SPENCER, VIRGINIA ANN. A Comparison of Wear and Cost of Selected Wood Floor Finishes. (1967) Directed by: Dr. Jane H. Crow. Pp. 59.

Blocks of quarter-sawn, strip red oak flooring, finished with eight different wood floor finishes and a factory-finished block were field tested to determine the degree of wear of the finishes and the degree of wear under three surface conditions: unwaxed, waxed with a solvent base liquid wax, and waxed with a solvent base paste wax. A cost-performance ratio among the various finishes was developed from the wear data and costs of installation and finishing as furnished by local builders or flooring contractors.

Ten blocks were finished with each of the eight wood floor finishes, nine for testing and one control. Of those tested, three received no wax, three received solvent base paste wax, and three received solvent base liquid wax. The prefinished blocks were waxed accordingly. A randomized block design was utilized to determine the position of the test specimen within each test area which contained three blocks representing three replicates of each finish. Panels within each test area were rotated once each week and test areas were rotated every nine weeks according to a three-factor Latin square design so that in time each group received the same exposure to traffic.

The Zeiss Light-Section Microscope was utilized in measuring film thickness. Measurements were taken prior to installation in the test floor, and at the end of each complete rotation; an average film thickness of five sites was computed for each panel. After each complete rotation, the researcher visually evaluated the surface condition of each panel.

Standard analysis of variance was utilized to determine any differences in wear among the surface conditions and among finishes, and the interaction of surface conditions and finishes.

Results indicated the following conclusions: (1) wear life of wood floor finishes is significantly affected by the type of finish used, (2) surface conditions tested had no significant effect on the wear of wood floor finishes, (3) differences in appearance of the surface condition of the worn finishes are definitely apparent, (4) proper floor care including waxing, greatly enhances the appearance of the worn finishes, (5) cost and performance of the newer finishes are not superior to cost and performance of the conventional finishes, (6) the surface appearance of the wood floor finishes waxed with a solvent base paste wax is more desirable than the same finishes in an unwaxed condition but less desirable than those waxed with a solvent base liquid wax, (7) optical appearance does not seem to be an accurate estimate of degree of surface wear, and (8) choice of a wood floor finish should not be based on wear and cost alone. Other important considerations are appearance and ability of the finish to seal out dirt and grease.

A COMPARISON OF WEAR AND COST OF SELECTED WOOD FLOOR FINISHES

by

Virginia Ann Spencer

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APPROVAL SHEET

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CHAPTER I

INTRODUCTION

The application of some type of coating to wood solely for preservation and protection was first recorded in ancient times. McFadden stated that:

> Noah used natural asphalt to seal and protect his ark. The Chinese used an extract from a small tree related to our poison ivy bush and in India, Lac, an insect secretion, was used as a preservative.(1,p.V)

It was not until the middle of the 18th Century that improvements in these crude materials were made. During this period, a mixture of linseed oil and natural resins, shellac in the form of French Varnish and primitive stains made from colored earths and insect extracts were used to some extent by artisans in Europe and parts of Asia. Following these advancements, there was a lull in the finishing process until late in the 19th Century when the first true varnish was made by melting down fossil gums from Africa and India and mixing them with linseed oil. Oil stains made by mixing clay-type materials with linseed oils were introduced early in the 20th Century. These stains produced rich looking colors, but like the first true varnish, they were very slow drying.

In the early 1920's, faster drying gums were introduced and the varnish-type finish became adaptable to the accelerated production processes of the industrialized world. At this time high quality stains were produced by mixing aniline dyes with linseed oil.

The basic formula for lacquer was discovered by accident in 1923 when a workman making a batch of viscose mitrocellulose mixed some caustic soda into the material. This, being thinner than the more viscous batches, could be sprayed at a higher solids content and produced a thicker, tougher film.

Research during World War II produced data about many different plastics which the coatings industry put to use after the war. Acrylics, butyrates, epoxies, styrene, phenols, and many other materials were studied. As a result of this research, faster drying materials, materials with a catalyst added before applying which react chemically on the wood, and unbelievably tough coatings have become commonplace.

McFadden also stated that "Its been a long trip down the road of time from the asphalt of Noah's Ark to the complicated, catalyzed finishes used today."(1, p. VI) However, progress can also produce problems. With the many floor finishes available on the market today, selection becomes more difficult and information on the comparisons of wear and cost of wood floor finishes is limited.

The purpose of this study was to determine the wear and cost relationship of selected wood floor finishes.

I. THE PROBLEM

Statement of the Problem

The objectives of this study were:

1. To determine the degree of wear of selected wood floor finishes.

2. To determine the degree of wear of the selected wood floor finishes under three surface conditions: unwaxed, waxed with a solvent base liquid wax, and waxed with a solvent base paste wax.

3. To determine the cost of installing and finishing wood flooring with selected finishes and the cost of installing prefinished wood flooring.

4. To compare the cost of installing and finishing wood flooring to the cost of installing prefinished wood flooring.

5. To develop a cost-performance ratio among the various finishes.

Importance of the Study

New flooring finishes and new prefinished panels are advertised to have wearing qualities superior to the conventional finishes. Some of the newer flooring finishes cost more initially, but a cost-performance ratio is needed to determine whether or not the greater initial cost is offset by longer wear. Without this information, selection of the best wearing finish to apply to wood flooring is complicated.

In addition to the increase in the kinds and number of wood floor finishes for consumer use, many recent studies have shown that hardwood, particularly oak strip, is preferred for floors in American homes wherever conditions are suited to its use.[2]

This study of the wear and cost of selected wood floor finishes should have implications both for consumers and manufacturers regarding comparative costs of installing and finishing wood flooring and the relative wear resistance of the finishes.

This study should also provide additional information for the research on floor surfaces being conducted by the housing research area at The University of North Carolina at Greensboro.

II. DEFINITIONS OF TERMS USED

Plain Sawn

The process of sawing the log on a tangent to the annual rings which gives a "U" shaped pattern as the annual rings are exposed to the surface of the piece.[3]

Quarter-Sawn

The process of sawing the log at such an angle that the wood rays appear prominently. The annual rings appear as straight lines.[4]

Prefinished Flooring

Flooring completely finished at the factory with a penetrating seal finish made from alkyd resins designed to convert or cure by infra-red radiation.[4]

Zeiss Light-Section Microscope

A combination of two microscopes in one body: an illumination microscope which projects light from a narrow slit onto the surface to be tested at a 45-degree angle and an observation microscope, positioned at 90-degrees to the plane of incidence, to magnify the slit image in the form of a light band adapting the 45-degree profile of the test area. The eyepiece of the observation microscope is equipped with a crossline reticle that can be shifted within the field of view by a calibrated measuring drum. The drum is calibrated in microns, and its range is from one to four hundred microns.[5]

Conventional Wood Floor Finishes

Shellac. Shellac is a secretion of the coccus Lacca on the smaller branches of certain members of the fig family in India and neighboring countries. The secretion is gathered, purified, and dried in flake form. Shellac producers "cut" these flakes with alcohol in various proportions (2 pound cut = 2 pounds of shellac to 1 gallon alcohol; 3 pounds cut = 3 pounds shellac flakes to 1 gallon alcohol) to make the floor finish.[6]

Varnish. A broad term used to describe a clear (no pigment) coating comprised principally of resins, oils, plasticizers and solvents. When spread upon a surface in a thin film, varnish dries by the evaporation of its volatile constituents, by the oxidation or chemical reaction of other constituents, or partly by evaporation and partly by oxidation and chemical reaction to a continuous protective coating which may be either highly lustrous or practically devoid of luster.[6]

> Lacquer. The term Lacquer is restricted to coatings of which the characteristic ingredient is a solution of nitrocellulose or "pyroxylin" in a combination of ester, ketone and alcohol solvents. . . . Drying of a lacquer film is accomplished through the evaporation of the solvent.(7, p. 4)

> Penetrating seal. A floor seal chemically identified as a linseed oil - modified polyol, moleate, phthalate polyester reduced in an aliphatic mineral spirits solvent. It is used as a penetrant for wood substrates to increase abrasion resistance of the wood.(7, p.4)

Newer Wood Floor Finishes

> Epoxy. Epoxies are a class of resins derived from the interaction of epichlorohydrin and bisphenol. These resins are thermosetting when cured in the presence of catalysts and yield hard, tough, adherent films with good abrasion, water and alkali resistance. Combined with vegetable oil fatty acids, they yield esters which are useful in the manufacture of highly resistant, industrial finishes.(7,p.4)

Polyurethane. One of the products formed when an isocyanate reacts with a hydroxy compound. If polyfunctional compounds are used , useful polymers, polyurethanes are formed and some of these find application in the surface coating field. Polyurethane finishes contain polyisocynates and polyhydroxy compounds and, in some cases, amines which serve as catalysts and cross linking agents.[7]

Amino resin. A thermosetting-type resin finish, composed of a reaction product of an amino resin and a polyester.[8]

Vinyl. As a chemical term, "vinyl" refers to a chemical radical composed of two carbon atoms joined by unsaturated bonds capable of combining with two other atoms or similar radicals. When the word "vinyl" is used in connection with synthetic resins, it refers to polymerized vinyl-toluene or polymerized vinyl chloride plus vinyl acetate.

