Flooring materials – life-cycle costing for educational facilities

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Abstract

The tight schedule of developing, designing, and managing educational facilities limits the time and resources needed to correctly assess the full cost of building materials. As a result, the selection of interior finishing materials is commonly driven solely by initial cost. This study evaluates interior floor materials currently available for use in K-12 educational facilities in the State of Florida. The range of materials chosen for the comparison encompasses common flooring materials installed over appropriate sub-floor materials. The flooring alternatives are evaluated using a service life-cycle cost (LCC) analysis based on the 50-year service life specified by the Florida Department of Education. A net present worth (NPW) analysis that includes initial costs, operation and maintenance costs, and replacement costs of each selection is used to evaluate the materials. Interior floorings initial cost, replacement cost, service life, and operations and maintenance costs are compared to the materials resulting LCC.

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Introduction

The conscientious selections of materials by designers or facility managers are often constrained by strict budget requirements. As a consequence, the selection of materials for new educational facilities is usually based on manufacturers' information, personal experience, or solely driven by the product's initial cost (Drummond *et al.*, 1999). In order to address this matter, the Florida Department of Education (FDOE) sponsored a comprehensive study that provides a tool for a practical evaluation of building materials used in renovations and new construction of school buildings. FDOE officials were particularly interested in an assessment of continuing costs, i.e. the costs experienced after the initial purchase of the material because currently there is no state funding for these expenses. This study assesses the service life of the interior flooring materials by using a life cycle cost (LCC) analysis to address the following hypothesis: lowering the initial cost of a facility – by selection of lower initial cost materials – will likely result in higher LCC of the facility. The higher LCC is expected due to the continuing cost of the flooring materials.

The investigation examined a total of 20 interior and exterior flooring materials both natural and synthetic. The flooring materials are identified in Figure 1. Each surface material is combined with the appropriate substrate materials for installation on a concrete subfloor. When presented with several installation methods for a given flooring alternative, the different installation methods were analyzed for their potential impact on the LCC. The LCC analysis examines each alternative and the true cost of the material for the FDOE dictated 50-year service life. These costs include initial cost, installation cost, operation and maintenance cost, such as custodial work and repairs, and replacements cost. The LCC analysis provides quantitative results based on specific and pre-defined assumptions. The assumptions used for this study were defined by state officials from the FDOE and are identified within the body of the article.

This article is based on a comprehensive study conducted by University of Florida's researchers for the State of Florida Department of Education. For more information see Drummond *et al.* (1999).

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Figure 1 Evaluated flooring alternatives

MATERIAL			FLOOR CHARACTERISTICS									MAINTENANCE PROCEDURES												
★ = Above Average = Average = 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			Strength	Durability	Thermal Insulation	Moisture, oil, chemical resistance	Stain Resistance	Abrasions Resistance Wearability	Mildew Resistance	Heat Absorption	Limitied Application Locations	Sweeping or dust mopping	Vacuuming	Damp mopping	Wet mopping	Scrubbing	Stripping	Dry cleaning (chemicals)	Hot water extraction	Waxing	Buffing	Resealing	Regrouting	Sanding & refinishing	Overall Maintenance Ranking
Flooring	Hard	Ceramic Tile (6"x6"x1/2") - Mortar & Grout	★	★	★	V		★	★			D		D		Y							P		Low
		Ceramic Tile (6"x6"x1/2") - Mastic & Grout	★		★	V		★	★			D		D		Y							P		Low
		Quarry Tile - Mortar & Grout	★	★	★	★	★	★	★			D		D		Y							P		Low
		Exposed Concrete - Sealant (2 coats)	★	★				★		★	✓	D		W		M						P			Medium
		Terrazzo (1 3/4") - Cast in place	★	★		★	★	★	★			D		W		M				Y	Y				Medium
		Epoxy resin			★	★	★		★			D		W		M									Low
		Laminated wood (synthetic core) - vapor barrier & Adhesive			★				★			D		W											Low
		Wood plank (2 1/4") - vapor barrier & urethane	★		★				★			D		D								P		P	Low
		Bamboo flooring - vapor barrier & adhesive	★		★			★	★			D		D										P	Low
	Resilient	Linoleum (.125") - Adhesive		★	★			★	★			D		D						Y	Y				Medium
		Vinyl Composition Tile (VCT) - Vapor barrier and Adhesive			★		V					D		D		S	S			M	M				High
		Vinyl Sheet - Vapor barrier and Adhesive			★		V					D		W		Y	Y			M	M				High
		Rubber Sheet (1/8") - Adhesive	★		★	★		★				D		W	Y					Y					Medium
		Cork (1/8") - Adhesive			★							D		W								Y			Low
	Soft	Carpet tile (18"x 18", 20oz/syd) - Hard back			★		★			★	✓		D					S	S						Medium
		Carpet tile (18"x 18", 20 oz/syd) - Cushion back		★	★		★			★	✓		D					S	S						Medium
		Carpet (Nylon loop pile 40oz/syd) - Adhesive			★		★			★	✓		D					S	S						Medium

Methodology

Project background

The complete project investigation was conducted in four phases. The first phase consisted of reviewing official documents, such as specifications and ordinances, provided by the FDOE. The second phase required the collection of empirical data regarding construction, performance, cleaning procedures, repair maintenance, and replacement of building materials on selected schools. The third phase compared the empirical data to codes and standards currently in use. In addition, data was collected, compiled, analyzed, and used to determine the materials selected for analysis. The final phase evaluated the materials selected using a service LCC analysis.

