uniform gradient series:** Converts uniform series of a number of payments that increase each year by a similar amount to an equivalent uniform gradient (Khisty, & Lall, 1998, p.702).

$$F = (G/i) * \frac{(1+i)^n - 1}{i}, \text{ where}$$

$G$  = Amount increase by payment each year

$F$  = future value

$i$  = interest rate

$n$  = period of years

To convert this sum into an equivalent uniform period payment over  $n$  period,

$$A = (G/i) - (nG/i) * \frac{i}{(1+i)^n - 1}$$

### **Floor Materials**

Many published studies about floor materials focus on the environmental and indoor air quality caused by carpet and vinyl composite tiles but not on their respective life cycle cost. The only two LCCA studies identified in the literature focused on school facilities. The first study (Moussatche & Languell, 1999) comparing flooring in public educational facilities in the state of Florida was the precedent for the researcher's motivation and interest in studying flooring material selections. The second study (Carpet Rug Institute, 2002) focused on a life cycle cost between carpet and vinyl, also for school facilities. For the Carpet and Rug Institute study the results state that on an annual basis, hard surface flooring requires two and one-half times more cleaning time than carpet, and cleaning supplies were approximately seven times more expensive for vinyl floor than for carpeted floors.

A study focused on healthcare facilities was done by the Vinyl Institute in 2002. The researchers developed a survey to identify which of a variety of commonly specified materials were the most often specified for healthcare projects, as well as why those materials were selected. The purpose of the survey was to provide a baseline for designers and information for manufacturers who develop products for healthcare facilities. The survey, conducted by JSR Associates, Inc., surveyed 400 members of the International Interior Design Association's (IIDA) Healthcare Forum Members. The result for material was that vinyl composition tile was the most common finish material specified for public spaces, followed by sheet vinyl and broadloom carpet. Seventy five

percent of designers said it was because of initial cost, 73% because its durability, 69% for aesthetics, 68% because of client's preferences and 51% for ease of maintenance.

For private spaces, sheet vinyl was the floor material most frequently specified, followed by VCT. Sheet vinyl flooring was the most specified because of its aesthetics, durability, ease of maintenance, clients preferences, infection control and cost of maintenance, in that order.

For the bathrooms the most commonly used material was ceramic tile mainly because of its performance in wet areas.

Currently there is a tendency to focus on the selection of so called green/sustainable materials and alternative floor finishes. Selecting materials for the built environment has become a very tough and intense task for design professionals and facility managers. Their selection is typically based on time, past experience, convenience or budget restraints, limiting their ability to select materials. Design professionals are often unaware of the impact of their selection of building/finish materials due to the lack of post occupancy evaluations<sup>3</sup>. In addition, few resources are available for professionals who want to learn more about the environmental consequences attributed to a material.

Floor surfaces can be divided into three major categories: hard surface flooring, resilient flooring and carpet. Where to use them is one of the most controversial aspects of any design and construction process.

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<sup>3</sup> Systematic Evaluation of opinions about buildings in use, from the perspective of the users. It assesses how well buildings match user's needs, and more important identifies ways to improve building design, performance and fitness for purpose.

For educational facilities, resilient and hard surface flooring are the “traditional” finishes used. Choices include vinyl composition tiles, sheet vinyl, linoleum, rubber, and ceramic tiles. Carpet has been considered as a flooring choice for private spaces such as faculty offices, and lately it has been used in classrooms. Carpet surfaces may tend to prevent falls or reduce the impact when they occur.

Other important characteristic of a flooring material is its wear life factor. This depends on: (1) durability, (2) appearance and (3) maintenance of the floor.

- “Durability refers to the ability of endurance or not wear out” (Beamer, 1988, p.12). The most common cause of wear in flooring finishes is traffic flow. Overall, hard surface flooring is the most durable.
- Appearance refers to the ability of a material to recover from deformation and the ability to sustain in good condition until maintenance.
- The maintenance factor will be discussed in detail further in this paper.

In educational facilities environmental concerns have become an important factor when selecting flooring materials. “School officials are becoming more and more insistent upon looking at the green aspect of the products chosen” (Kennedy, 2004, p. 2).

This means choosing carpeting and vinyl made up of recyclable materials that can be recycled again after they are removed from a school. It also means taking into account how the flooring will be cleaned and maintained, and what chemicals and other resources are expended in the cleaning process. (Kennedy, 2004, p. 2)

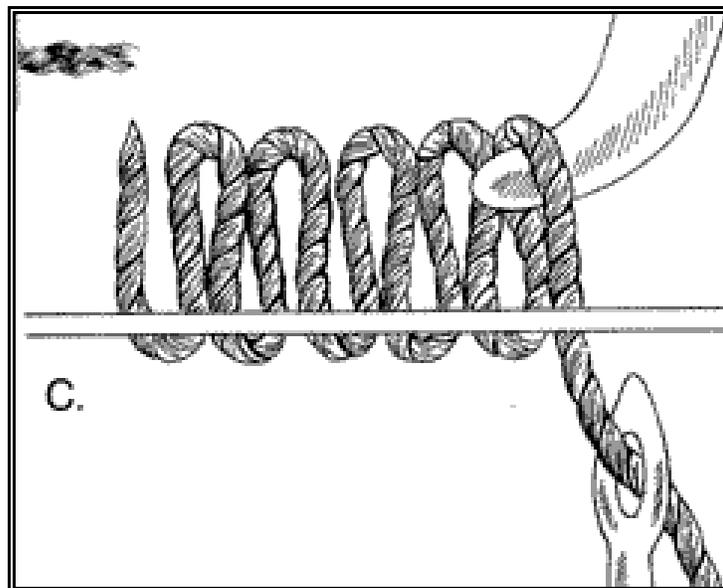
## **Carpet**

To better understand which carpet is suitable for a certain use first is it important to understand its structure and properties. The properties and structure of any carpet depends upon the fibers used and how these are put together. Carpet durability depends on the turf density, face weight, turf type and the nature of the fiber itself. Appearance depends upon the face fiber as well as color, dye method, texture and pattern.

### Tuft density

Tuft density is the amount of tuft per unit of area of the carpet (i.e. square feet, square yards, etc.). The fiber thickness and compactness prevent dirt from getting down into the carpet, and the denser the fiber the less weight each turf has to support. To assure a sufficiently dense carpet face the size of the turf yarn is important. It will contribute to the overall density of the face pile. Density index or density factor is the property that takes into account the turf density plus the turf size. This factor and the overall performance of the carpet are directly related, but this relation is not constant. As the density of index increase the performance improvement increment decrease. Beyond a certain point, an increase in density will have a negligible effect on performance.

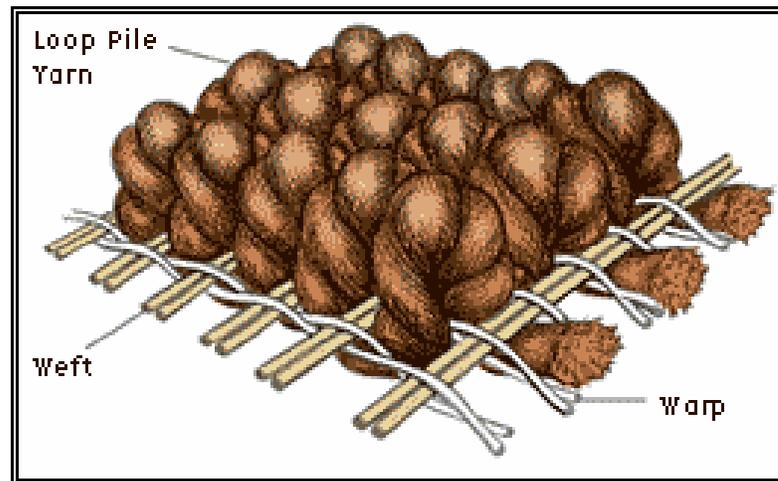
A tufted carpet is rows of tufts inserted by a row of needles, the tufts per inch are identified by the gauge or the distance between tufting needles (Figure 3-8). In a tufted carpet the number of tufts per inch is the reciprocal of the gauge, for example a 1/8 gauge carpet will have 8 tufts per inch (Beamer, 1988, p.21).



Source: <http://www.missouri.edu>

Figure 3-8: Tufted Carpet

In woven carpet (Figure 3-9), “the tufts per inch are measured by the pith, which is the number of warp yarns in a 27” width. In this type of carpet another row is formed every time the weft yarn is woven through the warp yarns” (Beamer, 1988, p.21). The number of tufts per inch in a woven carpet is the pitch divided by 27.



Source: <http://www.crossley.com>

Figure 3-9: Woven Carpet

### Face weight

Face weight or pile weight is defined as the “amount of pile density value or simple density” (Beamer, 1988. p. 24). The higher the density, the more pile yarns per unit of area and thus more expensive the carpet will be. The best performance for the money is a carpet with low pile height and high turf density.

The ratio of the face weight (ounce per square yard) and the pile height (inches) is called pile density value or weight density. This relation is the weight of the pile yarn in a unit volume of carpet ( $\text{oz}/\text{yd}^3$ ). Increasing the face weight and decreasing the pile height will increase the density of the carpet, and probably increase the performance.

Face weight is also positively related to the performance of the carpet but just up to a point of diminishing return. This means that increasing the face weight beyond this point will not increase the performance of the carpet.

The lower the pile height, the less effort required to move the equipments over the carpet. A higher density would also contribute to a firmer and less deformable surface.

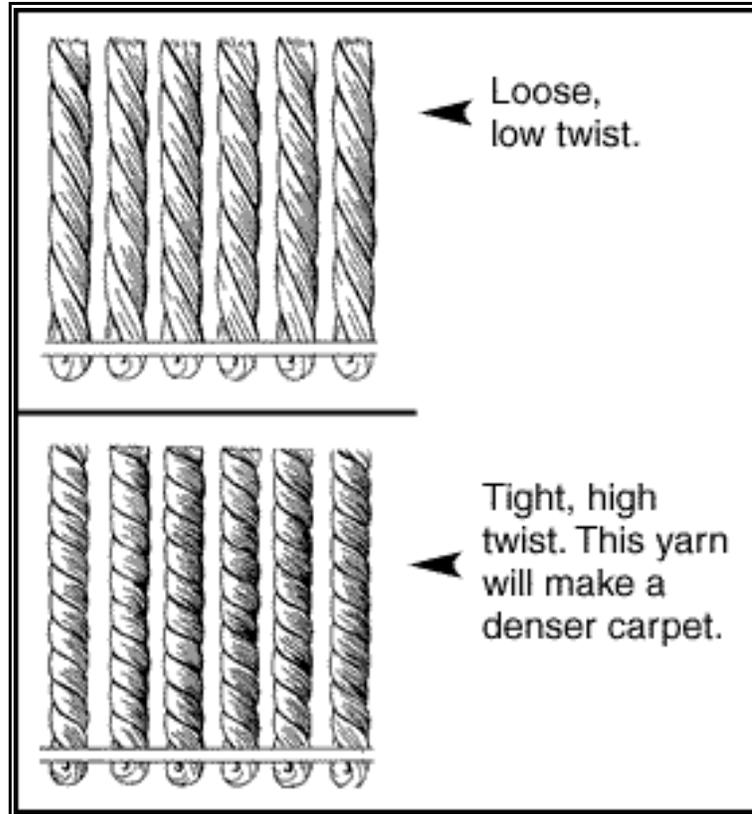
### **Yarn construction**

“Fibers are manufactured into yarns, which are used to construct the carpet pile. Several strands can be twisted together to form a ply. Yarns that are too soft or loosely twisted may develop a fuzzy and matted pile. Synthetic yarns may be made from long fiber strands, called filament yarns, or short, staple fibers. Natural fibers are always staple fibers, which are more subject to pilling than filament yarns” (e.g., <http://www.missouri.edu>, Retrieved August, 2003). There are two types of carpet yarn twists: loose and tight. The twist type will affect the carpet’s appearance, durability and resistant to matting (Figure 3-10).

When the yarn is highly twisted and heat settled it will be more durable and resist matting better than a loose twisted carpet. The purpose of heat setting is to make the yarn less likely to unravel and loss the ability to resist matting.