The resin dries in two steps. First, the solvent evaporates leaving the non-volatile resin on the surface; then, the oil present in the resin oxidizes, changing the resin from a fluid to a solid.[9]

CHAPTER II

REVIEW OF LITERATURE

Investigations comparing the wear and cost of wood floor finishes are limited. According to Martens:

> There is definitely a lack of reliable information pertaining to this subject area. Many of the finish manufacturers, as well as flooring manufacturers, have data on the wearability of their particular products but these are generally found to be conflicting.[10]

Bruhn concurred that almost every major producer of wood floor finishes has conducted extensive tests of the wear resistance of their materials. Most of these tests have been on their own products and evaluations are not a matter of public knowledge.[11]

This review of literature includes the available studies concerned with the wearability of specific wood floor finishes, some of the techniques and instruments used to measure film thickness, and characteristics and comparisons of selected wood floor finishes and their cost.

I. STUDIES OF THE WEARABILITY OF WOOD FLOOR FINISHES

An indication of the importance of a floor finish was obtained by the United States Department of Agriculture Forest Service in a study of flooring use in houses with concrete slab subfloors. Of 347 homeowner respondents, thirty-six per cent stated that they were dissatisfied with their hardwood floors. The finish was one of the leading sources of complaints, some of which were the finish was too dull, it did not wear well and it was improperly applied.

Based on observations from that study, factors that may affect cost of flooring materials and/or the cost of installing wood floors are as follows:

1. The species, type, size, and grade of flooring used. The great bulk of hardwood flooring is oak. Plain sawn, strip flooring, 25/32-inch x 2 1/4 inches is the most commonly used type and size of oak flooring. Select grade, the "second best" grade, is most often used in houses.

2. Source of supply. Flooring may be purchased from retail building material dealers, flooring dealers, wholesalers, or directly from the manufacturer. Also the price will likely vary with the volume purchased.

3. Whether unfinished or prefinished flooring is used.

4. The supply-demand situation. If slumps occur in the home-building industry, a reduction in the price of flooring may result because of a reduced demand.

5. The type of subfloor used. Strip floors cost more to install over concrete slabs than over wood frame floor systems because slab construction requires more materials and takes more time.

6. The size of the job. Sizes of floor installation jobs vary from one room to an entire house, to apartment buildings with thousands of square feet of floor area.

7. The price of the house. Generally there is less emphasis on cost and more emphasis on quality of workmanship in higher priced and custom built houses than in lower priced and speculative houses.

8. Labor used to install the floor. Floor subcontractors are apt to be more experienced and better equipped to do the job than the builder's own crew.

9. Whether prefinished or unfinished flooring is used. The higher price of prefinished flooring is generally offset by savings in time and labor of installation. Quality of workmanship and type of finish applied affect the cost of job-applied finishes. Experience from this study indicated that better job applied finishes would significantly increase homeowner satisfaction with wood floors.[12]

The William Zinsser Company investigated the wear and color-fast qualities of four floor finishes - lacquer, penetrating seal, oil-modified polyurethane, and an amino-resin finish. Seven panels, each 22 x 22 inches, of standard oak or maple flooring, were finished in accordance with the manufacturer's instructions. The panels were installed in a fourteen foot narrow corridor leading from the street into the Zinsser factory. The passage was subjected to more severe traffic than the usual exposure to wear in the home. Each day the location of the panels was changed so as to expose each one to the same wear conditions. Results of this investigation showed that lacquer and penetrating seal did not compare with amino-resin with respect to wear. Although the wear in the tests was no doubt in excess of that in a home, the few months of testing served to represent prolonged wear under home conditions. The urethane finish wore equally as well as amino-resin, but because of its gloss, it tended to show scratches more and it tended to darken.[13]

According to Hart, urethane has made floor finishing worthwhile. In tests conducted at Chatham Manufacturing Company, ten foot stretches of a main traffic alley were finished with different type finishes. After four days of wear, the differences began to show; and after two months, all but the urethane finish showed signs of breaking down. As a result of this test, the Chatham Company applied a urethane floor finish on its 390,000 square feet of wooden floors. With the wood dressed to the desired smoothness, the first coat was applied and allowed to dry eight hours. It was then sanded with fine sand paper to give "tooth" for adherence of the second coat. The finish was hard enough to stand

up under a shoe heel without scuffing, was more lustrous, clearer, and freer from lint than anything previously used on the plant floors. It was indifferent to oil, had bonded well, and gave off no odor.[14]

Findings of a twenty-six month test of a urethane finish on hard maple flooring in production areas of the Brown and Williamson Tobacco Corporation's plant at Petersburg, Virginia, indicated that the urethane finish dried faster under humid conditions, showed no darkening with age, was relatively easy to refinish without resanding, had greater resistance to dirt and chemicals, and gave two and one half to four times longer life than previously used materials. All these factors resulted in substantial cost-saving per square foot per year. On a typical 12,000 square foot area, the total initial installation cost (sanding, nailsetting, vacuuming, materials and labor) of the urethane finish was 13.3 cents per square foot.[15]

A paper presented at the Forest Research Annual Meeting in 1960, reported research on wood finishes to increase the performance of the coating. At that time, floor finishing products usually utilized one of three types of materials: shellac, varnish and alkyds, or lacquer. Products containing shellac were cited as fast drying, easy to repair, and having an excellent appearance. Varnishes and alkyds were characterized as drying by an oxidative-polymerization process. These products reportedly have good durability but require longer drying time than other finish types. Lacquer materials were mentioned as widely accepted, especially in the refinishing field. Present research has taken different approaches. One approach to the improvement of floor finishes

is through chemical modification or the use of additives. Specifically, oils modified with urethanes or epoxies have resulted in products having faster drying time and better resistance to chemicals and wear. Another approach is through the development of new materials or the use of new concepts in application and formulation of the products. Presently the two areas of this research are the use of a two part system and a study of emulsion or water-dilutable clear finishes on wood.[16]

II. INSTRUMENTS AND TECHNIQUES USED TO MEASURE FILM THICKNESS

Both destructive and nondestructive instruments and techniques have been used to measure the thickness of transparent coatings. In the nondestructive techniques different magnetic and eddy-current types of instruments have been used. Among these are the Filmeter and Dermitron, but these have a general functional requirement that limits their application to coatings on metallic substrates. Nondestructive optical techniques have also been used to measure coating thicknesses up to three mils.[17] An accurate and convenient method for measuring film thicknesses of paint films while still attached to the substrate is possible with the Zeiss Optical Slit Microscope. This instrument can be used to measure film thicknesses of paints on any substrate, but it is most useful for paints on nonmagnetic materials. Calibration is accurate from one to four hundred microns. The microscope measures surface roughness and thickness of transparent or opaque coatings and films without coming into contact with or damaging the sample.

The measuring technique consists of projecting a thin razor-like strip of light at a 45 degree angle upon the surface to be inspected. This band of light, which traces out the profile of the surface, is viewed through the microscope at a 90 degree angle.

Measurements are made by moving the reticle, visible in the eyepiece, to the peaks and valleys of the profile by means of a measuring drum calibrated in microns.[5] The microscope was calibrated by measuring known depths. To obtain known depths, a smooth piece of metal was milled to different thicknesses in steps and the depth of each step was measured with a micrometer.

> Profiles of solid, non-transparent surfaces are measured and cross-section areas calculated by tracing the configuration of the light band. When surfaces which have been coated with a lacquer, or thin films are measured, two lines . . . are visible in the eyepiece. This happens because both the top surface of the coating or layer and the surface beneath it reflect light. The distance between the two bands of light indicates the thickness of the film.[18]

III. CHARACTERISTICS AND COMPARISONS OF SELECTED WOOD FLOOR FINISHES

Selecting a finish for wood floors is not as simple as it once was. Previously one bought either shellac or paint and that was it. This is no longer true. Today, there are so many products to choose that the only way to make a wise choice is to know, beforehand, what one's requirements are and which of the several standard floor finishes will come closest to meeting them.