Phase 1: analysis of official documents

The State of Florida Department of Education provided survey documents from newly constructed schools from 1992, 1996, and 1997. These surveys contained information on each school building's type, location, size, dates and costs of construction, site development, applied materials, and systems specifications. The documents were analyzed and used to create a preliminary list of materials commonly used in Florida's educational facilities.

Phase 2: empirical data collection

Surveys, questionnaires, and direct observations of 12 case study schools were used to collect empirical data. Questionnaires were sent to facilities managers and maintenance directors to obtain accurate information on the performance of flooring materials and systems in place and the current costs of operating and maintaining the floors. Direct site observations were conducted in 12 schools located in the north, central, and south climatic regions of the State of Florida. The information collected from direct observations included data on the service use of the flooring materials in each facility and variations in the age of the student occupants. Informal interviews with school principles, maintenance staff, and facilities managers followed the direct observations. These interviews provided additional data and current 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 3: codes, standards, and materials specifications

Manufacturers technical specification data sheets (MSDS) were collected on possible flooring alternatives. These sheets provide information regarding recommended cleaning

procedures and expected durability of each flooring alternative. In addition, the Southern Building Code Congress International, Inc. (SBCCI) Standard Building Code (1997), the State of Florida Requirements for Educational Facilities (1997) and the Dade County Public Schools Master Specification Guidelines (1998) were used as a basis for refining the list of flooring alternatives.

Phase 4: LCC analysis

The DOE specifically requested an analysis of actual costs felt by the school district during the use and replacement of the flooring materials over a 50-year building service life. For this reason, the analysis consisted of a service LCC comparison of selected materials. The dollar values used in the LCC calculations come from the actual monetary expenditure to purchase, properly maintain, and replace these flooring materials to serve the building for 50 years. Although there are many methods of LCC analysis available; for example, the "cradle to cradle" and "cradle to grave", that completely track a materials true cost from raw materials to end use, these types of LCC analysis were not used in this study.

Selection of materials for analysis

Interior floor surfaces refer to the finishing materials, the substrate or subfloor where they are applied, and the materials used to attach the finish to the substrate. Research was conducted in Florida and as such, all public schools' subfloors are made of concrete. The information collected in phases 1, 2 and 3, was used as a basis for the selection of flooring materials for analysis. The final flooring material alternative list also incorporated current practices, availability of materials, code compliance, and adequate performance criteria for Florida's educational facilities.

Figure 1 shows the floor surface materials considered in the LCC analysis, the materials major flooring characteristics and actual maintenance procedures. The chart is broken into flooring categories, hard, resilient, and soft. Each flooring system is only compared within its given category. For example, the strength rating of ceramic tile may be directly compared to the strength rating of epoxy resin, but not directly compared to that of linoleum (as linoleum is a resilient flooring and not a hard flooring). When reading the chart, for example, *quarry tile* can be compared to *laminate wood* flooring. Quarry tile has higher strength, durability, and abrasion resistance; equal thermal insulation; and lower heat absorption than laminate wood flooring.

LCC analysis assumptions

The basic assumptions for the LCC analysis are based on standards set by the FDOE, recommendations of the FDOE steering committee, the Florida Energy Modeling Program (FEMP), and the National Institute of Standards and Technology (NIST). For example, the FDOE and the steering committee required a LCC analysis with no discount rate because the State does not currently allocate funds to future expenditures. Table I provides a list of assumptions used to perform the LCC calculations. All assumptions were required or approved by a FDOE steering committee prior to analysis.

Results

The analysis results are found in Figure 2. LCC examines the associated ownership costs of competing alternatives by discounting the costs to a common reference point. For the purposes of this study, the common reference point is the net present worth (NPW). All of

Table I LCC asumptions

Inflation rate	3 per cent (Energy, 1997). 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 system
Discount rate	None (0 per cent as required by the FDOE)
Operation and maintenance	Derived from equipment and supplies used, the time consumed for each procedure, the required frequency of performance, the number of people involved, and the average wages and labor fees in Florida
Building service life	50 years
Capital cost	Derived from manufacturer's data and appropriate installation costs
System service life	Derived from information provided by the product manufacturer and observations. Service life assumes manufacturer recommended cleaning and maintenance is preformed
Number of replacements	The appropriate number of replacements for each system was assumed to support the educational institution for a 50-year service life
Salvage value	The LCC assumes no salvage value of system at time of replacement