### **Tuft type**

The turf type will not only define the aesthetic of the carpet but also determines the appearance retention of it. There are different types of turf in carpets: (1) level loop pile, which is a single level uncut loop pile that makes a smooth and level surface, (2) multi level loop pile constructed with two or more different height loops; this texture hides soiling better than level loop pile, but is not as durable, (3) cut pile which is upright pile with cut ends; there are three different kinds: plush/velvet, saxony or frieze, and (4) cut and loop pile which are a combination of both (Figure 3-11).

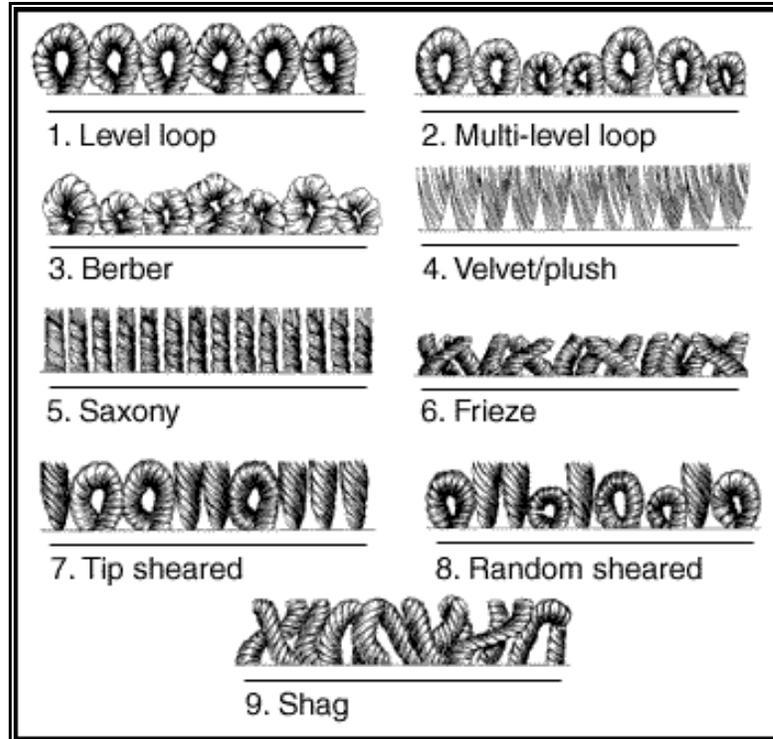


Source: <http://www.missouri.edu>

Figure 3-10: Types of Yarn Twists

### Face fibers

Most manufactured fabrics are composed of natural fibers such as wool, cotton, silk, jute, coir or flax, and man-made fibers such as nylon, rayon, acrylic, olefin, polypropylene, viscose, and polyester. Nylon is known to have the most durable fibers and the best appearance retention properties. Carpets made of fibers such as cotton, jute, hemp or sisal are not usually found in wall-to-wall, consumer carpet (e.g., <http://www.missouri.edu>, Retrieved August, 2003).



Source: <http://www.missouri.edu>

Figure 3-11: Types of Carpet Tufts

- Nylon

Nylon was the world's first true synthetic fiber and one of DuPont's most successful products. It was discovered in 1934 by Dr. Wallace Carothers. He found a strong polyamide fiber that stood up well to both heat and solvents. (e.g., [http://www.antron.dupont.com/content/about\\_us/ant20\\_03.shtml](http://www.antron.dupont.com/content/about_us/ant20_03.shtml), Retrieved August, 2003)

Nylon is the most common synthetic fiber used for consumer carpet. About 90 percent of all carpeting sold today is nylon. Advances in fiber chemistry have made enormous improvements in nylon over the last 30 years. In addition to stain-resistant properties, which are widely advertised, modern nylon has excellent abrasion, crushing and matting resistance, as well as reduced static electricity, pilling and fuzzing. It repels soil and cleans well, is non-allergenic and mold-, mildew- and moth-proof.

(e.g., <http://www.muextension.missouri.edu/explore/regpubs/ncr463.htm>, Retrieved August, 2003)

Today, Antron® nylon is the most specified commercial [carpet fiber](#). This synthetic fiber was developed using Dr. Carother's process, known as polymerization. It is manufactured by INVISTA, a DuPont Textiles & Interiors Company. INVISTA is a performance leader by demonstrated superiority in: resistance to dry soil and liquid stain, pile height retention, and resistance to matting, crushing and abrasive wear.

- **Olefin**  
Olefin is commonly used for institutional applications. It is less expensive than nylon, but maintaining many of the same properties. However, Olefin has lower appearance retention, is less resilient and difficult to clean.
- **Polyester**  
It is soft and has good abrasion and soil and stain resistance but has a tendency toward crushing and pilling.
- **Wool**  
Considered is considered a luxury fiber. It is the standard against which other fibers are compared. American manufacturers import wool, which makes it more expensive. (e.g., <http://muextension.missouri.edu/explore/regpubs/ncr463.htm>, Retrieved August, 2003)

### **Color**

Color is composed of hue, (i.e. red, green and blue), value (relative darkness or lightness), and intensity (degree of purity). These three elements should be considered when selecting a carpet. A neutral colored carpet shows less dirt than a darker or lighter color. Patterned carpet especially those with organic patterns will disguise signs of use between cleanings. Also the color of the local soil should be considered. Beamer (1988) stated that “carpets in the entryways should be in the same part of the color wheel as the local dirt” (p. 34) in order to maintain the appearance of the carpet for a longer time.

### **Dye methods**

The consistency of the carpet color and its lasting qualities depend upon the dye methods used to color it. These methods can occur at the solution, fiber, yarn or piece good stages. Table 3-1 compares the dyeing methods. The ranking range is between 0-5 been 0 the lowest and 5 the higher property quality.

### **Texture and pattern**

Texture is defined as the visual and tactile qualities of the carpet. The Encarta Encyclopedia (2000) defines it as the distinctive physical composition or structure of something, especially with respect to the size, shape, and arrangement of its parts. “In a

carpet, the texture is directly affected by the turf density and type, face weight and pile height, fiber crimp and twist, yarn twist, fiber coarseness, yarn piles and the type of construction”(Beamer, 1988, p. 38).

Table 3-1: Dying Methods for Carpet (Beamer, 1988, p.37)

<b>Table 3-1: Dying Methods for Carpets</b>					
	<b>Properties</b>				
<b>Dye Method</b>	<i>Lot Size</i>	<i>Streak Resist</i>	<i>Color Match</i>	<i>Color Fastness</i>	<i>Color Clarity</i>
<i>Solution</i>	5	5	4	5	4
<i>Fiber</i>	4	5	4	4	5
<i>Yarn</i>	3	4	3	4	5
<i>Piece</i>	2	3	2	3	5
<i>Continuous</i>	4	3	1	3	4
<i>Printing</i>	4	5	3	3	4

Pattern is a structural or applied configuration that has a particular shape or form, either repetitive or individual that makes up a large model. These forms can be created using colors, textures, or both. Patterns are important because they can camouflage dirt and stains. A random pattern will disguise more than geometric patterns.

Table 3-2 summarizes which properties of carpets are affected by various components of the carpets’ structure.

Table 3-2: Structural Components of Carpet (Beamer, 1988, p.37)

<b>Table 3-2: Structural Components of Carpet</b>							
<b>Properties Affected</b>	<i>Turf Density</i>	<i>Face Weight</i>	<i>Turf Type</i>	<i>Face Fiber</i>	<i>Color</i>	<i>Dye Method</i>	<i>Texture Pattern</i>
<b>Durability</b>							
<i>Abrasion/ Resistance</i>	x	x	x	x			
<b>Appearance Retention</b>							
<i>Resilient</i>	x	x	x	x			
<i>Soil Hiding</i>				x	x		
<i>Color Change</i>			x	x	x	x	

<b>Maintenance</b>							
<i>Cleanability</i>	x		x	x	x	x	x
<b>Environmental</b>							
<i>Acoustic</i>	x	x	x				
<i>Comfort</i>	x	x					
<i>Ambience</i>	x	x	x		x		x
<i>Wheeled Equipment</i>	x	x	x				

### **Resilient Floor Coverings**

Resilient flooring is produced in two forms: sheet goods (rolls) and tiles. With sheets goods the seams are fewer than with tiles. This is important in facilities where fluid spillage and water leakage are significant concerns. Either tiles or sheets goods can be chemically or heated welded which also protect against bacteria and air pollutants.

Because of its durability, comfort under foot, aesthetic appeal, long lasting beauty, resilient flooring is used in a wide range of commercial and residential applications. Commercial resilient flooring has long been the most popular flooring used in schools, health care facilities, and mercantile settings. In schools, resilient flooring offers a cost-effective floor, which is easily and economically maintained and can last for many years before needing replacement. In health care facilities, resilient flooring is commonly used because it is impervious to water, resists stains, and can easily be disinfected, thus providing significant sanitary advantages over other types of flooring surfaces. Because of its durability and the availability of a wide range of colors and designs, resilient flooring has long been a favorite of stores and shops in creating design statements. Because of its performance attributes and wide variety of colors and designs, resilient floors are frequently used in laboratories, clean rooms, computer rooms, lavatories, super markets, drug stores, lobbies, storage areas, spas, dormitories, libraries and restaurants. (e.g., Resilient Floor Covering Institute, <http://www.rfci.com>, Retrieved August 2003)

Resilient floor covering are constructed by mixing ingredients at high temperatures and then pressing into homogeneous<sup>4</sup> sheets of the desired thickness. The different properties of each type will be determined by the ingredients used in the manufacturing process. Properties such as durability, resilience, sunlight resistance, resistance to

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<sup>4</sup> Homogeneous is related to the composition of the tile, it means equal properties throughout the complete thickness of the material.

staining, color, texture and pattern, acoustics, light reflectance, and slipperiness define the structural strength of the material. These properties depend on the component ingredients such as vinyl, vinyl composition, asphalt, and rubber existent. The ingredients in each of these types determine the properties of the flooring.

### **Vinyl and vinyl composition tiles**

Vinyl flooring is the result of a process that converts hydrocarbon-based raw materials (petroleum, natural gas or coal) into synthetic products called polymers. The vinyl polymer is part hydrocarbon feed-stocks: ethylene obtained by processing, or cracking, natural gas or petroleum, and the natural element chlorine.

The final product is composed of resins, plasticizers, fillers, stabilizers, and pigments. All pressed together to sheets of vinyl that later will be cut in sheet goods of 6', 6'-6", 9', and 12" widths, and 9" by 12" tiles. Stabilizers provide an uniform color and stability, and plasticizers furnish flexibility. One of the most important and versatile properties of vinyl is that, depending on the additives and modifiers used, vinyl compound can be used indoors or outside, be crystal clear or opaque, and matched to virtually any color in the rainbow.

Sheet vinyl have large seams that can be heated welded so neither liquid nor bacteria can penetrate the floor. For maintenance purpose this is also an advantage when water flushed over the floor for cleaning. Sometimes the vinyl is also used as a flash cove, that is, the sheet is coved up the wall to form a wall base, this means that no dirt can hide between the floor and the wall juncture. This provides an aesthetically pleasant finish as well as simplifies maintenance.

Vinyl composition tiles (VCT) are composed with the same ingredients as the vinyl previously mentioned but adding mineral fibers. Unfortunately these fibers decrease the

flexibility of the vinyl, making it not suitable to be used in sheet goods. VCT properties are homogeneous throughout the width of the tile, maintaining its color and pattern even after the surface has been worn out.

For commercial purposes VCT has limited options. They come in limited patterns, textures, and solid colors.

### **Rubber**

“Rubber flooring is made of vulcanized compounds of rubber, mainly butadiene styrene rubber . . . , and sometimes reclaimed rubber” (Beamer, 1988, p.75). Other ingredients are: stabilizers, mineral fibers, oils, resins, and pigments for color. Rubber is known to be used in educational facilities primarily in stairs treads and risers. Some of the advantages of this flooring are (1) wear resistant, (2) extremely long lifetime, (3) dirt repellent, (4) no need of coating, (5) resistant to cigarette burns, (6) fire resistant properties, (7) high footfall sound absorption, (8) joint sealing not necessary, (9) easy to install, (10) very flexible, and (11) less slippery than most resilient flooring.