According to Hand, a good finish should seal out dirt and grease, resist stains, and be reasonably easy to patch. It should not scratch, chip or flake off, require excessive care or change colors materially.

Other points to consider in choosing a finish are appearance, cost, and ease of application.[19]

Whether one wants a high gloss, a soft satin finish, or something in between depends on one's aesthetic values. There are indications that gloss is disappearing from residential floors. A major reason for this is that people are learning to dislike the garish shine that shows blemishes so readily.[20]

Finishes vary greatly in price. A bargain product could indicate stinting on important ingredients. On the other hand, one may not need the toughest, most expensive finish.[21]

Basically, there are two types of materials to choose, penetrating seals or surface finishes. The latter includes shellac, varnishes, and other synthetic coatings.

Because of the importance of choosing a wood floor finish that meets the individual's needs, the following section is included to compare the properties of selected wood floor finishes.

Penetrating Seal

Penetrating materials are actually thin varnishes made with slow-drying oils or with specially controlled drying properties that allow them to work well into the pores of the wood. On hardwoods, a good quality seal covered by a high grade wax produces a floor that is almost indestructible. In appearance, it has a modest gloss instead of a mirror shine.[19]

Penetrating seal is easy to apply as it takes little skill to brush on a coat, let it soak in, and then wipe off the excess.[20] Routine maintenance consists of regular waxing to keep a good protective coat on the surface.

Since it is in the wood, the seal cannot chip or flake off and scratching and marring are negligible. With some seals, the floor retains a bright, natural wood tone. Others produce a richer color.[19]

Hand also stated that penetrating seals ". . . have always been the best wearing finish, and have only to overcome yesteryear's love for a shiny floor to become today's favorite."[20]

Shellac

Shellac is the oldest, cheapest, and fastest drying of the surface finishes. Vast quantities are used on floors and its quick-drying property has helped it maintain its popularity as a much-used floor finish. While manufacturers of shellac maintain that high-quality shellac is as tough as other finishes, others contend that shellac is not as abrasion-resistant as varnish or synthetic coatings. Waxing extends the life of shellacked floors and prevents water stains.

To obtain the best results with shellac it should be less than six months old; used as a four-or-five pound "cut" and diluted, one part to one, with denatured alcohol; kept in a closed glass jar; applied only on dry days, as moisture can cause clouding; and applied in three coats at 24-hour intervals, allowing the last coat to dry a full day. Shellac is easier to patch than varnish. A light sanding is enough preparation for a new coat if the old finish is not worn to the bare wood.[20]

Varnish

Varnish comes in different grades and types. Spar varnishes, the orthodox type, are a mixture of gum and oil heated together. The alkyd-resins, developed since 1930, are related to auto enamels.[20] A third type, phenolic, is often used to finish gymnasium floors. This type is non-slippery, does not show rubber burns, and is durable. Floor varnishes are available in several degrees of gloss, but the high gloss is more wear-resistant.[22] Varnish is a good, long-wearing material under relatively gentle use; however, it scratches white, does not resist hard abrasion, and should not be used where there is heavy abuse.[20] Varnish holds up much longer when waxed. Without wax however, it resists water, alcohol, and acid stains.

Varnish is more difficult to work with than shellac. Because it undergoes a slow chemical change while drying, it hardens more slowly, thus increasing the possibility of dust marking. Finish testers for the Maple Flooring Manufacturer's Association stress the necessity of allowing each coat to harden for at least 24 hours. Egner of the New York Woodfinishing Supply Company stated that "It's the only way to get durability and a really fine shine."[20]

Lacquer

Lacquer is deposited on floor surfaces by the evaporation of a solvent. Although it gives a hard, glossy finish, the sheen is generally not as high as that of shellac or varnish unless several coats are applied. Some lacquers are harder to apply than varnish as skill is needed to move fast enough to avoid lap marks, However, the major problem is fire

danger, due to lacquer's highly volatile solvents. The best lacquer will eventually show scratches in wear areas, although it is hard and highly impervious to water, acid, and dirt.[19]

Polyurethane

Toughness and abrasion and chemical resistance are the outstanding characteristics of the polyurethane coatings. However, three major limitations with the two-package systems are short pot life, pigmentation problems, and toxicity.

A polyurethane finish, properly formulated, produced, handled, and applied, gives a clear finish on wood so tough that marring the finish is almost impossible. In Taber Abrasion Tests, polyurethanes showed from two to twenty times better wear resistance than conventional finishes.[23]

This floor finish also has excellent water and detergent resistance. In one test, a mahogany panel coated with urethane floor varnish was immersed in water for twenty-six months. At the end of this time, it showed no blistering, softening, whitening, lifting, or loss of film gloss.

Because a urethane dries with such a hard finish, care must be taken when applying a urethane over itself. Thorough sanding between coats is necessary to provide a good "tooth" for the next application.[24]

Hand further maintained that ". . . from the standpoint of wear, the best on-the-surface material is moisture-cured urethane."[20] The surface gloss is similar to that of varnish, with good color, and only

slightly yellowing. A major disadvantage associated with some solvents is toxic vapors.

Epoxy

At a Paint and Wallpaper Association of America Workshop entitled, "The New Coatings," panelists agreed that, while chemically different from polyurethane, epoxy displays some of the same physical qualities. It is a hard coating but not as hard as polyurethane, and it generally adheres better than polyurethane.

The panel members maintained that the oil-modified epoxies are not much superior to conventional finishes, but the two component epoxies have many desirable qualities. Also, the panelists warned that the epoxy coatings require caution in use, particularly in that the second coat must be applied within time limits to avoid lifting. Neslage stated that the adhesion of epoxy is better than that of polyurethane but not as good as conventional oleo-resinous varnishes.[25]

Epoxies are not as clear as the urethane varnishes, but they are less likely to darken with age when used indoors. Both epoxies and urethanes are made in high-gloss and semi-gloss finishes. These new finishes are quick-drying (two to four hours). However, the last coat needs from 7 to 15 days for full curing. To attain a proper cure and maximum hardness, the solvents must evaporate thoroughly. Unless there is adequate ventilation, the heavier than air solvent vapors tend to remain suspended over the surface. This can result in a sticky film and a soft finish susceptible to peeling and rapid wear.[24]

Amino-Resin

In the article, "What's the Best Finish," Hand ranked the two part amino-resin coating second.[20] It consists of a base varnish and a separate chemical hardener. After the hardener is added, amino-resin has a pot life of at least six months. This is one of the quick-drying materials, since it dries dust-free in fifteen minutes. Tests indicate that two coats give an exceptionally durable floor finish that will out-wear practically all conventional floor varnishes and floor lacquers. In addition, it is resistant to chemicals. The amino-type varnish is very clear and will not darken or yellow with age.[20]

Vinyl

The vinyl-type wood finishes have the drying speed of lacquer and also a few of its disadvantages. In most cases, they dry within fifteen minutes and can be sanded and recoated in approximately two hours. Vinyl has no offensive odor. It is very clear and requires no special thinner. One important limitation is low abrasion resistance.[34] Other limitations include low resistance to some chemicals and solvents and a requirement of several coats to build up a high finish because of its relatively thin film.[20]

Costs of Finishes

The newer finishes usually cost more than a conventional varnish. Hand states that a regular clear varnish may still be the best except for those applications that need the extra toughness or chemical resistance that some of the newer finishes provide.

Two-part epoxy coatings are the most expensive, a gallon costing from $18 to $22. Most of the better-quality urethane finishes sell for $10 to $12 a gallon. The vinyl-type coatings cost less than either lacquer or the urethane and epoxy finishes; usually $6 to $7 a gallon. The cost of amino-resin is similar to that of epoxy; both approximately $7.50 a gallon.[20]

Prefinished Flooring

Prefinished flooring is available in an increasing number of styles and colors, and in many cases it is cheaper than flooring finished on the job.[20] It is finished at the factory with a smooth, hard surface that can outlast a brushed-on finish applied on the job.[36] In prefinished flooring the grades are prime, standard and better, standard, and tavern.[27]

IV. USE OF STRIP OAK FLOORING IN RESIDENTIAL CONSTRUCTION

Production statistics of the National Lumber Manufacturers' Association for 1959 through 1962 indicated that about 91 per cent of all hardwood flooring used in the building industry was red or white oak.[28] Due to its distinctive and attractive appearance, durability, availability, and relatively low-cost oak has long been the favored flooring material for living rooms, dining rooms, bedrooms, and hallways in American homes.[28] A Forest Service survey of wood used in single-family houses inspected by the Federal Housing Authority in 1962 revealed that 93.1 per cent of the houses built over crawl-space or basement had hardwood strip or

block flooring as the principal finish flooring material in living rooms, dining rooms and bedrooms.[28]