Figure 2 Service LCC results

HARD FLOORING SYSTEMS									
IDENTIFICATION NUMBER & RANKING	FLOORING SYSTEMS	CAPITAL COST	SYSTEM SERVICE LIFE	NUMBER OF REPLACEMENT SYSTEMS	NPW OF REPLACEMENT SYSTEMS	MAINTENANCE AS A PERCENTAGE OF CAPITAL COST	MAINTENANCE COST	TOTAL NPW OF O&M	TOTAL COST OF SYSTEM IN NPW
1	Ceramic Tile (6"x6"x1/2") Mortar & Grout	$7.31	50	0	$0.00	1.00%	$0.07	$8.25	**$15.56**
2	Ceramic Tile (6"x6"x1/2") Mastic & Grout	$6.69	30	1	$16.24	2.00%	$0.13	$15.09	**$38.02**
3	Quarry Tile Mortar & Grout	$6.70	35	1	$18.85	2.00%	$0.13	$15.11	**$40.67**
4	Exposed Concrete Sealant (2 coats)	$0.79	50	0	$0.00	76.00%	$0.60	$67.72	**$68.51**
5	Terrazzo (1 3/4") Cast in place	$7.10	50	0	$0.00	8.00%	$0.57	$64.07	**$71.17**
6	Epoxy resin	$1.60	12	4	$2.28	37.00%	$0.59	$66.78	**$85.16**
7	Laminated wood (synthetic core) vapor barrier & adhesive	$12.00	20	2	$21.67	5.00%	$0.60	$67.68	**$140.50**
8	Wood plank (2 1/4") vapor barrier & urethane	$9.31	30	1	$22.60	24.00%	$2.23	$252.03	**$283.94**
9	Bamboo flooring vapor barrier & adhesive	$13.22	25	1	$27.68	17.00%	$2.24	$253.50	**$294.40**
RESILIENT FLOORING SYSTEMS									
IDENTIFICATION NUMBER & RANKING	FLOORING SYSTEM	CAPITAL COST	SYSTEM SERVICE LIFE	NUMBER OF REPLACEMENT SYSTEMS	NPW OF REPLACEMENT SYSTEMS	MAINTENANCE AS A PERCENTAGE OF CAPITAL COST	MAINTENANCE COST	TOTAL NPW OF O&M	TOTAL COST OF SYSTEM IN NPW
1	Linoleum (.125") Adhesive	$4.50	30	1	$10.92	20.00%	$0.90	$101.52	$116.94
2	Vinyl Composition Tile (VCT) Adhesive	$1.43	15	3	$11.11	86.00%	$1.23	$138.72	$151.25
3	Vinyl Sheet Adhesive	$2.05	15	3	$15.92	60.00%	$1.23	$138.74	$156.71
4	Rubber Sheet (1/8") Adhesive	$5.30	10	4	$46.85	23.00%	$1.22	$137.50	$189.65
5	Cork (1/8") Adhesive	$3.43	6	8	$66.11	36.00%	$1.23	$139.28	$208.82
SOFT FLOORING SYSTEMS									
IDENTIFICATION NUMBER & RANKING	FLOORING SYSTEM	CAPITAL COST	SYSTEM SERVICE LIFE	NUMBER OF REPLACEMENT SYSTEMS	NPW OF REPLACEMENT SYSTEMS	MAINTENANCE AS A PERCENTAGE OF CAPITAL COST	MAINTENANCE COST	TOTAL NPW OF O&M	TOTAL COST OF SYSTEM IN NPW
1	Carpet tile (18"x 18", 20oz/syd) Hard back	$2.21	10	4	$19.53	29.00%	$0.64	$72.29	$94.04
2	Carpet tile (18"x 18", 2o oz/syd) Cushion back	$2.51	12	4	$26.33	25.00%	$0.63	$70.78	$99.62
3	Carpet (Nylon loop pile 40oz/syd) Adhesive	$3.61	11	4	$34.74	18.00%	$0.65	$73.30	$111.65

Note: The flooring alternatives are listed from lowest NPW (lowest NPW being the preferred alternative based on LCC) to highest NPW. All dollar values are given on a per square foot basis

Identification Number and Ranking
This number represents the preferred order ranked from lowest NPW to highest NPW.

Flooring System
The information contained in this column is a description of the flooring system

Capital Cost
This cost represents the cost of the flooring per square foot

System Service Life
System service life for each flooring alternative as indicated by manufacturers and direct observations

Number of Replacement Systems
The number of replacement operations is dependent on the specific flooring alternative's expected service life

NPW of Replacement Systems
Total cost of all replacement systems as needed to support the facility for a 50 year service life

Maintenance as a percentage of Capital Cost
Maintenance cost required shown as a percentage of the initial cost of the flooring alternative

Maintenance Cost
Maintenance cost converted to dollars per square foot

Total NPW of O&M
Total cost of all operating and maintenance cost of the flooring alternative for the 50 year service life

Total cost of system in NPW
This number represents the total Net Present Worth or Life Cycle Cost of the system based on a 50 year building service life. This number takes into consideration the initial and replacement costs and the operation and maintenance expenses for all expenditures from installation to through year 50.

the cash flows associated with a specific flooring alternative were calculated to the present time equivalent. All variables for the flooring alternatives are costs; there are no incomes associated with the purchase and maintenance of the floors. Therefore, all numbers in Figure 2 indicate cost or expenditures and as such minimizing the total NPW is preferred. The system with the lowest NPW is the most cost-effective system based on this LCC analysis, and is ranked highest.

Discussion

A significant burden is placed on designers, facility managers and school officials to provide the best possible building at the lowest possible cost. This often results in the selection of materials based on the lowest initial cost. Although the initial cost of a facility is important and often constrained by strict budget requirements, the most economical choice for selecting materials is based on LCC. There is little benefit to the individual school if low initial cost materials is selected and the maintenance costs are beyond the facility budget. This could result in neglecting proper maintenance procedures and the need for more frequent replacements of the flooring.

The ideal choice for flooring materials is a low LCC material. These ideal materials would show very little cost after the initial purchase. Non-ideal flooring alternatives may or may not have a low initial cost, but they will always have a high LCC. In Florida, budget constraints are used as justification for selecting materials based only on low initial cost without considering continuing costs. Figure 3 shows an initial and LCC cost graph for an ideal and non-ideal flooring alternative.

Analysis

Hard flooring

A key observation from the research results is the lack of relationship or correlation between initial cost and the LCC results, i.e. the lowest initial cost is not necessarily the lowest cost alternative based on NPW. Figure 4 shows alternatives from lowest initial cost to highest initial cost (left column). Adjacent to each alternative is the resulting NPW. Figure 5 shows an increasing trend in initial cost and the variability of the NPW.