Rubber tiles are available in 9” and 12” squares and in sheets of 36 ¾” wide. Rubber for stairs treads and risers are also available in different sizes and shapes.

### **Linoleum**

Linoleum, a natural material made from linseed oil, its primary component. Linoleum was invented and patented in Britain back in 1845. Today it is widely promoted and specified as an alternative to other flooring. The ecological and sustainable importance of this alternative material is that the primary raw material in it is renewable. Linseed oil is squeezed from seeds of the flax plant, which is widely grown not just in USA but in Canada and Argentina. To produce the final material known as linoleum, a six week process is required. In terms of the disposal of an already used

material, it can be said that linoleum does very well from an environmental standpoint. Linoleum is biodegradable and readily broken down, into carbon dioxide and water vapor. In terms of the environmental concerns, it is known that PVC contains chlorine, which is a primary environmental contributor to pollution. PVC contains endocrine disruptor which are plasticizers added to increase flexibility. Our body can mistake these plasticizers for natural hormones which can interfere with embryo development and reproduction. Besides all these advantages of linoleum over PVC, linoleum is also more durable and requires less maintenance. It's also naturally antistatic, so dust, dirt and pollen particles are repelled, making it easy to clean. It has a natural antibacterial property that inhibits the growth and spread of microbes. As flooring, linoleum is thermally insulating, quiet and shock-absorbing, available in vibrant colors that offer a wide range of design possibilities.

### **Hard Floor Coverings**

The durability, strength and ease of maintenance of these materials make them the most common floor material used worldwide. However, the cost of materials and installation is generally higher than any other floor covering surface, making them not suitable for low budget projects.

Other limitations are: lack of sound absorption, less slip-resistant when wet, less flexibility when alteration occurs, and some are heavy enough that a structural system is needed to support them.

### **Ceramic tiles**

In simple words, ceramic tiles are nothing more than beautiful, baked clay. They are a mixture of clays that are shaped, dried and fired at high temperatures resulting in a hard body, called bisque, can then be treated (glazed) or left untreated (unglazed). When

treated, a glaze is added to the surface. This glaze material, when heated, forms a permanently hard layer of glass over the surface of the tile.

In general, ceramic tiles are attractive, versatile, durable, easy to maintain, hard, impervious to heat, and resistant to chemical attack and moisture. Dark color tiles can also be used as thermal mass materials that will absorb and retain heat during cold weather.

The structural properties of the ceramic tiles are determined by 1) body composition; 2) method of forming; 3) degree of vitrification; and 4) finish treatment.

The body composition consists of: 1) clays of different plasticities; 2) non plastic ingredients; 3) mineral fluxes; and 4) minerals.

The methods of forming most commercial tiles are extrusion or dust pressing. The first method is one in which the “damp clay is forced through a die in a continuous column and a wire is used to cut the extruded material into tiles. In the second method the ground clay is compressed in a mold box. The density of the tile is partially dependent on the intensity of the pressure exerted” (Beamer, 1988, p. 82).

The degree of vitrification refers to the transformation from clay to a glassy substance by heat and fusion. If a water repellent tile is needed then the clay would have to be 1) fire to a temperature at which it becomes vitrified or 2) glazed.

There are two major types of vitreous ceramic tiles: 1) impervious and vitreous types such as porcelain, ceramic mosaic tiles; and 2) semi vitreous quarry and brick pavers tiles (Figure 3-12). To make the selection of tiles easier, a rated system classified them by group depending on the intended use of the tile.

- Group 1: Tiles suitable only for residential bathrooms where softer footwear is worn.

- Group 2: Tiles suited to general residential traffic, except kitchens, entrance halls, and other areas subjected to continuous heavy use.
- Group 3: Tiles suited for all residential and light commercial areas such as offices, reception areas and boutiques.
- Group 4: Tiles suited for medium commercial and light institutional applications such as restaurants, hotels, hospital lobbies and corridors.
- Group 5: Tiles suitable for heavy traffic and wet areas where safety and maximum performance are a major concern. Used in exterior walkways, food service areas, building entrances, shopping centers and around swimming pools. (e.g., <http://www.ifloor.com/articles/ceramic/basics.html>, Retrieved August, 2003)



Figure 3-12: Example of Paver Tiles (<http://www.southviewdesign.com>)

### **Tile strength**

The strength of the bisque is determined by its density. The density is measure by the amount of water or moisture that is absorbed by the tile. The strongest bisques have the greatest density, which is characterized by the smallest and fewest number of air pockets in the clay, less porosity will mean lower moisture absorption. High-density tiles are suited for heavy commercial installations as well as residential projects. Low-density tiles that are too porous and absorb more than 3% moisture will freeze and crack if installed outdoors in cold climates.

### Tile density

The tile density determines whether a particular tile is appropriate for indoor or outdoor use. Remember that higher the density, less air pockets, less moisture absorption, stronger flooring tile (Table 3-3).

Table: 3-3: Moisture Properties of Different Ceramic Tiles

<b>Table 3-3: Moisture Absorption Properties of Ceramic Tiles</b>	
<i>Non Vitreous Tiles</i>	Absorb 7% or more of their weight in water. They are suited for indoor use only.
<i>Semi Vitreous Tiles</i>	Absorb 3% to 7% water and are suitable only for indoor use.
<i>Vitreous Tiles</i>	Absorb 0.5% to 3% water and are considered frost resistant. They are suitable for both indoor and outdoor use.
<i>Impervious Tiles</i>	Are the strongest available. They absorb between 0 and 0.5% of their weight in water. These frost resistant tiles are appropriate for indoor and outdoor uses.

### Types of ceramic tile

Ceramic tiles are available in two forms: glazed (Figure 3-13) or unglazed (Figure 3-14). Glazed tiles undergo an additional process of glazing in which a glass wear layer is applied and then subjected to heat in a kiln<sup>5</sup>. This process liquefies the glass and fuses it to the bisque. The advantage of this finish is that it creates a surface that is practically stain proof. Glazed tiles are appropriate for light residential and medium commercial traffic; however they are not suitable for heavy duty commercial use.

On the other hand, unglazed tiles are simply baked pieces of clay whose colors are determined by the mineral content of the clay. Colors, which are limited to the natural colors of the clay, range from light sand to darker red brick tones. They have a rugged surface texture and slip resistant mat finish. Because of their toughness they are ideally suited for extra heavy commercial installation and wet places. Popular unglazed tiles

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<sup>5</sup> Oven to heat clay.

include: 1) quarry tiles (Figure 3-15); 2) porcelain tiles (Figure 3-16); 3) terra-cotta tiles - i.e. Saltillo tile (Figure 3-17) from Mexico; and 4) mosaic tiles.

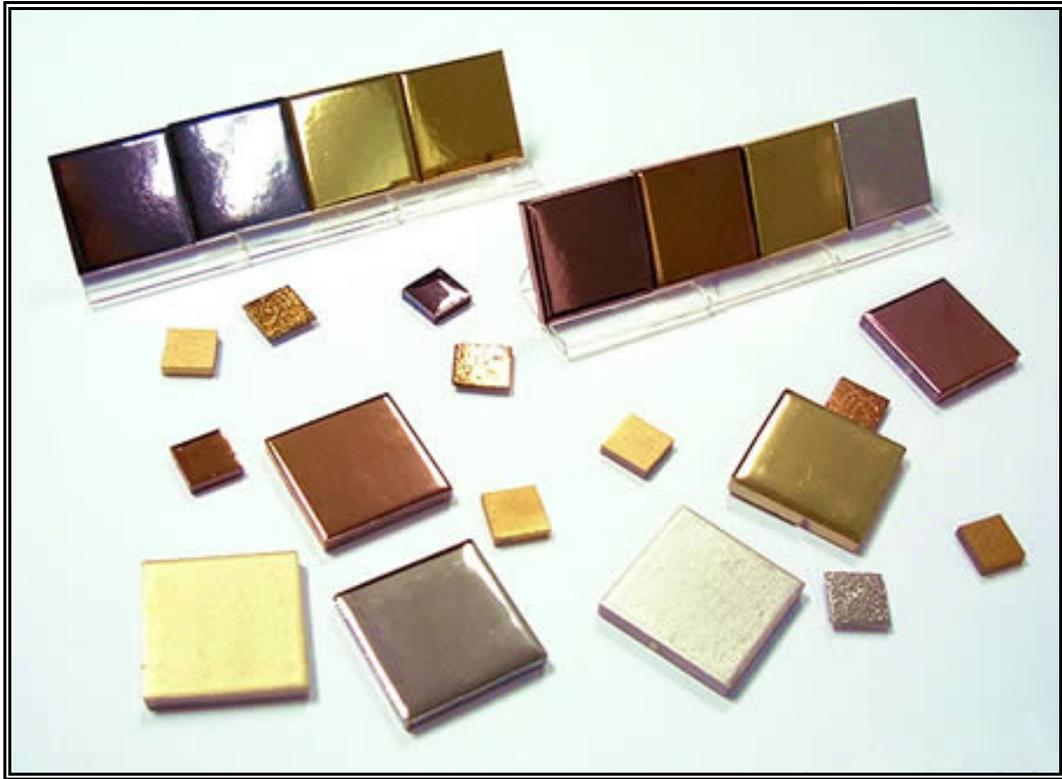


Figure 3-13: Glazed Ceramic Tiles  
([http://www.nanofilm.com.sg/eng/images/ceramic\\_tiles.jpg](http://www.nanofilm.com.sg/eng/images/ceramic_tiles.jpg))



Figure 3-14: Unglazed Ceramic Tiles (<http://www.infotile.com.au>)



Figure 3-15: Quarry Tile Application (<http://www.vanstone.co.za>)

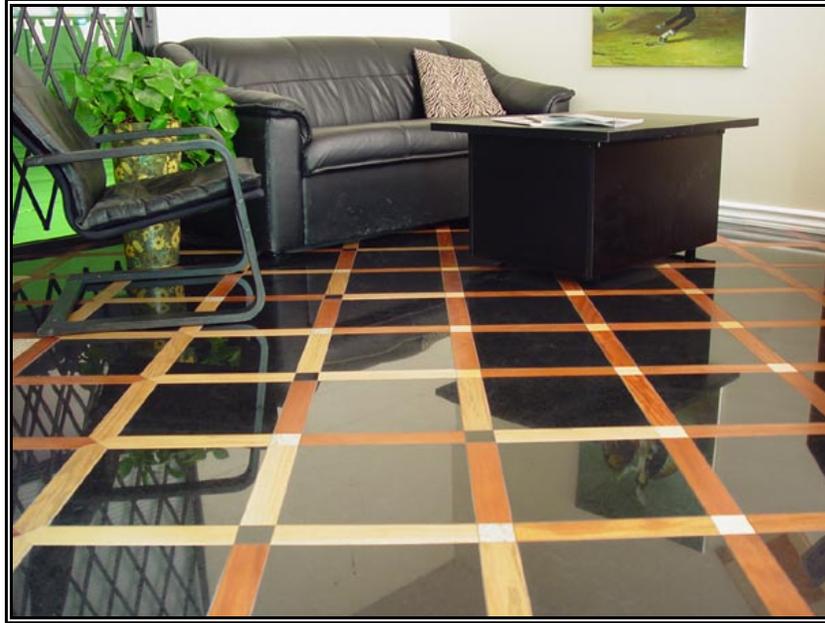


Figure 3-16: Porcelain Tile Application (<http://www.customdreamfloor.com/office.htm>)



Figure 3-17: Saltillo Tile Application  
(<http://www.customsaltillo.com/a/images/tilesandtable.jpg>)

### **Ceramic tile applications**

Ceramic tiles can be used either in walls or floors. Commonly, wall tiles have very porous bodies and therefore should never be used on floors or outdoor applications. The

most commonly used tiles are those that are very thin, high glossed and very decorative. The traditional size for wall tiles is square tiles of 4 ¼", 6" or 8".

Floor tiles can be glazed or unglazed, but with sufficient strength, impact and abrasion resistance to withstand weight and foot traffic. Their sizes range from small mosaics of less than a square inch to 24"x24" tiles. In the United States, most floor tile measures 8"x8" or 12"x12", but there is a growing trend toward larger tiles. Most tiles are sold in nominal sizes such as 8" x 8" or 12" x 12" though the actual sizes will be more like 7 7/8" x 7 7/8" or 11 7/8" x 11 7/8".