Wood flooring comes in four main types: strip, plank, parquet, and block. Strip flooring, the most widely used type, is generally the most economical. It is produced in several standard widths and thicknesses. That most commonly used is 25/32-inch by 2-1/4 inches tongue-and groove with matching ends that lock together to make a completely integral floor.[26]

Standard grades of flooring are based almost completely on appearance. They exclude or limit such defects as knots, wormholes, and the like in the higher grades and permit increasing sizes and numbers of these characteristics in the lower grades. Natural variations in color are generally not limited except that, in certain grades, the amount of lighter colored sapwood is restricted.[29]

The National Oak Flooring Manufacturers' Association has established the following specifications for tongue-and-grooved strip flooring: Clear--practically clear face with 3/8-inch of bright sap, average length 4-1/4 feet; Select-face contains imperfections as small streaks, pinworm holes, and burls averaging not more than one every three feet, average length 3-3/4 feet; No. 1 Common--face contains varying imperfections as heavy streaks, worm holes and knots, average length 3 feet; No. 2 Common--contains sound natural variations and manufacturing imperfections, average length 2-1/2 feet; and 1-1/4 Foot Shorts--pieces ranging from 9 to 18 inches in length but averaging 15 inches.[30]

Some twenty species of white and red oak are made into flooring.[7] In quality and utility little difference exists between red and white oak. Even in appearance, they are similar; both are light in color. White oak has a brownish tinge, while red oak has a pink cast that usually turns reddish brown when a finish is applied.[8]

Oak is manufactured into plain sawn and quarter sawn flooring. Plain sawn, the lower priced of the two, is the most extensively used. Quarter sawn oak is characterized by a rather striking figure and by a minimum shrinking and swelling in width.[9]

CHAPTER III

EXPERIMENTAL PROCEDURE

This chapter includes a discussion of the following:

Selection and preparation of test panels.

Selection and application of specific wood floor finishes.

Selection, application, and removal of wood floor waxes.

Field testing procedure.

Data collection and analysis.

I. SELECTION AND PREPARATION OF TEST PANELS

Blocks of 9 x 9-inch, red oak, quarter sawn, tongue-and-grooved strip flooring, 25/32-inch x 2-1/4 inches, select grade were purchased for this study. Although quarter sawn flooring is not as extensively used as plain sawn, it was chosen for this study upon a recommendation from the School of Forestry at North Carolina State University at Raleigh because of its more equal distribution of summer and winter growth.

Before applying the finish, a wide belt sanding process was used to sand each test sample uniformly.

Prefinished flooring blocks of identical construction were also purchased for testing.

II. SELECTION AND APPLICATION OF SPECIFIC WOOD FLOOR FINISHES

According to the National Oak Flooring Manufacturers' Association, the ideal qualities of a finish for hardwood floors are attractive appearance, durability, ease of maintenance, and capacity of being retouched in worn spots without revealing a patched appearance.[30]

Selection and Application of Wood Floor Finishes

A survey was made of the paint and hardware stores in the Greensboro, North Carolina area to determine the types of wood floor finishes available. Eight types available on the local market selected for testing were: a gloss varnish, shellac, lacquer, penetrating seal, epoxy, polyurethane, vinyl, and amino resin. One finish of each type was chosen according to the solids content. The School of Forestry staff at North Carolina State University at Raleigh suggested the use of finishes with comparable solids content; therefore, the highest solids content of each type finish was selected for this study. According to one source, "The percentage of solids in a material is an indication of the build or thickness of the dry film that the material gives.[31] The eight finishes represented products of six manufacturers. A table of random numbers was used in assigning finishes to the test panels. Finish application in each case was in accordance with the directions prescribed by the specific manufacturer.

III. SELECTION, APPLICATION, AND REMOVAL OF WOOD FLOOR WAXES

Selection of Waxes

The wood floor waxes used in this study were a solvent-base paste wax and a self-polishing solvent-base liquid wax. One brand of each type was selected from the local market based on its high volume of sales as reported by retail personnel.

Application and Removal of Waxes

The procedure recommended in the American Society for Testing Materials Designation: D1436-56T was used in applying the liquid floor wax.[32] The area of the test panel (81 square inches) was determined and the volume of wax needed to provide approximately 0.1 ml. of liquid wax for each four square inches of surface was calculated (2 ml. for 81 square inches). The required amount of liquid wax was pipeted onto the test panel. A two-inch strip cheesecloth pad weighing 0.60 grams was used to distribute the wax evenly over the surface. The used cheesecloth was placed in a ground-glass stoppered weighing bottle and weighed on a 100-gram balance. The net weight of the used, wet applicator was calculated and recorded. To insure a constant film thickness, the weight of the spent applicators could not vary more than 0.15 grams. If the weight variation exceeded 0.15 grams, the floor wax was stripped from the test panel and re-waxed.[33]

The same procedure was used to apply the paste wax to the test panels with the exception of the volume of wax. An amount comparable by weight to the liquid wax was distributed over each test panel. The wax

was allowed to dry and then each test panel was buffed with an electric floor polisher.

The method recommended by Shamburger[7] for cleaning and stripping the test panels of wax was followed. A solution of one part detergent and one part ammonia to six parts of water was applied with a sponge and allowed to stand for a few minutes. The floor materials were scrubbed, rinsed, and then thoroughly dried.

IV. FIELD TESTING PROCEDURE

Eight types of wood floor finishes applied according to manufacturers' recommendations, to 9 x 9 inch flooring blocks constructed of four 25/32 inch x 2-1/4 inch strips of quarter-sawn red oak flooring and one type of identical prefinished strip oak flooring were tested. Three of the 9 x 9 inch flooring blocks were finished with each of the eight finishes. Of the three blocks tested, one received no wax, one received solvent-base paste wax and one received self-polishing liquid wax. The prefinished blocks were waxed accordingly. Specimen were installed in a test floor in a corridor of the Home Economics Building at The University of North Carolina at Greensboro, where they were exposed to foot traffic.

The floor, consisting of three separate test areas, contained finished flooring specimen in the three surface conditions: unwaxed, waxed with a self-polishing liquid wax, and waxed with a solvent-base paste wax. In order to eliminate any wax carry-over to the individual test areas, the areas were separated by four rows of identical 9 x 9 inch

flooring blocks not included in the study. Each area contained three blocks representing three replicates of each finish-surface condition. A total of 81 blocks was tested. A randomized block design was used to determine the position of the test specimen within the test area. The initial position of the specimen within the block was also randomized. Once a week each test panel was rotated so that each specimen would be in each position in the block for an equal length of time. When the rotation of each test specimen within each block was completed, the test areas were rotated according to a three-factor Latin square design so that each group received the same exposure to traffic. The rotation of the test specimen in each block was repeated for each location. An illustration of the test floor is included in Appendix A.

The test floor was vacuumed daily and dry mopped weekly with a dust mop treated with a transparent, non-staining mixture of aromatic chemicals. The waxed specimen were stripped every nine weeks and rewaxed while the unwaxed specimen were damp mopped.

A wall-mounted photoelectric counter was used to record daily the number of persons walking on the test floor.

V. DATA COLLECTION AND ANALYSIS

Film Thickness Measurements

Eight film thickness measurements were taken at random locations on each newly finished 9 x 9 inch test panel. The Zeiss Light-Section Microscope was utilized in measuring film thickness. Average film thicknesses were computed for each test panel from the eight film thickness measurements. At the end of one complete rotation, eight film

thickness measurements were again taken on each of the worn 9 x 9-inch test panels and mean thickness computed.

Standard analyses of variance were used in analyzing the data with advice and assistance from the Department of Experimental Statistics, North Carolina State University. The analyses were computed on an IBM 360 computer according to the following model:

Source of Variation	Degrees of Freedom
Surface condition	2
Groups/surface conditions	6
Finishes	8
Surface condition x finish	16
Finish x groups/surface conditions	48

The statistical analysis included an evaluation of three factors for each of the eight wood floor finishes and of the prefinished samples:

1. The differences among the surface conditions (unwaxed, waxed with a self-polishing liquid wax and waxed with a paste wax).
2. The differences among finishes.
3. The interaction of surface conditions and finishes.

Cost Determination

A questionnaire was devised to secure information needed to determine the cost per square foot of installing and finishing wood flooring with selected finishes and the cost per square foot of installing prefinished wood flooring. This questionnaire was sent to all construction firms and flooring contractors in the Greensboro, North Carolina area associated with residential building who agreed to participate.