Upon examination of Figure 4, ceramic tile with mortar, which would normally be ranked sixth based on the initial cost of $7.31/SF, is the least expensive flooring alternative based on the NPW analysis. Ceramic tile installed with mortar is a flooring alternative that mimics the (ideal(flooring situation: low NPW with fairly low initial cost (see Figures 3 and 6). A flooring alternative such as exposed concrete has an even lower initial cost but presents a higher NPW. This is an example of a typical flooring selection based on initial cost.

To show how this flooring selection may affect a school budget, assume a new school is slated for construction, the school will need 2,000 square feet of hard flooring. Two selection options are available. Option 1 is to select the materials based on low initial cost and option 2 is to select the materials based on lowest service LCC. A cost comparison follows in Table II.

By spending an additional $13,035 to purchase the low LCC alternatives versus the low initial cost alternatives, the facility would save $105,900 in flooring costs over the service life of the facility.

Further analysis continues to show a lack of correlation between initial cost and 50-year LCC. The results show that ceramic tile installed with mortar and grout has an initial cost of $7.31 and a total NPW of $15.56/square foot. This is the economically preferred hard flooring alternative based on the LCC analysis. The second choice based on NPW is ceramic tile with mastic and grout having an initial cost of $6.69 and a NPW of $38.02/square foot. In this case, selecting the lower initial cost alternative at $6.69 results in a higher LCC. This is due to the significantly higher maintenance cost associated with the mastic alternative. The maintenance cost outweighs the increased initial cost of using mortar. Basically, increasing the initial expenditure by $0.62 per square foot results in a saving of $22.46 per square foot over the service life of the building.

There is a relationship between the maintenance cost and the resulting NPW. As the dollars per square foot of maintenance increases, the NPW of the alternatives also increases. The one exception is terrazzo due to its fairly low maintenance percentage (8 per cent) and long service life. This indicates that