### **Tile advantages**

- **Abrasion Resistance:**  
Commercial areas, as well as areas of the home subject to heavy use as kitchens, entries, and garages, require good abrasion resistance.
- **Water Absorption and Frost Resistance:**  
Any tile that absorbs more than 3% moisture glazed or not, is not suited for outdoor use in cold climates where it may freeze and crack.
- **Stain Resistance:**  
Ceramic materials are among the most stain-resistant building products. Glazed or unglazed tiles resist practically all solutions that could cause staining in other types of products.
- **Slip Resistance:**  
The slip resistance of ceramic tile in ordinary applications is comparable to most hard flooring materials. And it is significantly better than some. Unglazed tiles have greater slip resistance than glazed tiles and are recommended for areas subjected to frequent water spills).
- **Color Permanence**  
The colors in ceramic tiles will not fade from light exposure and is even throughout the whole material.
- **Dirt Resistance**  
Ceramic tiles do not retain dust or residues. Plain water or a damp cloth is generally all that is required to keep the tile clean.
- **Fire Resistance**  
Ceramic tiles will not burn or feed a fire. Their surface will not alter, nor will they give off any toxic gases, smoke or fumes during a fire. ([www.ifloor.com](http://www.ifloor.com), Retrieved August 2003)

**Exposed concrete**

Many industrial facilities have been using rough structural concrete slab as a flooring alternative. Nowadays it is becoming more popular within educational facilities due to its low initial cost. Properly laid exposed concrete can be a tough but elegant alternative that can be similar in properties to a stone type surface. Exposed concrete is created when wet concrete is vibrated during the pouring phase bringing the finest particles to the surface. If a smoother surface is desired the concrete can be polished with a machine similar to the one used to polish terrazzo. Other alternatives are to color or emboss the concrete surface before it is completely dry. Because the concrete is a very porous surface it needs to be sealed to avoid dust from leaving the surface and stain spots to be created.

**Cleaning and Maintenance Procedures**

Operational and maintenance procedures, such as cleaning and repair, performed on a regular basis can greatly reduce the maintenance cost expenditures of a facility. These procedures should be planned before installation occurs and implemented immediately after installation. A proper maintenance protocol and schedule will prolong the wear life of any floor materials. “The shorter the time an abrasive particle remain the less damage it can do. The shorter the time a spill remains, the less potential for permanent stain” (Beamer, 1988, p.13). Even a small amount of savings in operational and maintenance cost over a year will have significant effect on the life cost of the facility. For this reason, special effort should be placed over the proper and wise selection of materials.

**Carpet**

No matter how sensible the selection of the carpet is, its durability and appearance will depend upon regular and proper maintenance. A maintenance program for carpet

should address tracked in soil, particles deposited from the air, and substances<sup>6</sup> spilled in the carpet. Tracked in soil represents 85% of the total dirt that is accumulated in a carpet; this soil can be dry, wet and sometimes oily. This type of soil, specially the one from footwear tends to be deposited in the first portion of the carpet, at the entry. When this area is saturated with soil, the next area will be them covered with the dirt. This is why special attention should be concentrated in the building entries and transition areas. Soil that is deposited from the air, as dust and pollutants, represents 15% of the dirt in the carpet. Sometimes this airborne soil comes in the form of oily particles that when combined with the tracked in soil form sticky soil complexes. In order to remove oily particles, special cleaning materials such as absorbent powders, dry foam cleaning and absorbent pad cleaning must be used. Spills are “visually the most offensive because of their typically high contrast with the carpet” (Beamer, 1988, p. 53). They are usually easy to remove when treated promptly, but very difficult and sometimes impossible when the spill sets.

“A regular program of vacuum cleaning, touch up cleaning with an absorbent, and spill removal is the basis of maintaining carpet appearance” (Beamer, 1988, p. 53). And most important is to start a periodic shampoo treatment long time before the carpet is completely soiled. High traffic areas, such as entries, hallways and foyers, must be vacuum daily, light traffic areas, vacuum the traffic lanes twice weekly and the entire area once weekly. “The machine will need to be passed up to seven times in heavy soiled areas and up to three times for light soiling. The machine direction must be changed

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<sup>6</sup> Particles and substances can be dry, wet or oily.

occasionally to help stand the pile upright and reduce matting of the carpet” (e.g., <http://www.ifloor.com>, Retrieved August, 2003).

In order to prolong the beauty and the life of the carpet a good vacuum cleaner is vital. A good vacuum will not only remove surface dirt but will effectively remove the hidden dirt and particles embedded in the pile. A vacuum with a rotating brush or combination beater/brush bar that agitates the carpet pile and mechanically loosens soil for removal by the vacuum is recommended by most carpet manufacturers. However, to prevent fuzziness of carpet with thick loop piles like wool and wool blend styles, a suction-only vacuum or a vacuum with an adjustable brush that can be lifted away from the carpet is recommended. Vacuum bags may be replaceable and must trap particles smaller than two microns such as mold and mildew spores and dust mite byproducts, often found to be a source of allergies.

## **Resilient Flooring**

### **Vinyl composition tiles**

Floors should be maintained by using a good quality non alkaline floor cleaner and a floor machine. Thoroughly rinse the floor (but avoid flooding the floor) and allow the floor to dry completely. Apply three to five coats of the high quality cross-linked acrylic floor polish. Wait at least 30 minutes between applications to allow complete drying. For regular maintenance, clean the floor frequently with a treated dust mop or clean, soft push broom.

### **Linoleum**

Armstrong Industries recommends the following maintenance procedures: For initial cleanup and daily maintenance sweep or vacuum thoroughly, damp mop with a neutral detergent solution while carefully scrubbing black marks and excessive soil.

Apply two coats of a high quality commercial floor polish. For continuing regular maintenance damp mop or lightly scrub the floor with the appropriate pads or brushes, if the floor has been scrubbed, thoroughly rinse and allow it to dry. If there is sufficient polish remaining in the floor, buff, spray buff or burnish to restore gloss. Do not wax.

Because of the natural properties of linoleum the use of excessive amounts of liquids should be avoided during cleaning procedures. Any maintenance solutions must be 10 potential of hydrogen (Ph<sup>7</sup>) or less, higher values may damage the linoleum. If the material is going to be exposed to high traffic then a sealer is highly recommended.

### **Rubber**

Roppe Industries recommends the following maintenance procedures: For initial cleanup scrub with appropriate solution using a 175-rpm single disk machine equipped with a brush. Dry with a wet/dry vacuum. Apply coats of sealant with a mop in very thin coats to avoid pudding.

Rubber should be swept and damp mopped daily with a neutral pH detergent. If a buffing procedure is used for maintaining the floor, use a brush on your floor machine to maintain the high gloss, buffing in two different directions.

### **Hard Flooring Materials**

#### **Ceramic tile**

Ceramic tiles may be daily swept and mop with water and detergent. Because tile and grout are different materials with grout being more porous, any soil in it should be removed immediately. Periodically scrubbing of the floors is recommended.

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<sup>7</sup> A measure of the acidity or alkalinity of a solution, numerically equal to 7 for neutral solutions, increasing with increasing alkalinity and decreasing with increasing acidity. The pH scale commonly in use ranges from 0 to 14. (e.g., <http://dictionary.com>, Retrieved November, 4, 2004)

**Exposed concrete**

A sealer on exposed concrete provides an invisible barrier against water and oils, and produces a dust-free floor. Daily swept and damp mop using synthetic solutions are recommended for proper maintenance. Scrub the floor when needed with a neutral detergent. Daily vacuuming will be needed to remove dust particles when a sealer is not used.

## CHAPTER 4 METHODOLOGY

The completed study was conducted in phases. The first phase consisted of reviewing official documents such as specifications, drawings, finishes schedules, and purchases invoices. The second phase required the collection of the empirical data regarding the construction of the building, performance, cleaning procedures, repair maintenance, and replacement of building materials. The third phase compared the empirical data with manufacturer standards of the products currently in used. The last phase was to collect, compile, and analyze the gathered data using a life cycle cost assessment.

### **Phase One: Analysis of Official Documents**

The University of Florida provided official documents such as construction documents and specifications, Auto CAD drawings, finishes schedules, and purchase invoices for Rinker Hall. These documents provided the information regarding the type of flooring material used, the manufacturers, initial cost, total area for each material and system specifications. The data collected on this stage is summarized it Table 4-1.

Table 4-1: Flooring Materials used at Rinker Hall

<b>Table 4-1: Flooring Materials Used at Rinker Hall</b>				
<b>Material</b>	<b>Total Area (Sq. Ft.)</b>	<b>Manufacturer</b>	<b>Type</b>	<b>Color</b>
<i>Linoleum</i>	9,706.61		Marmorette 0.125"	Bluebird & Silver Mist

<i>Rubber</i>	290.72		#30 Square Nose, Heavy Duty, Raised Diamond and #60 Wide Rubber Raiser	Silver Gray
<i>Carpet</i>	26,118.19		Tanagra	Plateau
<i>Ceramic Tile</i>	1,587.28		6" x 6" Floor Tiles (Class II) 6" x 6" Accent Tiles (Class IV)	Frost White Lazule
<i>Exposed Concrete</i>	15,872.17		Watershield	No Color

### Phase Two: Empirical Data Collection

The administrative assistant at the Physical Plant Division of the University of Florida provided accurate information on the performance of flooring materials and the current cost of operating and maintaining them. Direct site observations were conducted at Rinker Hall. From direct observation we collected data on the service use of the flooring materials in the facility. Informal interviews with university maintenance staff and facility managers supported the directed observations. These interviews provided additional data regarding custodial work wages, time consumed for various cleaning and repair procedures, actual type of equipment and cleaning materials used for regular maintenance, and frequency of standard operations and maintenance procedures.

### **Phase Three: Codes, Standards, and Material Specifications**

Once the flooring materials were identified, manufacturer's technical specification data sheets were collected. For each finish, these sheets provided information regarding the technical characteristics, recommended cleaning and maintenance procedures and expected durability. This information was used to compare the actual cleaning and maintenance procedures with those specified by manufacturers.

### **Phase Four: LCC Analysis**

A service life cycle cost analysis of actual projected cost for Rinker Hall during the use and replacement of the flooring materials over a 100 year building service life was completed. The dollar values used in the LCCA calculations come from the actual monetary expenditures to purchase, properly maintain, and replace these flooring materials to serve Rinker Hall for a period of 100-years (Moussatche, & Languell, 2002, p. 335).

#### **Life Cycle Cost Analysis Assumptions**

##### **Inflation rate**

A general inflation rate of 3% was used based on the U.S. Department of Commerce Energy Price Indices (e.g., <http://fire.nist.gov/bfrlpubs/build02/art017.html>., Retrieved April, 1 2004). "This rate was used to inflate the capital cost of each flooring alternative to determine the replacement cost and to inflate the operation and maintenance costs associated with any given flooring material" (Moussatche, & Languell, 2000, p.336).

##### **Discount rate**

"Typical LCC uses a discount factor when there are current funds available for future replacements and maintenance cost of a facility since some institutions allocate

funds for future replacement or maintenance” (Moussatche, & Languell, 2000, p. 336).

The University of Florida does not allocate funds for future replacements or maintenance cost, thus the discount factor is said to be zero.

### **Operation and maintenance**

“Derived from equipment and supplies used, time consumed for each procedure, the required frequency of performance, the number of people involved and the wage and labor fees of the custodial staff. Whenever specific data was not available O&M costs were considered as 3% of the application’s initial cost” (Moussatche, & Languell, 2000, p. 336).

The method used to project the O&M costs was a geometric gradient with a rate of increase equal to the inflation rate (Moussatche, & Languell, 2000, p. 337). This method take into consideration the fact that services and goods do not remain constant over the 100-year service life of the building. The value for operation and maintenance cost are given as a percentage of the initial cost of the system.

### **Building service life**

A 100-year building service life was used for all calculations.

### **Initial -capital- cost**

Initial cost was calculated based on contract and manufacturer’s provided data, including material and installation.