Cost per square foot of installing and finishing wood flooring with selected finishes and the cost per square foot of installing prefinished wood flooring were classified according to the following categories:

Type of contractor
Kinds of dwelling units built or floored
Volume of building or flooring
Price range of dwelling units built or floored
Construction or installation methods
Source of supply

Cost-Performance

A cost-performance ratio was developed for each finish tested and a comparison of the cost-performance ratio among the various finishes was made.

The hypotheses tested in the study were:

1. There is no difference in the degree of wear among the selected wood floor finishes.

2. There is no difference in the degree of wear of selected wood floor finishes when unwaxed, waxed with a solvent base liquid wax, and waxed with a solvent base paste wax.

3. There is no difference in the cost of installing and finishing wood flooring and the cost of installing prefinished wood flooring.

4. There is no difference in the cost-performance ratio for each floor finish.

CHAPTER IV

DATA INTERPRETATION AND ANALYSIS

Results and interpretation of a field test for wear of selected wood floor finishes applied to 9 x 9-inch, quarter sawn, red oak flooring blocks and one type of identical prefinished strip oak flooring are presented in this chapter. The specimen, installed in a test floor in a corridor of the Home Economics Building, were subjected to foot traffic for twenty-seven weeks (one complete rotation). An average of 325 people walked on the test floor daily.

Also presented in this chapter are data and discussion of results for the cost of installing and finishing strip oak flooring and the cost of installing prefinished strip oak flooring. Data analysis and interpretation are presented under three headings: surface conditions, floor finishes, and cost.

I. SURFACE CONDITIONS

The finished flooring panels were tested under three surface conditions: unwaxed, waxed with a solvent base liquid wax, and waxed with a solvent base paste wax. Analysis of variance showed no significant difference among surface conditions with respect to wear of the finishes (Table I). Total mean difference in surface film thickness, before and after twenty-seven weeks of wear, for the unwaxed surfaces was 12.28 microns, for the liquid wax group 11.20 microns, and 12.04

TABLE I

ANALYSIS OF VARIANCE FOR FILM THICKNESS

Variance source	Degrees of freedom	Sum of squares	Mean squares	F value
Corrected total	80	923.286762	11.541085	
Surface condition	2	17.367358	8.683679	2.04
Groups/surface condition	6	21.438246	3.573041	1.00
Finishes	8	612.292140	76.536517	18.00*
Surface condition x finishes	16	68.142703	4.258919	1.00
Groups x finishes/ surface condition	48	204.046316	4.250965	

*Significant at .01 level.

microns for the paste wax specimen (Table II). This led to retention of the null hypothesis that there is no difference in the degree of wear of selected wood floor finishes under the three surface conditions. Percentage of wear was computed for each finish in each surface condition (Table III). When the percentages were compared, all finishes waxed with a self polishing, solvent base liquid wax, with the exception of vinyl, lacquer, and penetrating seal, showed less wear than those finishes with no wax or those waxed with a solvent base paste wax. Lacquer showed least wear when no wax was applied. Only two finishes, vinyl and penetrating seal, showed less wear when waxed with a solvent base paste wax.

Although there was no significant difference among surface conditions with respect to wear of the floor finishes, appearance as evaluated by the researcher, was affected. Those specimen waxed with a solvent base liquid wax appeared to have the least wear and the least soil adherence of the three surface conditions tested. Also, fewer scratches were visible on these specimen.

After twenty-seven weeks of testing, the appearance of the finishes waxed with a solvent base, paste wax was less desirable than the same finishes waxed with a solvent base liquid wax, but more desirable than those unwaxed. Soil adherence, visible scratches and apparent wear were more marked on the unwaxed and paste waxed blocks than on the blocks with liquid wax.

Visible scratches was the most evident factor differentiating the appearance of finishes waxed with a solvent base paste wax and those with no wax; those with no wax appeared more scratched.

TABLE II

MEAN FILM THICKNESS MEASUREMENTS IN MICRONS OF NEW AND WORN FINISHES UNDER THREE SURFACE CONDITIONS

Finishes		Unwaxed		Mean	Liquid		Mean	Paste		Mean
		New	Worn	difference	New	Worn	difference	New	Worn	difference
NEWER FINISHES										
Amino resin	1	22.86	15.03		24.63	15.31		23.35	14.10	
	2	25.34	11.91		23.28	15.88		23.88	14.02	
	3	22.64	14.72		25.77	15.57		25.60	15.28	
		23.61	13.89	9.72	24.56	15.59	8.97	24.28	14.47	9.81
Epoxy	1	30.35	17.42		27.43	14.68		27.73	15.02	
	2	28.51	18.70		28.06	14.91		27.55	14.43	
	3	30.31	14.21		27.91	16.77		28.66	15.68	
		29.72	16.78	12.94	27.80	15.45	12.35	27.98	15.04	12.94
Polyurethane	1	29.15	18.79		35.59	24.38		34.80	22.76	
	2	34.65	20.06		34.38	24.36		36.75	22.99	
	3	31.85	19.22		33.85	23.84		31.54	21.71	
		31.88	19.36	12.52	34.61	24.16	10.45	34.36	22.49	11.87
Vinyl	1	31.81	18.24		30.59	18.91		32.78	22.73	
	2	29.30	16.06		30.05	21.48		31.53	22.63	
	3	30.36	21.13		27.01	16.90		30.65	21.09	
		30.49	18.48	12.01	29.22	19.10	10.12	31.65	22.15	9.50
CONVENTIONAL FINISHES										
Lacquer	1	41.71	34.55		41.35	27.58		43.49	30.03	
	2	43.21	32.59		45.36	32.49		44.15	26.86	
	3	43.75	28.48		45.68	34.26		42.84	29.08	
		42.89	31.87	11.02	44.13	31.44	12.69	43.49	28.66	14.83

Table II (Continued)

Finishes		Unwaxed		Mean	Liquid		Mean	Paste		Mean
		New	Worn	difference	New	Worn	difference	New	Worn	difference
Shellac	1	25.62	13.61		29.05	16.40		26.33	11.77	
	2	30.50	15.55		28.30	20.45		26.35	14.21	
	3	29.58	17.31		30.58	16.66		29.16	18.50	
		28.57	15.49	13.08	29.31	17.84	11.47	27.28	14.83	12.45
Varnish	1	39.55	26.30		42.08	31.33		38.50	26.00	
	2	42.86	30.98		37.98	26.58		41.30	27.50	
	3	40.10	24.58		40.05	27.30		41.87	22.62	
		40.84	27.29	13.55	40.04	28.40	11.64	40.56	25.37	15.19
Penetrating seal										
	1	19.76	10.59		17.48	9.81		18.56	13.29	
	2	19.94	13.65		17.74	10.68		17.79	12.79	
	3	20.22	12.96		18.29	12.51		19.94	10.43	
		19.97	12.40	7.57	17.84	11.00	6.84	18.76	12.17	6.59
PREFINISHED	1	19.82	00.00		17.33	00.00		12.72	00.00	
	2	20.23	00.00		18.55	00.00		15.72	00.00	
	3	18.22	00.00		16.06	00.00		17.30	00.00	
		19.42	00.00	19.42	17.31	00.00	17.31	15.25		15.25
Total		267.38	155.56	12.43	264.82	162.98	11.32	263.61	155.18	11.65

TABLE III

PER CENT WEAR IN FILM THICKNESS OF FINISHES AFTER 27 WEEKS

Finishes	Surface condition			Mean
	Unwaxed	Liquid	Paste	
Newer				
Amino resin	41	37	40	39
Epoxy	44	44	46	45
Polyurethane	39	30	35	35
Vinyl	37	31	30	33
Mean	41	36	37	38
Conventional				
Lacquer	26	29	34	30
Shellac	46	39	46	44
Varnish	33	29	37	33
Penetrating seal	38	38	35	37
Mean	34	32	38	36
Prefinished*	100	100	100	100

*Surface wear only.

There was a marked difference in the appearance of the floor finishes before cleaning and rewaxing and after cleaning and rewaxing. After removing the old wax and rewaxing the specimen at equal intervals, the surface appearance of all the finishes tested was greatly enhanced.

II. FLOOR FINISHES

There was a highly significant F ratio for degree of wear among floor finishes as reported in Table I. Among the applied finishes, lacquer showed the lowest mean percentage of wear under all surface conditions (30%) while shellac and epoxy showed the highest mean percentage of wear under all surface conditions (44% and 45%) as shown in Table III. The prefinished or factory finished specimen showed the greatest mean percentage of wear under all surface conditions (100%) of any finish tested. Since the prefinished sample was treated with a penetrating seal finish, it was concluded that the film thickness measurement was not an accurate measure of the total performance of this specimen and the prefinished specimen has been eliminated from subsequent discussion. Vinyl and varnish showed the same mean percentage of wear under all surface conditions (33%) while the mean percentage of wear under all surface conditions for polyurethane, penetrating seal, and amino resin was 35%, 37%, and 39% respectively. When the newer finishes were compared to the conventional finishes there was little difference in mean percentage of overall wear, 38% and 36% respectively.