Figure 3 Initial and LCC cost of ideal and non-ideal flooring alternatives

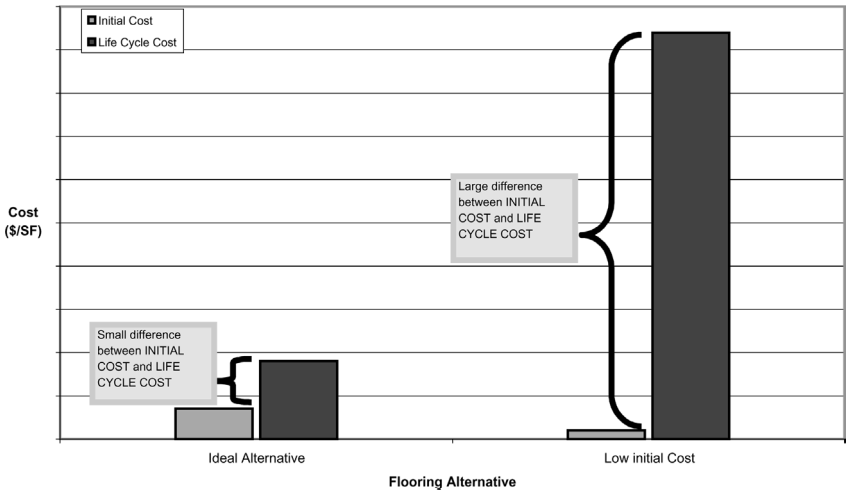


Figure 4 Increasing initial cost versus LCC

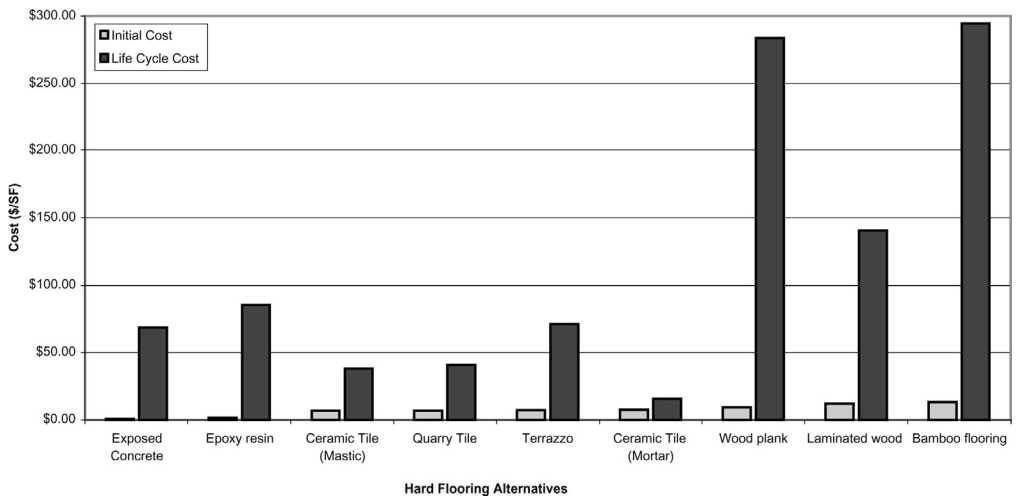


Figure 5 Increasing initial cost versus LCC

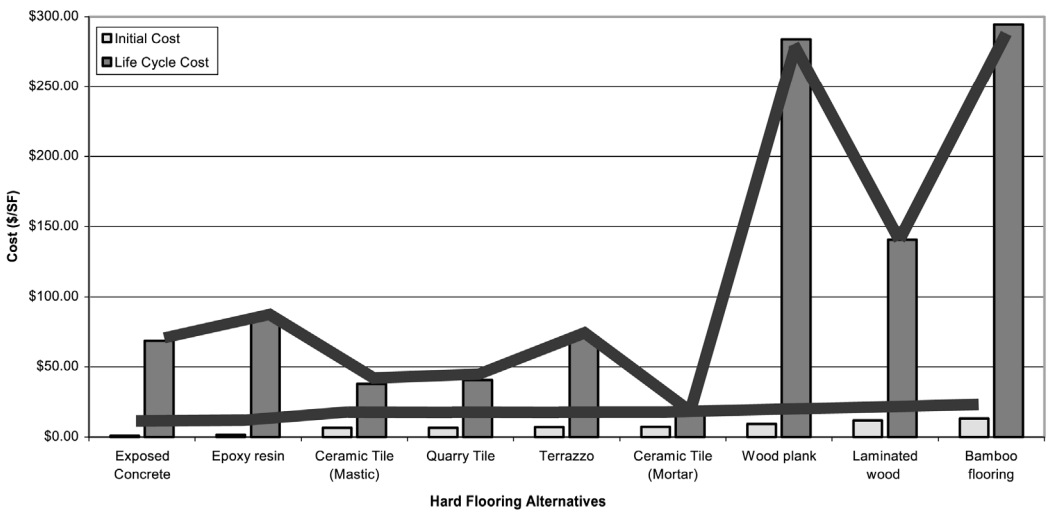


Figure 6 Exposed concrete versus ceramic tile (mortar)

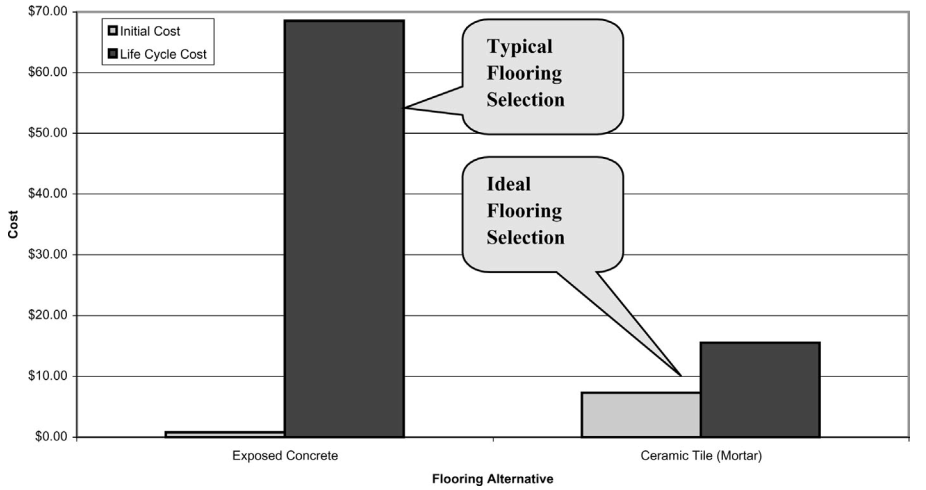


Table II Total cost comparison of a low initial cost option versus the low LCC option

	Option 1: low initial cost ($)	Option 2: Low life cycle cost ($)	
Hard flooring system	Exposed concrete	Ceramic tile (mortar)	
Initial cost	0.79/SF	7.31/SF	
Total NPW	68.51/SF	15.56/SF	
Total initial cost	1,585	14,620	
Total life cycle cost	137,020	31,120	
Additional initial cost needed for lowest LCC alternatives			**13,035**
Total savings from purchasing LCC alternatives			**105,900**

O&M is a driving factor in the resulting NPW LCC ranking. An example of the O&M effect is shown in the epoxy resin alternative. Epoxy resin is the second least expensive alternative based on initial cost $1.60/square foot but has a relatively high O&M, $0.59/square foot or 37 per cent of the initial cost. The high O&M of the epoxy resin results in a sixth place LCC ranking based on the NPW.

The hard flooring alternatives were plotted with increasing O&M (left column) and the resulting alternatives NPW as seen in Figure 7.

In this instance, as the O&M expenses increase, the NPW tends to increase. This trend may be seen in Figure 8.

This can be seen when comparing two alternatives with similar initial cost. Ceramic tile with mortar has an initial cost of $7.31/square foot and terrazzo has an initial cost of $7.10/square foot. The O&M cost is $0.07 and $0.57, respectively. The resulting NPW of ceramic tile is $15.56 and terrazzo is $71.17, a $55.61 difference. The less expensive initial cost alternative, terrazzo, has a $0.50 higher maintenance which results in a $55.61 higher LCC as shown in Figure 9.

Resilient flooring

Resilient flooring, again, shows no direct relationship between initial cost and the NPW. The initial and NPW are plotted in Figures 10 and 11.

This group of flooring alternatives again shows how standard selection of materials based on low initial cost, such as vinyl composition tile (VCT), will result in a much higher LCC. Figure 12 compares VCT and linoleum. Linoleum, for example is ranked fourth based on initial cost but ranks first based on LCC.

It is important to notice that if compared with the other resilient floor materials, linoleum's initial cost is the second highest and significantly more expensive than VCTs. The LCC analysis shows that the driving factor of the low ranking remains the O&M cost of linoleum, which is 73 per cent of the required cost to maintain vinyl floors. In addition, the service life of linoleum – when properly maintained – is twice as long as VCT's.

Resilient floorings do not show a direct relationship between increasing O&M and NPW (Figure 13) but show a relationship between the flooring service life and NPW (Figure 14).