### **System service life**

The expected life for each material was derived from the manufacturer’s information and direct observations. It is assumed that the manufacturer’s recommendations for cleaning and maintenance are performed.

**Number of replacements**

The number of replacements needed to support the facility during the 100 years of expected service life.

**Salvage value**

It is assumed that there is no salvage value at the time of replacement.

**Selection of Materials for Analysis**

For the purpose of this project, interior floor surfaces were studied, which include not only floor finishes but also the substrate or subfloor where they are applied, and the material used to attach the finish to the substrate. Table 4-2 shows the floor surface materials considered in the LCCA analysis. The materials major flooring characteristics and actual maintenance procedures are listed. The table is broken into three categories: hard flooring, resilient flooring, and soft floorings, allowing for proper comparison between flooring alternatives.

Table 4-2: Evaluated Floor Characteristics

Table 4-2: Floor Characteristics And Actual Maintenance Procedures																										
		MATERIAL	FLOOR CHARACTERISTICS								MAINTENANCE PROCEDURE															
		* = Above Average A = Average B = Below Average V = Variable D = Daily W = Weekly M = Monthly Y = Yearly P = Periodically S = Semiannually in high traffic areas or yearly in average traffic areas * = Done daily if needed	Strength	Durability	Thermal Insulation	Moisture Oil, chemical resistant	Stain Resistance	Abrasions Resistance	Wearability	Mildew Resistance	Heat Absorption	Sweeping or dust mopping	Vacuuming	Damp Mopping	Wet Mopping	Spot Mopping	Spills	Scrubbing	Stripping	Dry Cleaning (Chemicals)	Hot Water Extraction	Waxing	Buffing	Resealing	Regrouting	
Flooring	Hard	Exposed Concrete - Sealant (2 coats)-	*	*	B	B	A	*	A	*	D	2xW	3xW	D	M							2xW	P			
		Ceramic Tile (6" x 6") - Mortar & Grout	*	*	*	V	V	*	*	-		D	D	3xW	D	Y										P
	Resilient	Linoleum - Adhesive	A	*	*	A	A	*	*	B		D	2xW	3xW	D	S	Y				Y		W			
		Rubber - Adhesive	*	B	*	*	A	*	A	A		D		3xW	D	S					Y					
Soft	Carpet	A	A	*	A	*	A	A	*		D				D		S	S								

## Characteristics of Flooring Materials used at Rinker Hall

### Carpet

The carpet used at Rinker Hall (Figure 4-1) is manufactured by Crossly, Inc. It is a Crossweave<sup>®</sup> woven construction, cut and loop style carpet, patterned and yarn/beck dyed. It is made of ANTRON<sup>®</sup> legacy 6, 6- type<sup>1</sup> Nylon, a fiber manufactured by INVISTA<sup>®</sup>, a DuPont<sup>®</sup> division.



Figure 4-1: Office Space with Carpet Floor at Rinker Hall (Source: C.M. Lozada)

### Linoleum

The linoleum is a commercial linoleum sheet flooring manufactured by Armstrong<sup>®</sup> Inc. It has a thickness is 0.125” and a width of 6’7”. The seam treatment used for installation was head weld, and an S-240 adhesive.

### Rubber

Rubber was used at the stairs treads and raisers. A #30 diamond square nose tread design of 48” length and 12” depth was used (Figure 4-5, 4-6).

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<sup>1</sup> Type 6-6 is the molecular construction of the nylon. This type is supposed to be more resilient and stain resistant than the Type 6 nylon.

**Ceramic tile**

Glazed 6"x 6" ceramic tiles were used at the bathrooms and showers. A check pattern was used with white and blue tiles (Figure 4-7).



Figure 4-2: Inside View of Rinker Hall (Source: C.M. Lozada)



Figure 4-3: Gallery Area of Rinker Hall -Linoleum Flooring (Source: C.M. Lozada)



Figures 4-4: First Level Hallway at Rinker Hall – Linoleum Flooring (Source: C.M. Lozada)

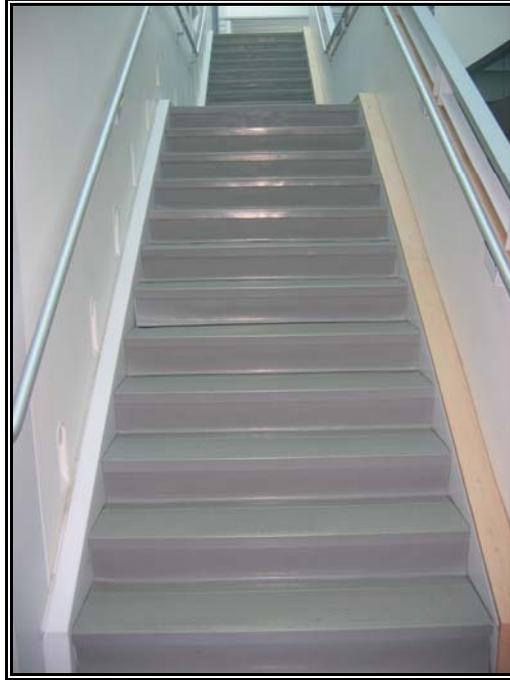


Figure 4-5: Stairs at Rinker Hall –Rubber Treads and Raisers (Source: C.M. Lozada)

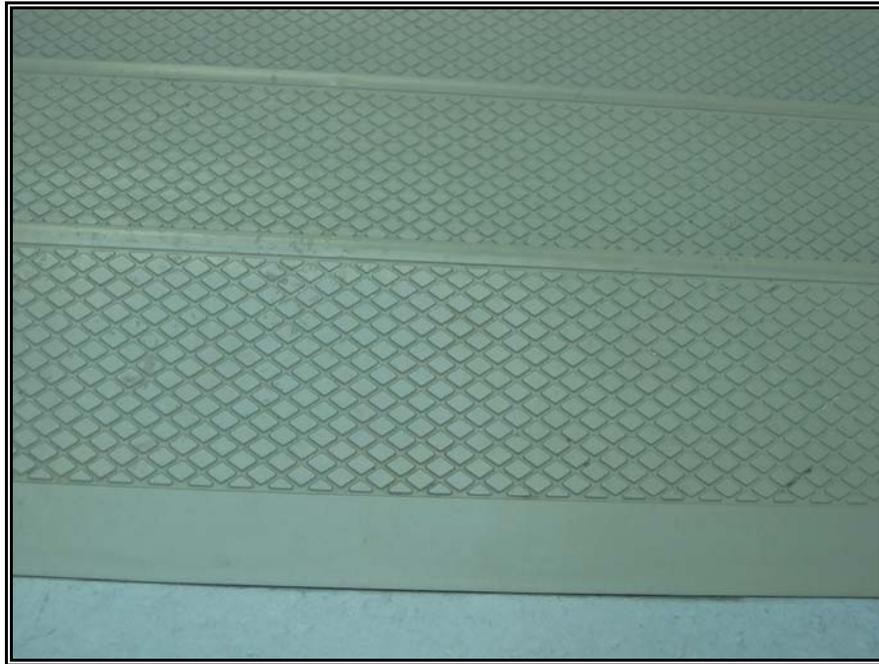


Figure 4-6: Zoom View of Rubber Treads (Source: C.M. Lozada)



Figure 4-7: Ceramic Tiles at Rinker Hall (Source: C.M. Lozada)

### **Exposed concrete**

Sealed exposed concrete was used in all the classrooms and laboratories. Two coats of Watershield sealant manufactured by AFM Enterprises were applied. This sealant is clear, versatile that provides an invisible barrier against water and resists oils, grease and is easy to clean. It is not toxic, non flammable, lead and formaldehyde free, and does not contain surface contaminating silicones (Figure 4-8).



Figure 4-8: Exposed Concrete at Rinker Hall (Source: C.M. Lozada)

## CHAPTER 5 RESEARCH DESIGN

### **Case Study Strategy**

The researcher will use the case study strategy for the development of this study. Groat and Wang (2002) define the case study as an empirical inquiry that investigates a phenomenon or setting, which includes historic phenomena and both historic and contemporary setting as potential foci of case studies (p. 343).

The essence of a case study strategy is its focus on studying a setting or phenomenon embedded in its real context. It implies much more than simply studying a phenomenon “in the field.” Rather, it involves studying a case in relation to the complex dynamics with which it intersects (Groat & Wang, 2002, p. 344).

A case study can be based exclusively on qualitative data or have a theory driven focus.

### **Data Collection Tools**

In their research, the Carpet Rug Institute (2002) state that any comprehensive maintenance and cleaning program will divide the floor into light, medium, and heavy traffic areas and schedule the work. Maintenance procedures vary depending on the type of floor finish used. For hard and resilient floors this will include: dust mopping, spot mopping, wet mopping, spray buffing, scrub/recoat, strip/finish, and chemical costs. For carpeted floors the maintenance includes vacuuming, spot removal, rinse cleaning, deep cleaning, and chemical costs. Frequency, time, and custodial hourly wage for maintenance are specifically defined by each facility’s protocol.

Using the net present worth (NPW) each item price is escalated at the given inflation rate to determine replacement cost and then brought back to the present for comparison. For example, due to inflation rate the future replacement cost of a \$3,494.58 system (Rubber in this study) at the end of year 15 (at the end of the service life of rubber) will be \$5,444.44. Since the discount factor is assumed to be zero, the NPW of that replacement is \$5,444.44 (See Formula 5-1).

- **Formula 5-1**

$$F = P(1+i)^n$$

$$F = \$3,494.58(1+.03)^{15}$$

$$F = \$5,444.44$$

Using Formula 5-1 the initial cost of each material was brought to a common reference point (today). For example carpet products initial cost in 2000 was around \$75,000.00. If we want to pay for that material today it will cost about \$84,400.00.

- **Formula 5-1**

$$F = P(1+i)^n$$

$$F = \$74,959.22(1+.03)^4$$

$$F = \$84,367.26$$

The O&M costs were expressed as a percentage of the capital cost for each product. A value of 3% was assigned to the geometric gradient value, G. This was then expressed as a uniform increment (\$/ft<sup>2</sup>) at the end of time = amount of year the product was to be maintain which is equal to building service life minus one. The obtained value for the equivalent uniform series of cost each year was then added to the original O&M cost. This annual payments then were brought to a NPW amount.

- **Formula 5-2**

$$\begin{aligned} \text{Amount of years in which the product needs to be maintained} &= \text{Building} \\ &\text{Service Life} - 1 \\ \text{For ceramic tile} &= 100 - 1 \\ &= 99 \end{aligned}$$

- **Formula 5-3**

The increment amount G was computed using Formula 5-3

$$G = \text{Maintenance of the system at the end of the first year} * 3\%$$

For exposed concrete

$$G = \$21,109.99 * 3\%$$

$$= \$633.30/\text{year}$$

- **Formula 5-4**

A yearly cost for O&M procedures was computed

$$A = (G/i) - (nG/i) [i / ((1+i)^n - 1)]$$

Four our example

$$A = (\$633.30/.03) - (99 * \$633.30/.03) [.03 / ((1+.03)^{99} - 1)]$$

$$A = \$17,406.66$$

Therefore the uniform series equivalent annual cost was

$$\text{Initial O\&M Cost} + A = \$21,109.99 + \$17,559.56$$

$$= \$38,669.60/\text{year for the next 99 years}$$

- **Formula 5-5**

Present Worth Formula: Computes the equivalent amount P today at interest i of annual payments done at the end of each year for n years

$$P = A [((1+i)^n - 1) / (1+i)^n * i]$$

$$P = \$38,669.60 [((1+.03)^{99} - 1) / (1+.03)^{99} * .03]$$

$$P = \$1,219,903.33 \text{ is the total amount today of all the O\&M cost for the next 99 years}$$

CHAPTER 6  
ANALYSIS OF RESULTS

Table 6-1 shows the final results for the life cycle analysis.