When mean percentages for wear were compared among the finishes under the three surface conditions, differences were evident. The newer

finishes in an unwaxed condition wore most (41%), while conventional finishes treated with a solvent base, liquid wax showed least wear (32%).

The results of this study do not agree with results of the Zinsser, Chatham, and Brown and Williamson studies of the wear resistance of wood floor finishes. Zinsser found that lacquer and penetrating seal did not wear as well as amino resin, but that polyurethane wore equally as well as amino resin. Findings of tests at Chatham and Brown and Williamson indicated polyurethane had the longest wear life of any finish tested. In this study, lacquer had the lowest mean percentage of wear under all surface conditions (30%) of all finishes tested. Polyurethane, penetrating seal, and amino resin wore less well, in the order listed.

At nine week intervals during the twenty-seven week testing period, the researcher visually evaluated the surface appearance of each finish. A marked difference was observed in the appearance of the finishes after wear. The oak flooring blocks finished with lacquer and vinyl had the least desirable appearance of the finishes tested. The poor appearance of vinyl was primarily due to the extreme adherence of dirt and soil and low abrasion resistance. This finding agreed with Hand that one important limitation of vinyl is its low abrasion resistance.[20] Those blocks finished with lacquer scratched white with wear, attracted soil, and appeared worn. From the standpoint of appearance, lacquer was unacceptable as a wood floor finish. Since lacquer had the lowest percentage of wear (30%) of any finish tested, wear life of this finish and its appearance seem to be inversely related. Therefore, surface thickness was not indicative of total wear of a floor finish.

Polyurethane showed little wear, soil adherence, and visible scratching. This finding agreed with McGinnis[27] who maintained that toughness and abrasion resistance are among polyurethane's outstanding characteristics.

Penetrating seal maintained a good appearance under each surface condition during the twenty-seven weeks of wear. Since this finish penetrates the wood, the film thickness measurement may not be a complete evaluation of its performance. Scratches and mars were not prominent, which concurred with Hand's findings.[19] However, those specimen finished with penetrating seal and waxed with the solvent base liquid wax were observed to be superior in appearance to those waxed with a solvent base paste wax and those unwaxed. The latter two surface conditions had more scratches and scuff marks than did the liquid waxed specimen.

Shellac's mean percentage of wear was 44 per cent during the testing period. This was one of the higher percentages of wear for the finishes tested. Also during the testing period, scratches were visible and shellac showed an affinity for soil and dirt, especially on the unwaxed and the paste waxed specimen. This finding was in accord with Hand's statement that shellac is not as abrasion-resistant as varnish and synthetic coatings. The review of literature indicated that wax extends the life of shellacked floors. In this study, shellacked oak flooring in unwaxed and paste waxed conditions wore 46 per cent after twenty-seven weeks of service. However, those specimen waxed with a solvent base liquid wax wore only 39 per cent. As a result of these

findings it appeared that the use of a solvent base liquid wax prolongs the life of shellacked floors.

Varnish rated second to least in wear (33 per cent). Its appearance was "fair" to "good." The varnished surfaces appeared worn and scratched and there was some soil adherence on the unwaxed and paste waxed specimen. These signs of wear were not as visible on those samples waxed with a solvent base liquid wax. Literature described varnish as holding up longer when waxed. In this study, the specimen waxed with a solvent base liquid wax wore only 29 per cent as compared to 33 per cent for the unwaxed specimen and 37 per cent for the specimen waxed with a solvent base paste wax.

Amino-resin rated fifth in percentage of wear (39 per cent). However, it maintained an excellent appearance under each surface condition during the twenty-seven week test period. The only visible difference between the worn samples and the control was in gloss retention. The control had more gloss than the worn blocks. Hand rated amino resin as the "second best" finish and one that would out-wear practically all the conventional finishes. Evaluation of appearance of amino-resin in this study concurred with Hand.

Epoxy wore the most of any finish tested (44 per cent). However, the appearance of the liquid waxed specimen was "good" while the paste waxed and unwaxed flooring blocks rated "fair." There was some soil adherence and scratching, but neither was extreme.

III. COST

Literature indicated that several factors may affect the cost of installing and finishing wood floors. A questionnaire related to these factors was sent to all building and flooring subcontractors in the Greensboro, North Carolina area who agreed to participate in this study. Data are presented in Appendix B.

Description of Respondents

Building and flooring contractors participating in the study indicated the greatest concentration of activity in custom and speculative built houses with the least concentration in FHA low cost housing and commercial buildings. The number of units built or floored in 1966 ranged from 5 to 388, costing from under $12,000 to $100,000. The $12,000 to $19,000 range was modal. Only one respondent reported construction costs under $12,000; these were apartment units.

Cost Factors

Factors reported to affect cost of installing and finishing wood flooring were number and type of houses built or floored, price of the house, type labor used, source of supply, size of the job, type flooring used, and the supply-demand situation. It was thought that the larger the job the lower the cost of flooring installation. Generally in higher priced and custom-built houses there is less emphasis on installed cost and more emphasis on quality of workmanship than in lower priced and speculative houses. In this study, none of these factors seemed to affect the cost of installing and finishing wood floors.

Floor Finishes Utilized and Their Cost

Respondents reported almost an exclusive use of varnish, penetrating seal, and polyurethane floor finishes. No builder or floor finisher reported using an epoxy finish.

Building contractor's cost per square foot for job applied finishes varied from 41-1/2¢ (varnish) to 65¢ (polyurethane). Cost of the same finish varied among the builders: polyurethane 52¢ - 65¢, varnish 41-1/2¢ - 52¢, and penetrating seal 48¢ - 55¢.

The floor finisher's cost for finishing strip oak floors also differed. The cost of finishing a floor with varnish varied from 10¢ to 15¢. The cost per square foot most often charged for finishing a floor with a conventional finish was 12¢ while more of the floors finished with a newer type finish cost 16¢ per square foot. The cost per square foot for installing prefinished strip oak flooring varied from 50¢ to $1.00.

Cost Comparison of Prefinished and Unfinished Flooring

The mean cost for installing and finishing strip oak flooring was 51¢ per square foot as compared to 58¢ per square foot for installing prefinished strip oak flooring treated with a penetrating seal finish. Literature stated that the higher price of prefinished flooring was generally offset by savings in time and labor of installing and finishing unfinished strip oak flooring. It was also reported that the cost of job-applied finishes varied with quality of workmanship and type of finish applied. The findings from this study showed that the cost for

furnishing, installing and finishing strip oak flooring were less than the cost for furnishing and installing prefinished strip oak flooring. The cost per square foot for installing and finishing strip oak flooring with selected finishes varied from 41-1/2¢ to 65¢; therefore the type of finish used affected cost. The quality of workmanship, proper sanding, filling, and application of finishes were not evaluated. However, these were recognized as important factors in the wear-life of a particular finish.

Cost and Performance of Selected Wood Floor Finishes

Data on the comparison of wear and cost of each wood floor finish tested is presented in Table IV. After twenty-seven weeks of testing, the mean percentage of wear under all surface conditions was least for lacquer (30 per cent) and greatest for epoxy (45 per cent).

Based on the mean per cent of wear for the 27 week test period and assuming that subsequent wear would be at the same rate as initial wear, a projected length of time for total wear to occur was calculated:

	Weeks
Newer Finishes	
Amino resin	69.2
Epoxy	60.0
Polyurethane	77.1
Vinyl	81.8
Mean	72.0
Conventional Finishes	
Lacquer	90.0
Shellac	61.4
Varnish	81.8
Penetrating seal	72.9
Mean	76.5

TABLE IV

COMPARISON OF WEAR AND COST OF FLOOR FINISHES

Floor finishes	Mean per cent of wear	Mean cost per square foot	
		Install and finish	Finish
Newer			
Amino resin	39		$ .16
Epoxy	45		
Polyurethane	35	$ .57	.16
Vinyl	33		.16
Conventional			
Lacquer	30	.50	
Shellac	44	.50	.12
Varnish	33	.47	.12
Penetrating seal	37	.52	.14

According to projected length of time for total wear to occur, lacquer appeared to have the longest wear life (90 weeks) and epoxy the shortest (60 weeks). The mean projected total wear life for the conventional finishes was 76.5 weeks as compared to 72.0 weeks for the newer finishes.