With the resilient flooring alternatives, a correlation can be seen between service life and NPW. As the service life increases the NPW decreases, i.e. the longer the life of the

Figure 7 Increasing O&M versus LCC

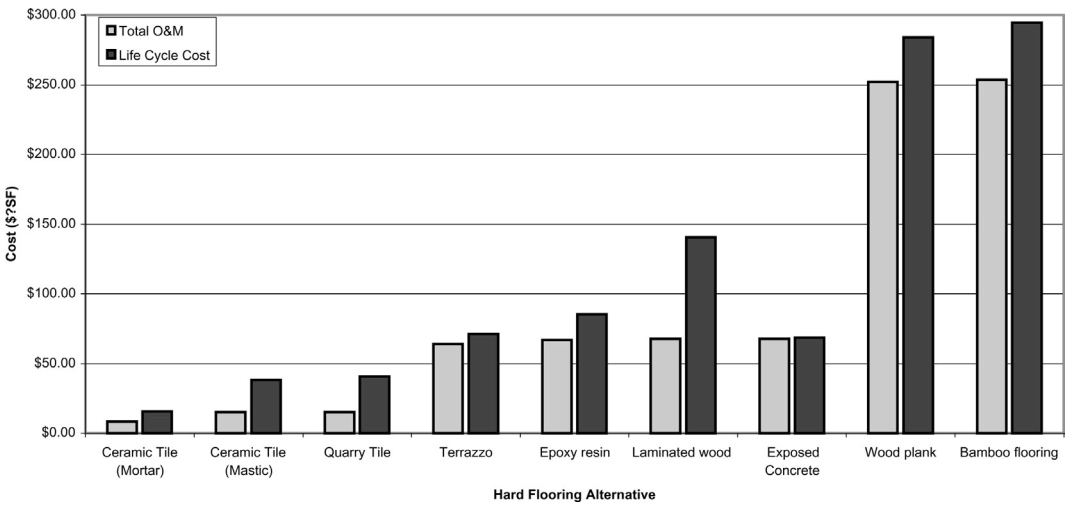


Figure 8 Increasing O&M versus LCC

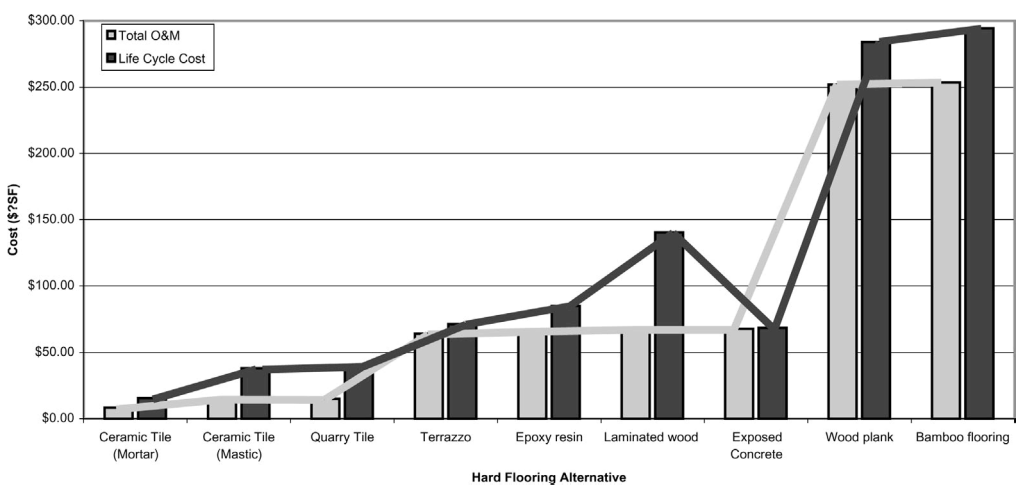


Figure 9 O&M and LCC – ceramic tile (mortar) and terrazzo

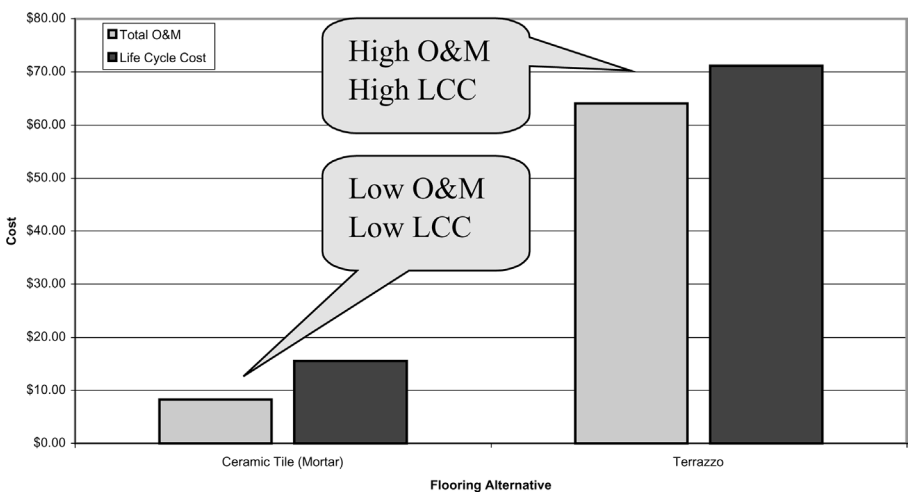


Figure 10 Initial cost versus LCC

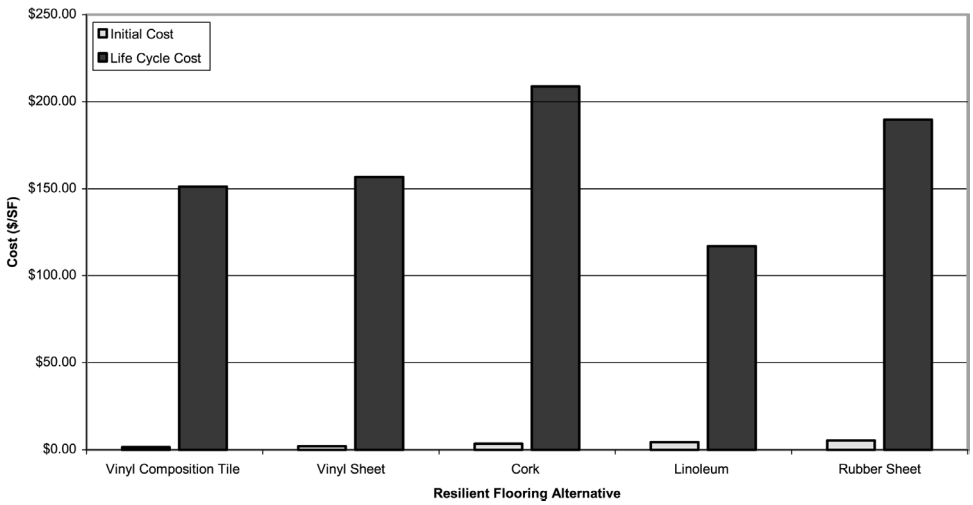


Figure 11 Initial cost versus LCC

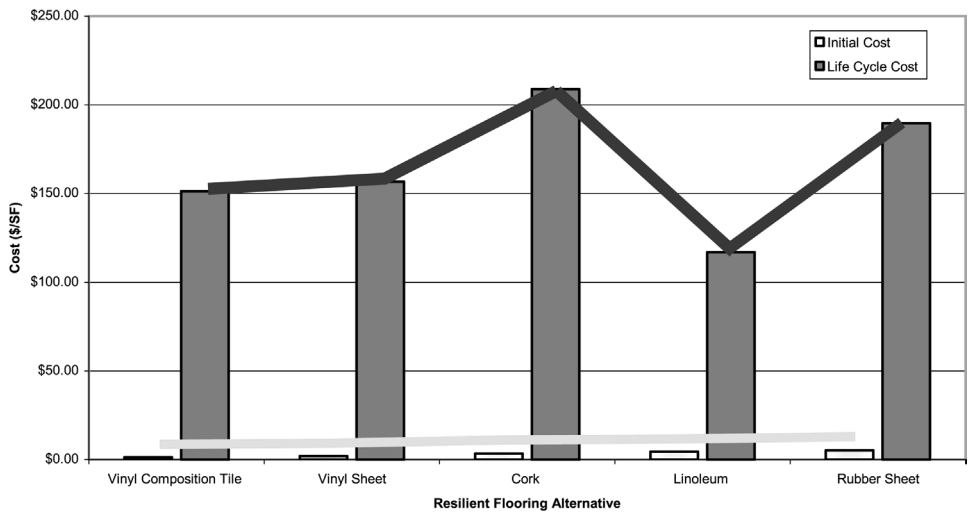


Figure 12 Initial cost versus LCC – VCT and linoleum

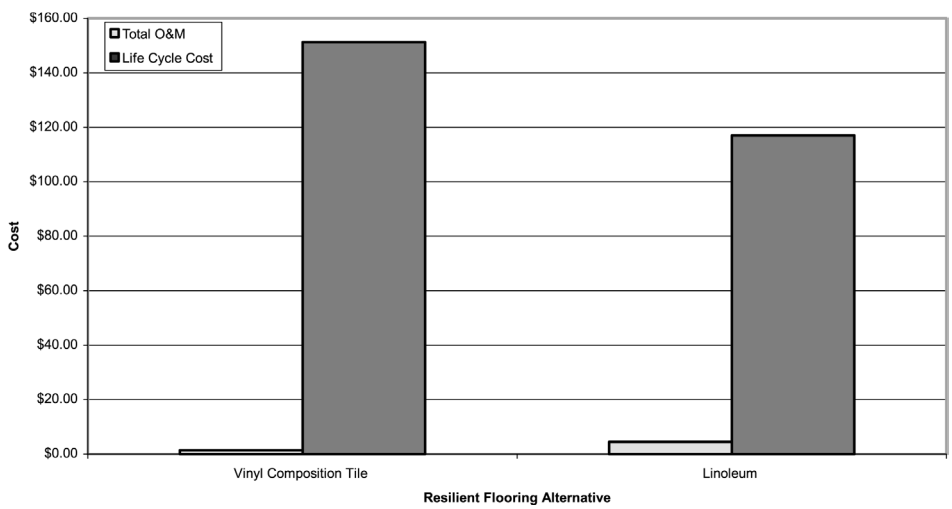


Figure 13 Increasing O&M versus life cycle cost

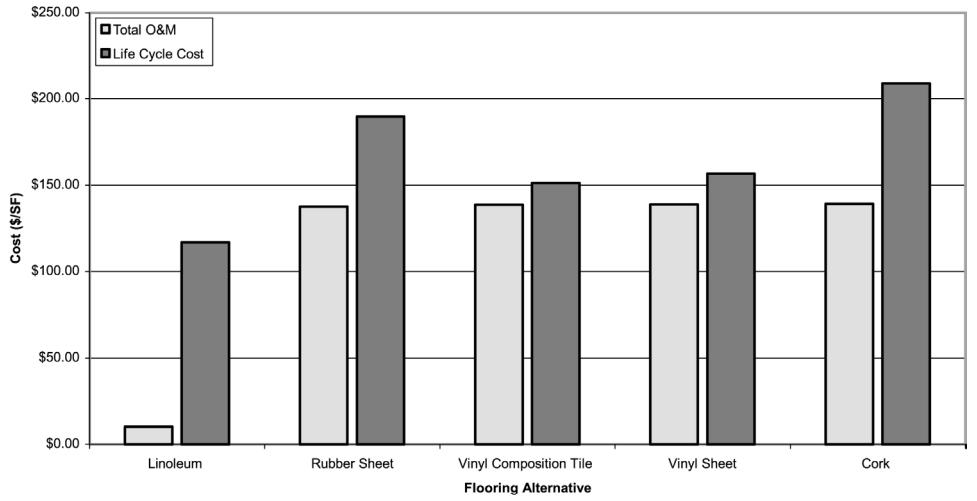
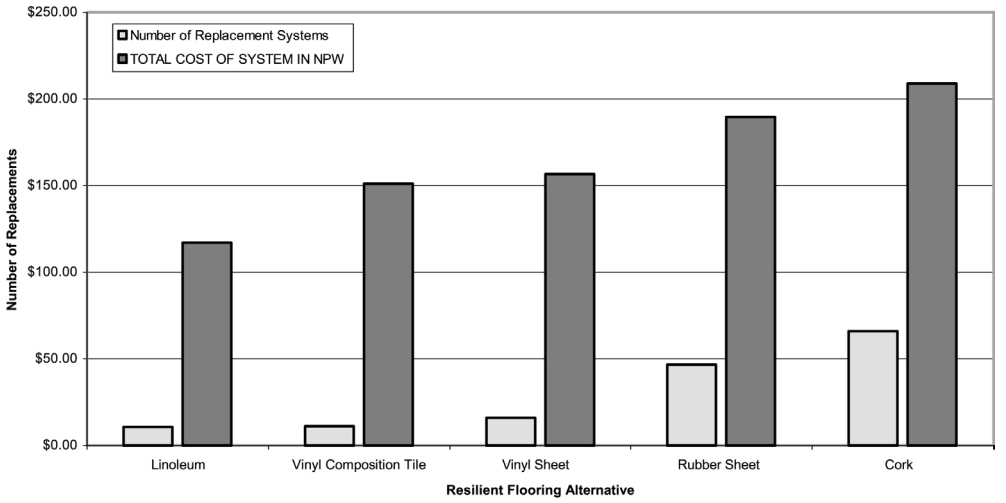


Figure 14 Increasing number of replacements and LCC



material, the fewer the replacements, the lower the total NPW of the alternative.

Soft flooring

The soft flooring alternatives for the purposes of this study are all carpet. The maintenance costs and service life are roughly equal which results in the initial cost driving the NPW among these alternatives.

Conclusion

After examination of the LCC results several important issues arose. First, the interior materials ranked as the most economical were not necessarily the ones with the lowest capital cost, confirming the initial hypothesis that lowering the initial cost of a facility – by selection of lower cost materials – will likely result in higher LCC of the facility. Second, the higher continuing costs (LCC) of the facility result from increased O&M costs, and more frequent replacement events for lower cost materials.