Table 6-1: Summary of Results for Life Cycle Cost Analysis

<b>Table 6-1: Summary Of Results</b>						
<b>Description of System</b>	<b>Service Life (years)</b>	<b>Initial Cost (\$/Sq. Ft.)</b>	<b>Maintenance and Operation(% of Initial Cost)</b>	<b>Cost of O&amp;M (\$/SF)</b>	<b>Total NPW (\$/SF.)</b>	<b>Rank</b>
<b>Linoleum - Adhesive</b>	30	\$4.18	20.00%	\$0.84	<b>\$67</b>	3
<b>Rubber - Adhesive</b>	15	\$10.68	23.00%	\$2.46	<b>\$226</b>	5
<b>Ceramic Tile - Mortar &amp; Grout</b>	50	\$8.65	1.00%	\$0.09	<b>\$24</b>	1
<b>Carpet (Nylon cut and loop pile)</b>	10	\$2.87	18.00%	\$0.52	<b>\$62</b>	2
<b>Exposed Concrete - Sealant (2 coats)</b>	40	\$1.75	76.00%	\$1.33	<b>\$83</b>	4

The chart is broken into flooring systems: linoleum, rubber, ceramic tile, carpet, and exposed concrete. The information is a description of the materials used for evaluation. In this research all the systems were laid in the same type of substrate material and were installed accordingly to the manufacturer's specifications. The second column represents the service life in years of each material. This information was obtained from manufacturer's specification data sheets. The third column is the capital cost which represent the dollar values on a per square foot basis including materials and installation. Some of these values were obtain from record documents and others from direct interviews with manufacturers and suppliers. Column number 4 is the cost of O&M for each material expressed as cost per square foot. For example, a material with 10 year service life, an initial cost of \$2.87/ft<sup>2</sup> and an O&M cost equal to 18% of the initial cost would have an O&M cost of \$ 0.52/ft<sup>2</sup>. If the total area of that material is said

to be 26,118.19 ft<sup>2</sup>, then the total O&M cost for that system would be \$13,492.66 year. It is assumed that the maintenance and operation cost will increase at a rate equal to the inflation over the service life of the system (i.e. 3%). The calculation is then repeated for the period of years from 11-20, 21-30, 31-40, 41-50, 51-60, 61-70, 71-80, 81-90, and 91-100. The value obtained is then brought back to the present using a zero discount rate value.

Column number five is the Net Present Worth or Life Cycle Cost of the system, over a period of 100-year. This value takes into consideration: NPW of initial cost, NPW of O&M costs, and NPW of replacements.

The last column shows a ranking system that organizes the materials in ascending order of NPW. The flooring system rank #1 -ceramic tile- is the preferred alternative based on LCC.

An important observation from the results is that the lowest initial cost is not necessarily the lowest cost based on the net present worth values. This means that there is no direct correlation between initial cost and life cycle cost results as seen in Fig. 6-1.

From the Table 6-1 it can be notice that ceramic tiles, which are ranked four based on initial cost of \$8.65 ft<sup>2</sup>, are rank one based on the NPW value of \$24.47 ft<sup>2</sup>. Exposed concrete which are ranked one based on initial cost ranked four based on NPW values.

Figure 6-2 shows increasing initial cost versus life cycle cost for hard flooring alternatives.

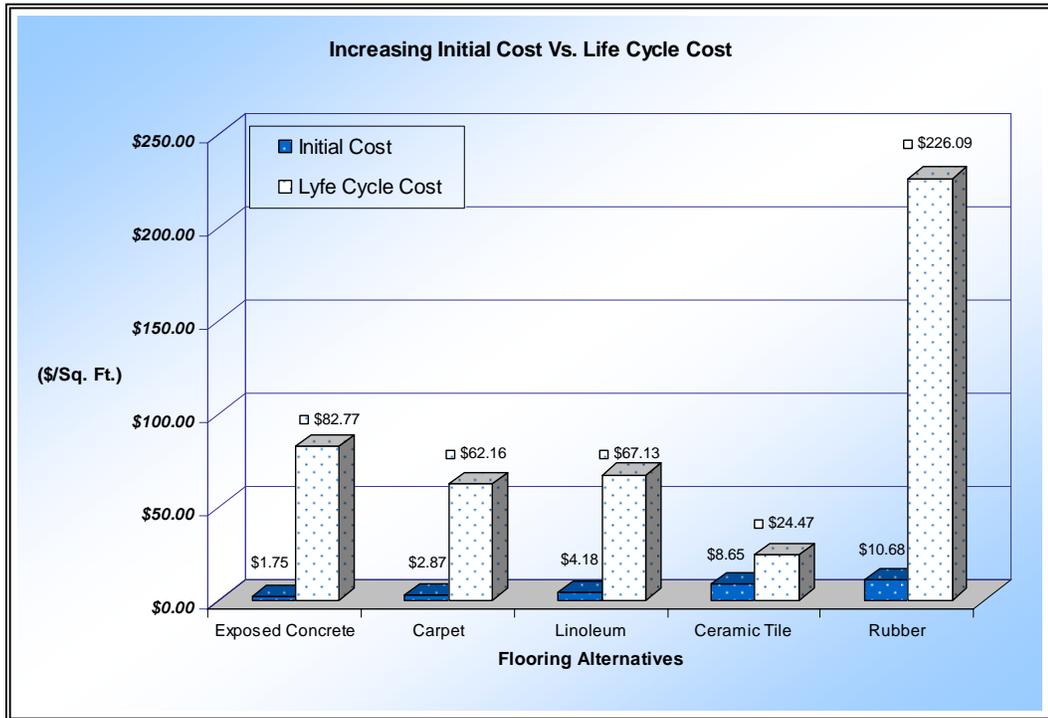


Figure 6-1: Alternatives of Flooring with Their Respective Initial Cost

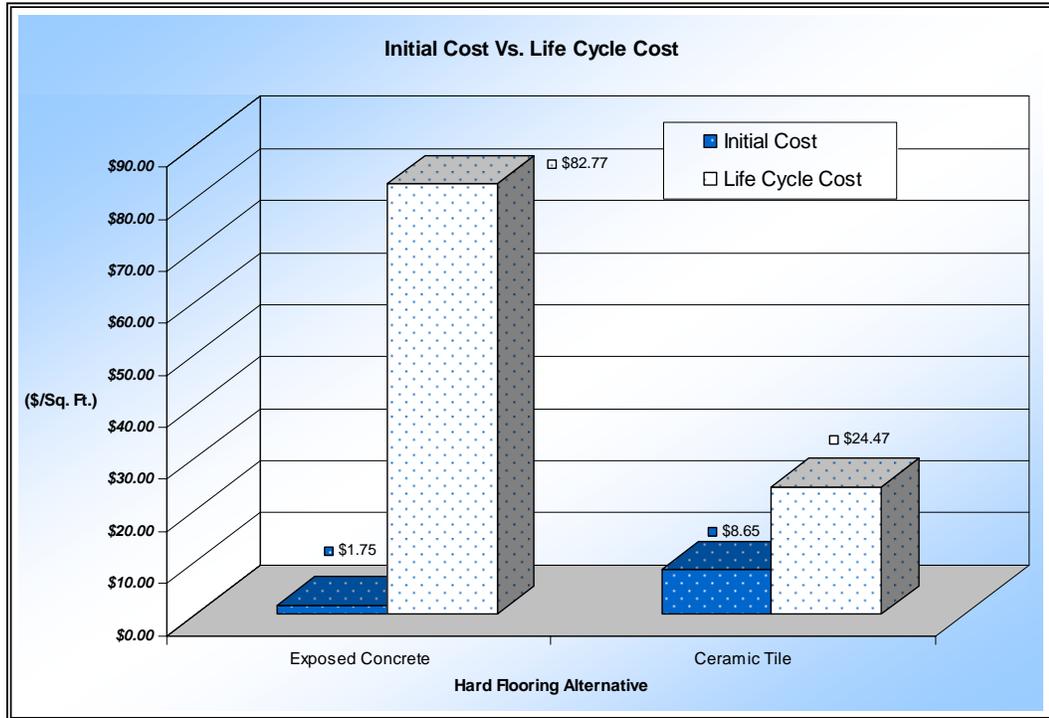


Figure: 6-2: Initial Cost vs. LCC – Hard Flooring

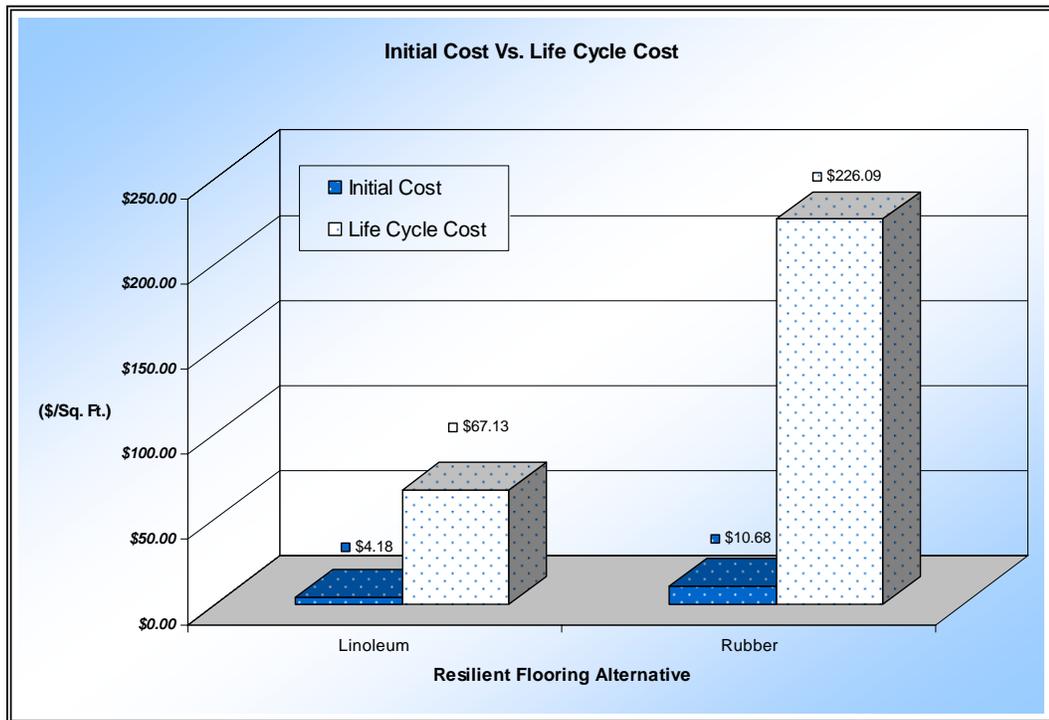


Figure 6-3: Initial Cost vs. LCC – Resilient Flooring

Figure 6-4 compares carpet flooring with linoleum flooring. No correlation exists either between these two different types of flooring materials. The alternative with the lower initial cost (carpet) resulted in the one with the higher life cycle cost over a 100-year period.

Figure 6-5 shows the ideal situation of an alternative with high initial cost but low NPW, and the typical alternative with low initial cost but high NPW.