Utilizing the installation and/or finishing cost data for red oak, strip flooring furnished by the building and flooring contractors and the projected total wear periods, the cost of each finish per week of wear was calculated:

Builders		Floor Finishers	
Lacquer	$.0056	Lacquer	$.0013
Varnish	.0057	Varnish	.0014
Penetrating seal	.0071	Penetrating seal	.0019
Polyurethane	.0074	Vinyl	.0020
Shellac	.0081	Polyurethane	.0021
		Amino resin	.0023

On this basis, lacquer would cost less per week of projected total wear than any finish tested; varnish would rate next in cost; shellac and amino resin would have the highest cost per week of projected total wear.

When cost and performance of the selected wood floor finishes were compared, the mean performance (in relation to wear) of the conventional finishes was better than the mean performance of the newer finishes. Also, with the exception of shellac, they wore longer and at a cheaper projected cost per week of wear. This does not agree with advertising that the newer flooring finishes have wearing qualities superior to the conventional finishes.

According to Hand,[19] a good finish should seal out dirt and grease and resist stains. It should not scratch, chip or flake off, or require excessive care. Also, appearance should be considered. When these criteria are added to cost and wear-life, the choice of a wood floor finish becomes multi-faceted. In this study, lacquer and vinyl had excellent projected wear-life (90.0 and 81.8 weeks respectively), but their appearance was unacceptable because of scratching and affinity for soil. Varnish rated second in wear (81.8 weeks) and second in cost per week of wear. Amino-resin rated sixth in projected wear-life (69.2 weeks) and it was the most expensive finish per week of projected wear; however, its appearance was excellent. It appears, therefore, that cost and overall performance of a wood floor finish are not proportionately related.

CHAPTER V

SUMMARY, CONCLUSIONS, AND RECOMMENDATIONS

I. SUMMARY

Manufacturers of wood floor finishes, producers of wood flooring materials and organizations concerned with use of wood as a building material, as well as the American consumer, have expressed a need for reliable information on the comparative cost of installing and finishing wood flooring and on the relative wear resistance of the finishes.

Evidence in literature revealed limited exploration in this field and generally it was confined to manufacturers of wood floor finishes.

This comparative study of the wear and cost of selected wood floor finishes was a part of a larger project entitled, "Wearability and Relative Cost of Wood Floor Finishes," which contributes to the Southern Regional Housing Project S-54.

Objectives of this study were:

1. To determine the degree of wear of selected wood floor finishes.
2. To determine the degree of wear of the selected wood floor finishes under three surface conditions: unwaxed, waxed with solvent base liquid wax, and waxed with a solvent base paste wax.
3. To determine the cost of installing and finishing wood flooring with selected finishes and the cost of installing prefinished flooring.

4. To compare the cost of installing and finishing wood flooring to the cost of installing prefinished wood flooring.

5. To develop a cost-performance ratio for each floor finish and to compare the cost performance ratio among the various finishes.

Blocks of 9 x 9 inch, red oak, quarter sawn, strip oak flooring in the standard pattern were used as panels.

Eight wood floor finishes were selected for testing: a gloss varnish, shellac, lacquer, penetrating seal, epoxy, polyurethane, vinyl, and amino resin. One finish of each type was chosen with respect to solids content. One prefinished flooring sample was also tested.

Wood floor waxes used in this study were a solvent base paste wax and a self polishing solvent base liquid wax.

Ten 9 x 9 inch flooring blocks were finished with each of the eight wood floor finishes, nine for testing and one control. Of the nine blocks tested, three received no wax, three received solvent base paste wax, and three received solvent base liquid wax. The prefinished blocks were waxed accordingly. A total of 81 blocks were tested. Prior to installing the specimen in a test floor to be exposed to foot traffic, eight film thickness measurements were taken at random locations on each of the 9 x 9 inch test panels. The Zeiss Light-Section Microscope was utilized in measuring film thickness. An average film thickness for each panel was computed from the eight measurements.

The test floor, consisting of three separate test areas, contained finished flooring specimen in three surface conditions: unwaxed, waxed with a self polishing, solvent base liquid wax, and waxed with a solvent base paste wax. Each test area contained three blocks represent-

ing three replicates of each finish. A randomized block design was used to determine the position of the test specimen within the test area.

Once a week each test panel was rotated so that each specimen was in each position in the block for an equal length of time. When the rotation of each test specimen within each block was completed, the test areas were rotated according to a three-factor Latin square design so that in time each group received the same exposure to traffic.

At the end of one complete rotation, eight film thickness measurements were again taken on each of the worn 9 x 9 inch test panels and means computed.

Standard analysis of variance was used in analyzing the data. The statistical analysis included an evaluation of three factors for each of the eight wood floor finishes and of the prefinished samples:

1. The differences among the surface conditions - unwaxed, waxed with a self-polishing, solvent base liquid wax, and waxed with a solvent base paste wax.
2. The differences among finishes.
3. The interaction of surface conditions and finishes.

A questionnaire was devised to secure information needed to determine the cost per square foot of installing and finishing wood flooring with selected finishes and the cost per square foot of installing prefinished wood flooring. This questionnaire was sent to all construction firms and flooring contractors in the Greensboro, North Carolina area who agreed to participate in the study.

At nine week intervals during the twenty-seven week testing period, the researcher visually evaluated the surface appearance of each finish.

Surface Condition

The finished flooring blocks were tested under three surface conditions - unwaxed, waxed with a solvent base paste wax, and waxed with a self polishing, solvent base liquid wax. Analysis of variance showed no significant differences among surface conditions with respect to wear of the finishes. Therefore, the null hypothesis that there is no difference in the degree of wear of selected wood floor finishes under the three surface conditions was retained. Although there was no significant difference among surface conditions with respect to wear of the floor finishes, appearance was affected. Those specimen waxed with a solvent base liquid wax appeared to have the least wear and the least soil adherence of the three surface conditions tested. Also, fewer scratches were visible on these specimen.

Floor Finishes

The statistical analysis of data showed a highly significant F ratio for degree of wear among the floor finishes tested. The null hypothesis that there is no difference in the degree of wear among the selected wood floor finishes was therefore rejected. Of the applied finishes, lacquer showed the lowest mean percentage of wear under all surface conditions while shellac and epoxy showed the highest mean percentage of wear. The prefinished sample showed the greatest mean percentage of wear of any finish tested. Since this sample was treated with a penetrating finish, it was concluded that measurement of film thickness was not an adequate evaluation of the performance of this finish. Therefore, the prefinished sample was deleted from the wear comparison conclusions.

Differences were apparent when percentages were compared for wear of the finishes under the three surface conditions. The newer finishes in an unwaxed condition wore most, while conventional finishes treated with the solvent-base liquid wax wore least.

Assuming that subsequent wear would be at the same rate as initial wear and using the twenty-seven week testing period as a base, a projected length of time for total wear to occur was calculated. Lacquer had the longest wear life at the cheapest cost per week of projected wear and epoxy the shortest. No cost figures were available for epoxy. Amino resin and shellac cost most per week of projected total wear. Therefore, the null hypothesis that there is no difference in the cost-performance ratio for each floor finish was rejected.

Cost

The cost per square foot for installing and finishing strip oak flooring with selected finishes varied from 41-1/2 to 65 cents while the cost per square foot for installing prefinished strip oak flooring varied from 50 cents to one dollar. The mean cost for installing and finishing strip oak flooring was 51 cents per square foot as compared to 58 cents per square foot for installing prefinished flooring with a penetrating finish. These findings led to the rejection of the null hypothesis that there is no difference in the cost of installing and finishing wood flooring and the cost of installing prefinished wood flooring.

II. CONCLUSIONS

The following conclusions were drawn as a result of this study:

1. There was a difference in wear life of the eight wood floor finishes tested. Under all surface conditions, lacquer generally had the longest projected wear life and epoxy the shortest.

2. The surface condition had no significant effect on the wear of wood floor finishes. Based on this result, self polishing, solvent base liquid wax, solvent base paste wax, or no wax could be used with the same results in wear.

3. There were definite differences in the appearance of the surface condition of the worn finishes tested. Generally, amino resin showed the fewest scratches, mars, and the least affinity for soil; the appearance of lacquer and vinyl was the least desirable.

4. Proper floor care including waxing, greatly enhanced the appearance of the worn finishes.

5. Cost and performance qualities of the newer floor finishes were not superior to the cost and performance of the conventional finishes.

6. The appearance of the wood floor finishes waxed with a solvent base paste wax was more desirable than the same finishes in an unwaxed condition but less desirable than those waxed with a self-polishing solvent base liquid wax.

7. The choice of a wood floor finish should not be based on wear and cost alone. Other important considerations are appearance and ability of the finish to seal out dirt and grease.