In addition, the study showed a particularly interesting aspect of the correlation between O&M costs and the capital cost: in some cases, such as of VCT, the O&M costs are almost equivalent to yearly replacing the system. The survey had surfaced the fact that schools funding for materials replacement tend to be easier to obtain than a budget increase to support the necessary custodial maintenance. The case studies showed that because of the low cost of replacement, Florida's school managers chose to replace rather than maintain VCT floors. This study

shows that this common practice significantly increases the SLCC of the facilities. Therefore, the SLCC assessment provides a quantifiable decision tool indicating a life-cycle preference of one building material or system over another.

There is a delicate balance of initial cost, service life, and O&M costs that must combine to create an "ideal" flooring alternative. All low initial cost alternatives will not have a high LCC, and all high initial cost alternatives will not have a low LCC. Based on this research, a correlation could not be found between the initial cost of the flooring alternatives and the resulting service LCC. Correlations were noted between an increasing NPW corresponding to a decreasing service life and increasing O&M costs. The analysis results indicate that selecting low initial cost flooring alternatives results in higher LCC. The impact of continuing costs, such as O&M costs, often outweighs the benefits of purchasing the less expensive alternative.

Recommendations

Owing to the variety of materials compared, the LCC analysis' ranking needs to be carefully analyzed during a decision-making process. High rankings do not mean the material is unacceptable for cost-effective school buildings. On the other hand, the characteristics and properties of the most cost-effective materials might not necessarily be adequate to every educational activity. The LCC ranking should be weighed equally with qualitative issues. Thus, rankings do not isolate any flooring alternative as a poor flooring choice. Rankings should be used to evaluate materials on a basis that includes service life cost in addition to initial cost.

It is important to stress the fact that the characteristics and properties of the most cost-effective materials are not necessarily adequate for the qualitative issues associated with every educational activity. The most economical set of choices for interior flooring material, for instance, is composed only of hard materials that do not have the required acoustical properties – to mention just one qualitative issue – for the optimal performance of most educational activities. In the case of interior flooring surfaces, the choice of materials must be based on a careful consideration of qualitative issues and the quantitative results of this study should be used only as partial indicators to support the decision-making process.

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