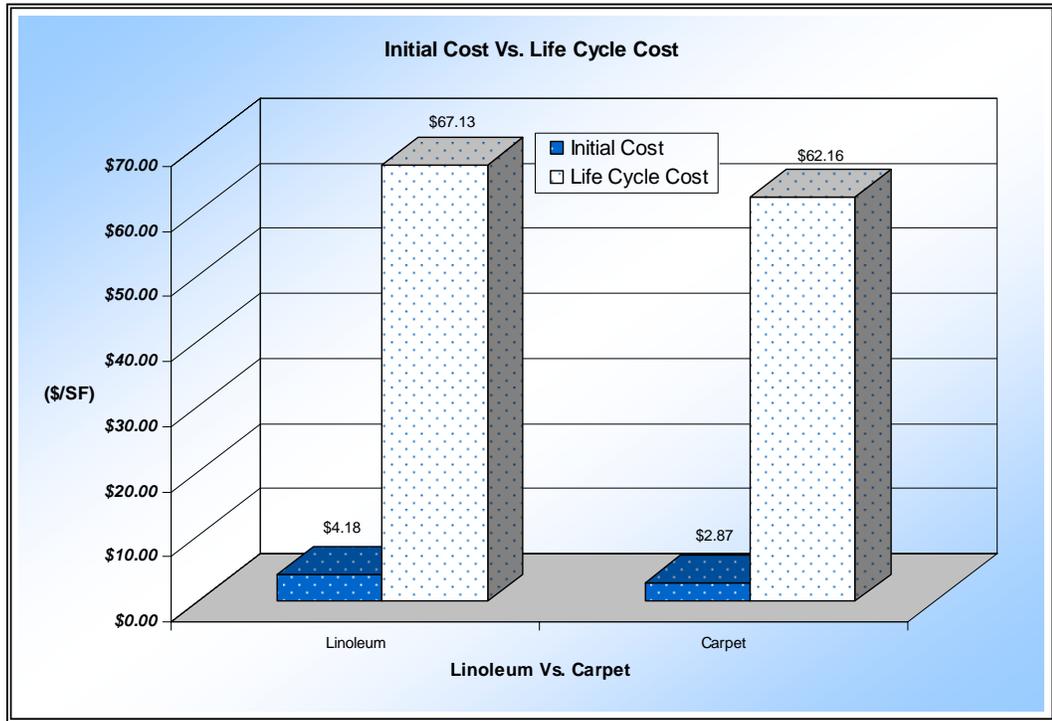


Figure 6-4: Initial Cost vs. Life Cycle Cost – Linoleum vs. Carpet

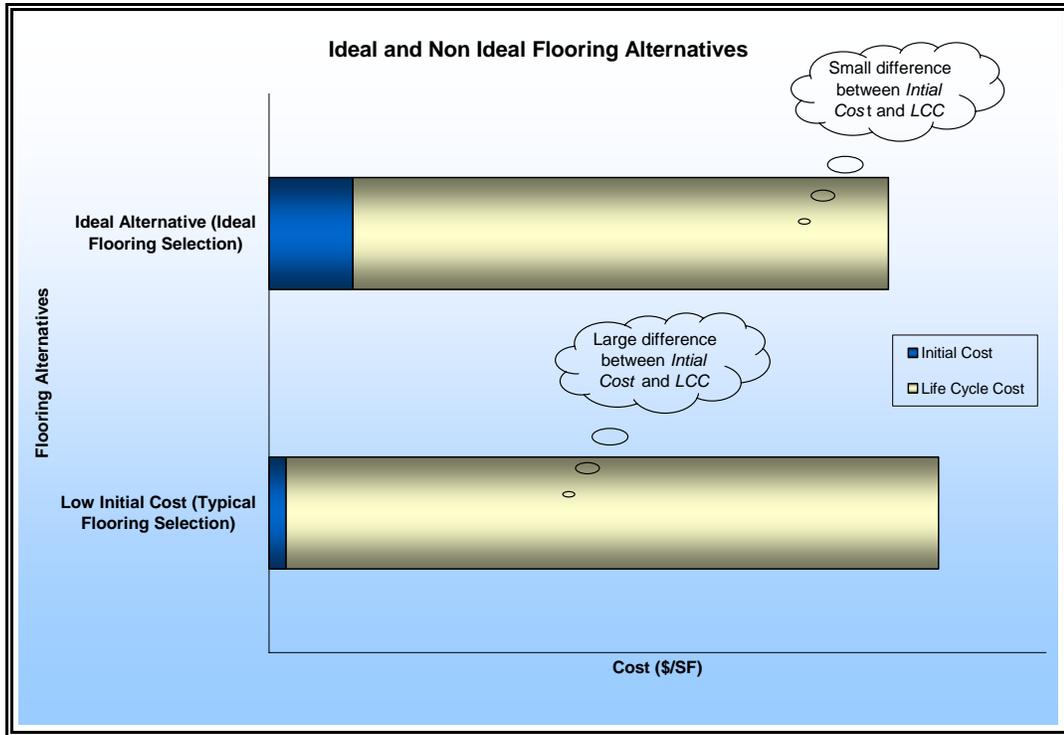


Figure 6-5: Ideal Alternative vs. Typical Alternative

Table 6-2 is an example that compares two alternatives assuming an area to be covered of 5,000 SF.

Table 6-2: Comparison between a Low Initial Cost Alternative and a Low LCC Alternative.

<b>Table 6-2: Comparison of a low Initial Cost Option Vs. the low LCC option</b>			
<b>Product Information</b>		<b>Option One</b>	<b>Option 2</b>
		<i>Low Initial Cost</i>	<i>Low LCC</i>
	Hard Flooring System	Exposed Concrete	Ceramic Tile
	Initial Cost	\$1.50 SF	\$6.50 SF
	Total NPW	\$26.26 SF	\$17.09 SF
	Total Initial Cost	\$7,500.00	\$37,500
	Total Life Cycle Cost	\$131,300	\$85,450.00
	Additional Initial Cost Needed for lowest LCC Alternative	\$25,000.00	
	Total Savings from LCC alternative	\$45,850.00	

This table shows that for an area of 5,000 SF of hard flooring inverting \$5.00 per square feet more in the initial cost of ceramic tiles would save the facility \$45,850.00 over the service life of the facility of 100 years.

There is a direct relationship between the total maintenance and operation cost per square feet of the material and the NPW (Figure 6-6).

Figure 6-7 shows the relationship between increasing O&M and NPW for resilient flooring. For these type of materials such as linoleum and rubber, as the service life increase the NPW decreases. This is because longer the service life of a material, fewer replacements, then lowers NPW values.

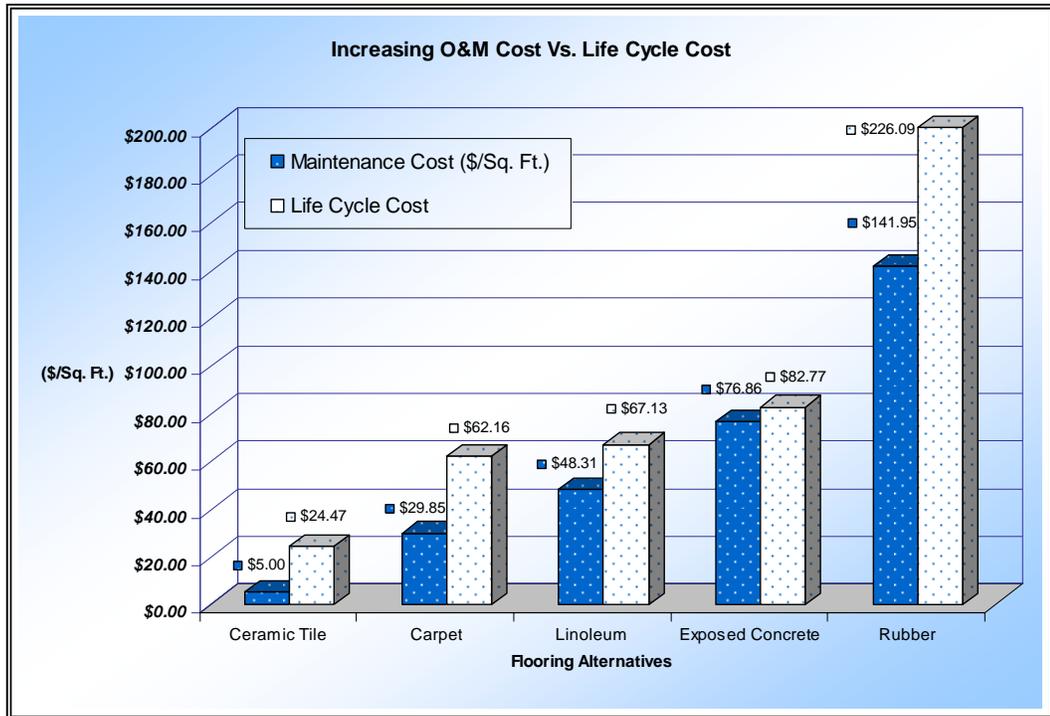


Figure 6-6: Total O&M vs. LCC

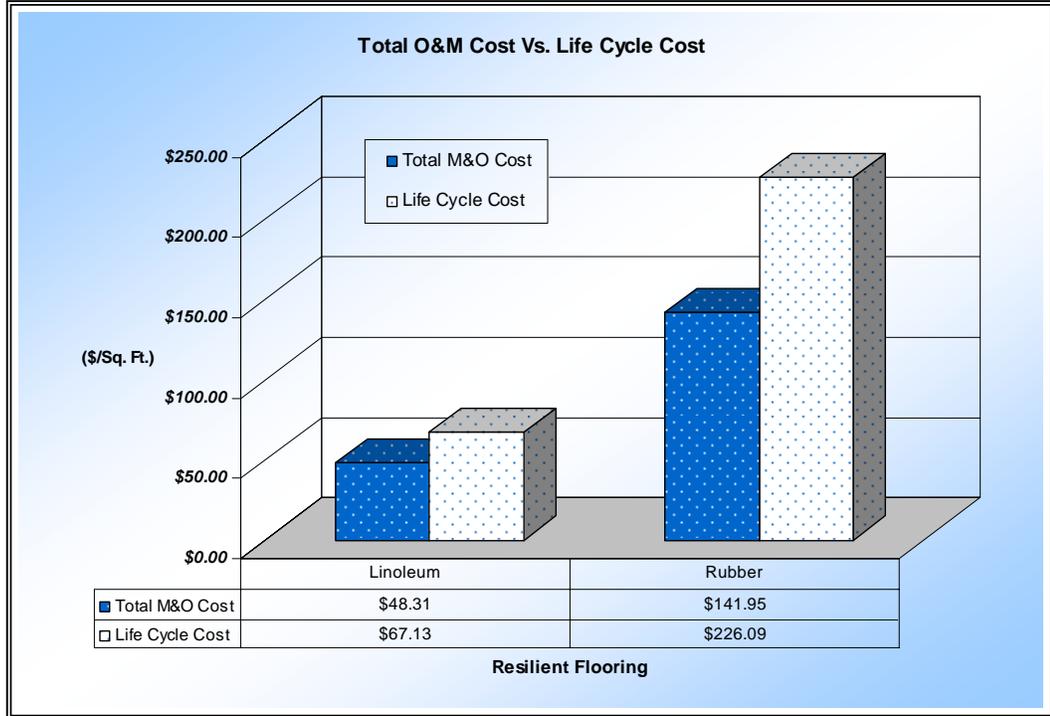


Figure 6-7: Total O&M Cost vs. Life Cycle Cost – Resilient Flooring

For hard flooring alternatives the same relationship exists between Total O&M cost and NPW (Figure 6-8).

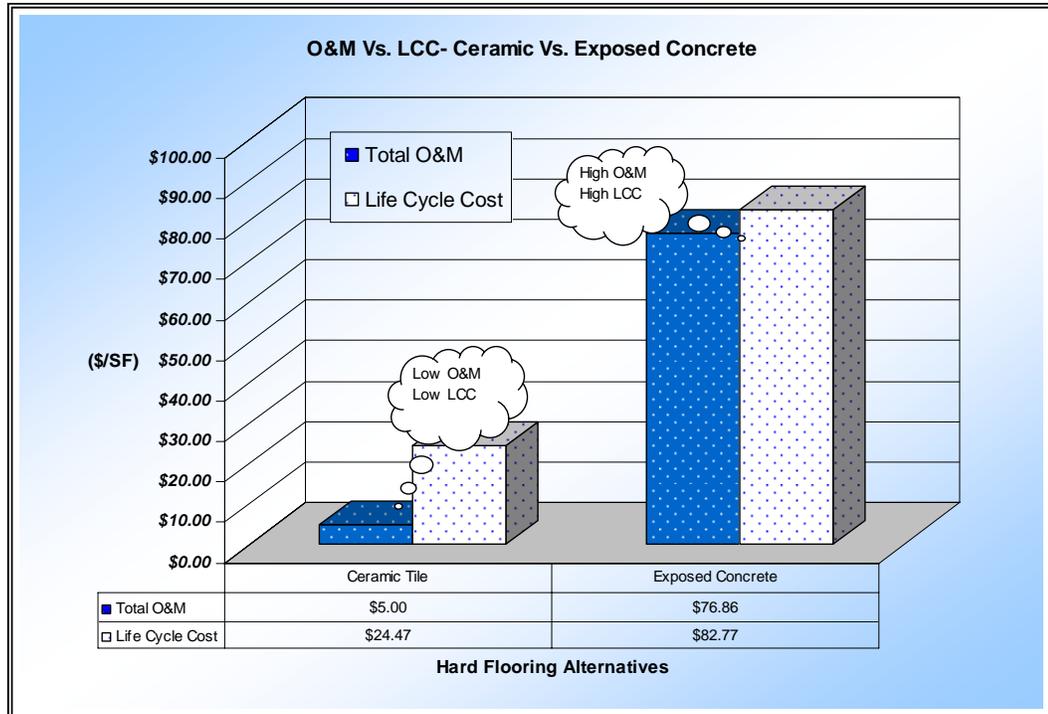


Figure 6-8: Total O&M Cost vs. Life Cycle Cost – Hard Flooring

Upfront the purchase and installation costs of carpet are less than those for linoleum, \$2.87/ft<sup>2</sup> and \$4.18/ft<sup>2</sup> respectively. However, at the end of the 100-year service life linoleum is more cost efficient than carpet. It cost 24% more to maintain and operate carpet than linoleum (Figure 6-9).

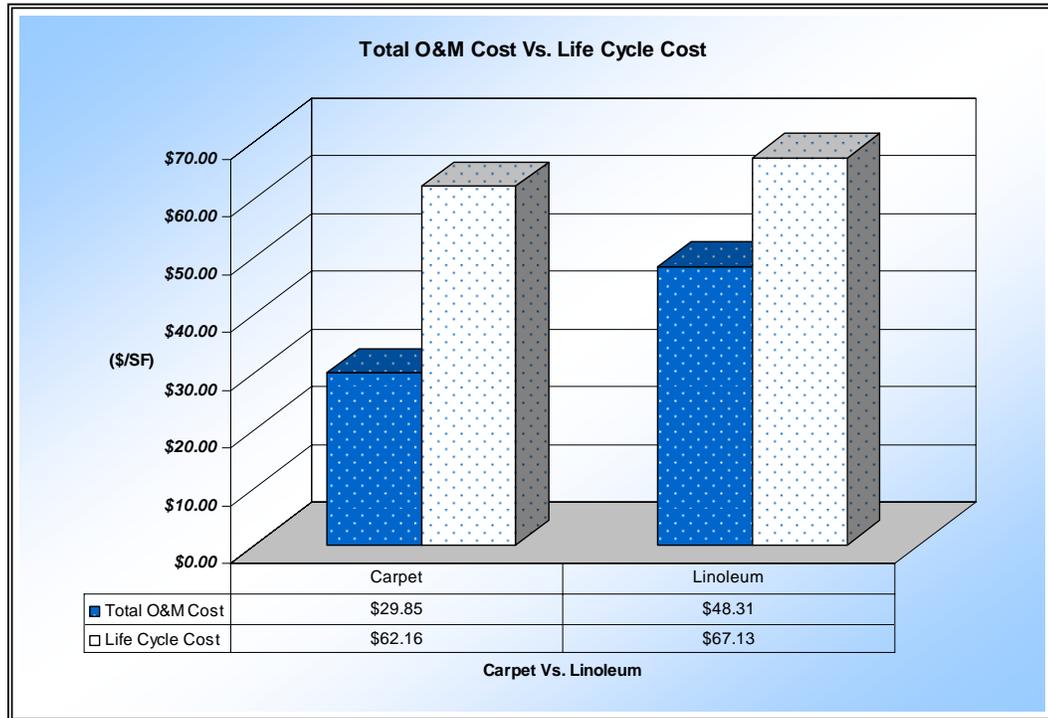


Figure 6-9: Total O&M Cost vs. Life Cycle Cost – Carpet vs. Linoleum

No correlation was found between service life values and values for NPW (Figure 6-10) and O&M cost (Figure 6-11). For example, rubber has the second lowest value for service life (15 years) but the highest value for life cycle cost (\$226.09/ft<sup>2</sup>). Ceramic, which has the highest value of service life (50 years), has the lowest value for maintenance and operational cost. A low service life value means more frequent replacements but does not mean higher values for life cycle cost and/or maintenance costs.

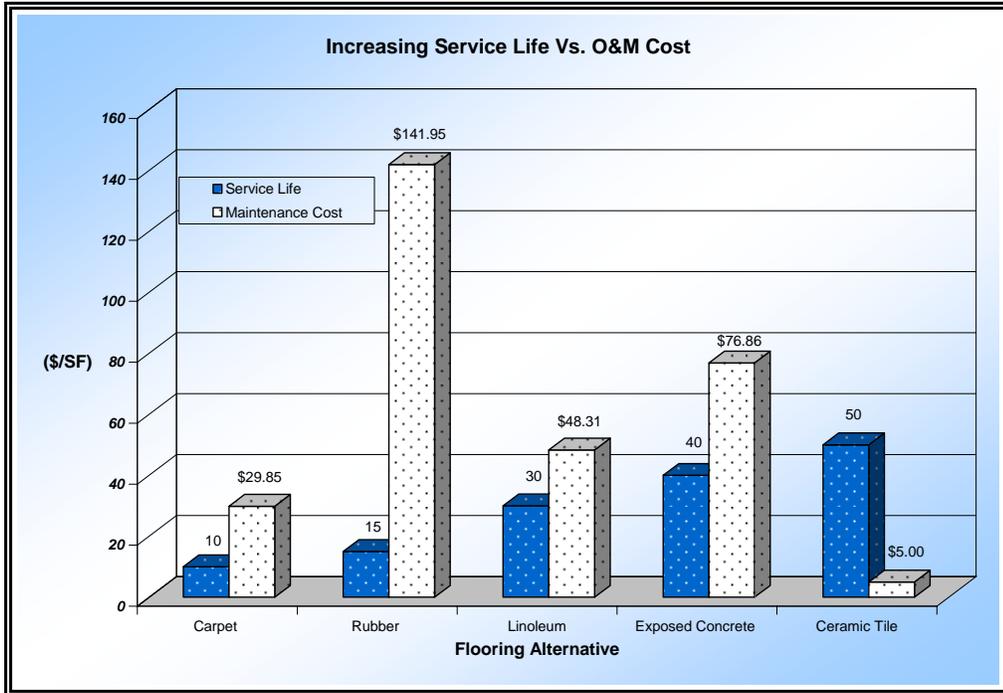


Figure 6-10: Increasing Service Life vs. Operation and Maintenance Cost

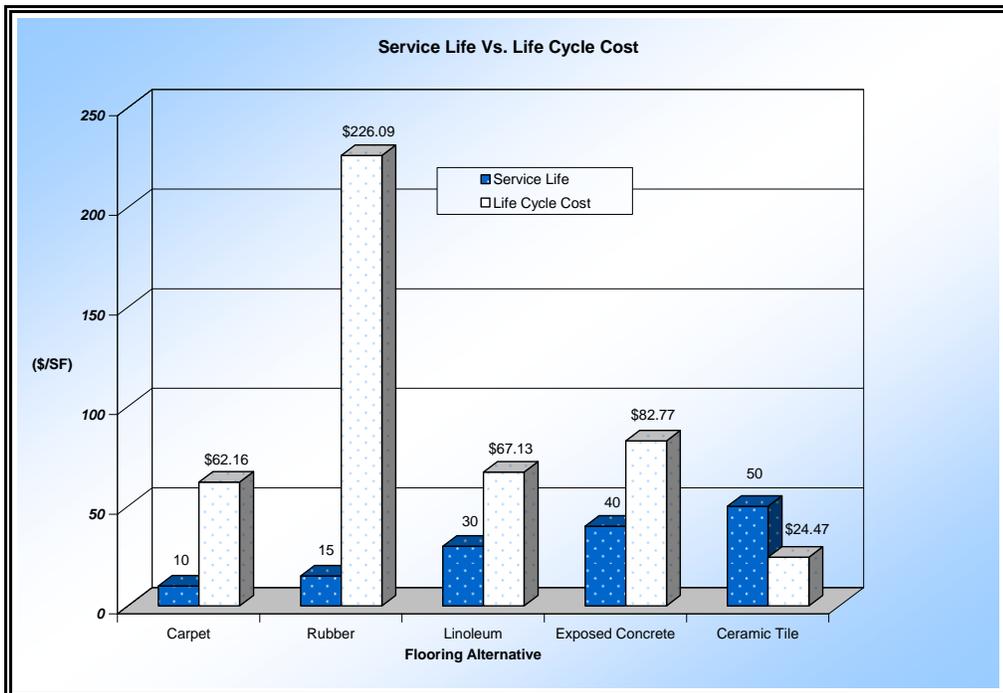


Figure 6-11: Increasing Service Life vs. Life Cycle Cost

## CHAPTER 7 CONCLUSIONS

Flooring selection for educational facilities is not an easy task. The process should take into account the needs of the users, and the physical qualities of the space. Also, design professionals need to understand the impact that their selection of materials may have on the users and on the global environment. Due to the rapidly growing worldwide interest in attaining global sustainability, a special interest should be placed on the selection of environmentally friendly materials. However, a successful design does not conclude with the proper and responsible selection of materials. Any flooring alternative chosen is reliant upon the maintenance program (cleaning, replacement and repair) and its proper execution. Lower initial cost materials are of little benefit if the maintenance costs are beyond the facility budget.

For this reason an ideal choice for selecting flooring materials is a low LCC material. These materials will have little cost after the original capital cost. Other materials may or may not have low initial cost but they will always have high values of LCC.

After examination of the LCCA results the initial hypothesis is confirmed: the most economical material was not necessarily the one with the lowest capital cost. For example, exposed concrete was the alternative with the lowest initial cost (\$1.75/ft<sup>2</sup>.) but was rank number four based on the NPW value of \$82.77/ft<sup>2</sup> for a 100 building service

life. Rubber, which is the material with higher values of life cycle cost (\$226.09), is also the one with the highest value for operation and maintenance cost of \$2.46/ft<sup>2</sup>.

Based on this research, it can be concluded that not all low initial cost alternatives will have a high life cycle cost, neither a high initial cost will guarantee a low life cycle cost. There must be a balance among the initial cost, the service life, and the O&M cost that allows for flooring alternatives that are within the budget limits of a facility's maintenance program. This can only be achieved with contentious knowledge of the different alternatives for flooring and their specific characteristics and maintenance requirements. From this study, a direct correlation between initial cost and the resulting NPW values was not found. However for both, resilient and hard floor alternatives, correlations were found between cost of operations and maintenance and the resulting life cycle cost. It was clearly demonstrated that in most of the cases the benefits of selecting alternatives with low initial cost are overshadowed by the projected cost for the proper maintenance of the facility.

A low life cycle cost material may not be suitable for the requirements associated with an educational facility. Materials characteristics and properties must be considered before selecting any flooring material. Designers' experience and knowledge is needed to properly evaluate the most effective alternatives taking into consideration not just a low LCC but also to ensure the proper functionality of a building. Life cycle cost quantitative results should only be used as partial indicators and not a final decisive tool for the selection of interior flooring surfaces.

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## BIOGRAPHICAL SKETCH

Cassandra Michelle Lozada-Figueroa grew up in Mayagüez, Puerto Rico, where she graduated second in her class from Our Holy Mary High School College (Colegio La Milagrosa) in June 1995. In August 2005, she started her university studies at the University of Puerto Rico, Mayagüez Campus. As an undergraduate student she was awarded and enrolled in the Dean's List of Honor Students. During her studies she worked as a research assistant for PRASA (Puerto Rico Authority of Sewer and Aqueducts Authority) in the improvement of the water supply system and the construction of a new service pump station at Humacao's filtration plant. A second research was performed in machineries and techniques available and used for rock excavation. These projects were presented at different engineering forums and an abstract, "Construction Cost Estimate and Specifications for PRASA Project," co-authored by her was published in 1999.

In August 1997 she was elected as the civil engineering department student delegate, a duty that was performed until May 2000. Cassandra graduated cum laude, earning a Bachelor in Civil Engineering in June 9, 2000. In 2001 she worked with Delon Hampton and Associates at Dulles, Virginia, as office engineer for the construction of new facilities for the Dulles International Airport. In August 2001, she started graduate studies at the University of Florida. She studied under the direction of Dr. Debra Harris. Cassandra's primary research interest lies in the area of life cycle cost of interior finishing materials.