8. Optical appearance does not seem to be an accurate estimate of degree of surface wear. The finish which cost the least and wore the longest, based on per week of projected wear (lacquer), was the least desirable finish in appearance after exposure to traffic.

III. RECOMMENDATIONS

The following recommendations for further study are made with respect to the results of this investigation:

1. The study be continued until the actual wear life of the finishes can be calculated.

2. A more extensive study of the wear and cost relationship of wood floor finishes be conducted under various environmental conditions: varied heat conditions, and wear as it is affected by oil, water, and/or grit.

3. In future studies, the test floor be subjected to foot traffic more representative of a home situation - traffic of men, women, and children.

4. A comparative study be made between wear, cost, and appearance of each commonly used finish and by groups - conventional and newer wood floor finishes.

5. Plain sawn flooring be used in a study of the cost and wearability of wood floor finishes, since this type flooring is most commonly used.

6. In future studies, more replicates of each finish be used in order to obtain more valid results.

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REFERENCES

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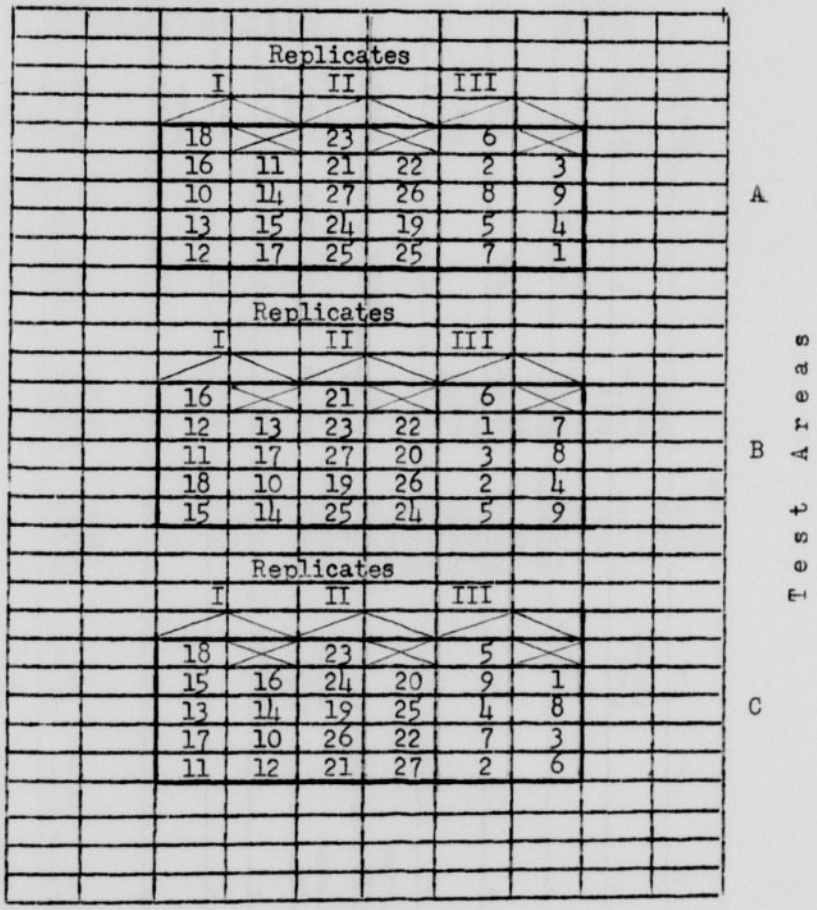
APPENDIX

APPENDIX A

TEST FLOOR SHOWING RANDOM DISTRIBUTION OF SPECIMEN, REPLICATES, AND TEST AREAS



APPENDIX B

FACTORS AFFECTING COST OF INSTALLING AND FINISHING WOOD FLOORS

Respondent	Type and number units built or floored		Price range	Labor used: Strip-oak Install	Labor used: Strip-oak Finish	Labor used: Prefinished install	Source of material: Strip-oak	Source of material: Prefinished	Grade of plain sawn flooring	Filler & stain use	Finish used	Cost/sq ft	Cost/sq ft for installed prefinished flooring
A[1]	Custom and speculative	31	$ 30,000-$100,000	Builder's crew	Floor finisher	Builder's crew	Building material dealer	Building material dealer	Select and clear	Often[3] Rarely[4]	Polyurethane Varnish Penetrating seal Lacquer	.52 .50 .51 .50	$ .75 - 1.00
B[1]	Custom	6	20,000-29,999	"	"		"	N.A.	Select	Rarely[3] Never[4]	Varnish Penetrating seal	.15	N.A.
C[1]	Speculative	4	12,000-19,999	"	"		"	N.A.	"	Never	Varnish Lignophol	.12½ .12½	N.A.
D[1]	Custom built Apartments	5 5	50,000-100,000	"	"	Builder's crew	"	N.A.	"	Rarely[3] Often[4]	Penetrating seal	.48-.55	.65- .70
E[1]	FHA low cost housing Apartments	388 72	12,000-19,999	Floor finisher	"	Floor finisher	Flooring distributor & dealer	Flooring sub-contractor	No. 1 common & clear	Often[3] Rarely[4]	Lignaphol	.45	.50
F[1]	Apartment units		Under 12,000	Floor finisher	"		Flooring manu-facturer	N.A.	Select	Rarely[3&4]	Polyurethane	.65	.62
G[1]	Custom built	60	12,000-19,999	"	"	"	Building material dealer	Building material dealer	"	Often[3] Rarely[4]	Varnish	.43	N.A.
H[1]	Speculative or tract		"	"	"	"	Flooring sub-contractor	Flooring sub-contractor	N.A.	N.A.	N.A.	N.A.	N.A.
I[1]	Custom built	10	30,000-49,999	"	"	Builder's crew	Building material dealer	Building material dealer	Select and clear	No[3] Often[4]	Penetrating seal Polyurethane	.55 .55	.60
J[1]	Speculative or tract	300	12,000-49,999	"	"	Floor finisher	Flooring manu-facturer	Flooring manu-facturer	"	Often[3&4]	Varnish	.41½	.50
K[1]	N.A.		N.A.	N.A.	N.A.	N.A.	Flooring sub-contractor			Rarely[3&4]	"	.52	.50

[1]Building contractor

[2]Flooring contractor or finisher

[3]Use of filler

[4]Use of stain

N.A. = Information not available

APPENDIX B

FACTORS AFFECTING COST OF INSTALLING AND FINISHING WOOD FLOORS

Respondent	Type and number units built or floored		Price range	Labor used: Strip-oak Install	Labor used: Strip-oak Finish	Labor used: Prefinished install	Source of material: Strip-oak	Source of material: Prefinished	Grade of plain sawn flooring	Filler & stain use	Finish used	cost/sq ft	Cost/sq ft for installed prefinished flooring
A[1]	Custom and speculative	31	$ 30,000-$100,000	Builder's crew	Floor finisher	Builder's crew	Building material dealer	Building material dealer	Select and clear	Often[3] Rarely[4]	Polyurethane Varnish Penetrating seal Lacquer	.52 .50 .51 .50	$ .75 - 1.00
B[1]	Custom	6	20,000-29,999	"	"		"	N.A.	Select	Rarely[3] Never[4]	Varnish Penetrating seal	.15	N.A.
C[1]	Speculative	4	12,000-19,999	"	"		"	N.A.	"	Never	Varnish Lignophol	.12½ .12½	N.A.
D[1]	Custom built Apartments	5 5	50,000-100,000	"	"	Builder's crew	"	N.A.	"	Rarely[3] Often[4]	Penetrating seal	.48-.55	.65-.70
E[1]	FHA low cost housing Apartments	388 72	12,000-19,999	Floor finisher	"	Floor finisher	Flooring distributor & dealer	Flooring sub-contractor	No. 1 common & clear	Often[3] Rarely[4]	Lignaphol	.45	.50
F[1]	Apartment units		Under 12,000	Floor finisher	"		Flooring manufacturer	N.A.	Select	Rarely[3&4]	Polyurethane	.65	.62
G[1]	Custom built	60	12,000-19,999	"	"	"	Building material dealer	Building material dealer	"	Often[3] Rarely[4]	Varnish	.43	N.A.
H[1]	Speculative or tract		"	"	"	"	Flooring sub-contractor	Flooring sub-contractor	N.A.	N.A.	N.A.	N.A.	N.A.
I[1]	Custom built	10	30,000-49,999	"	"	Builder's crew	Building material dealer	Building material dealer	Select and clear	No[3] Often[4]	Penetrating seal Polyurethane	.55 .55	.60
J[1]	Speculative or tract	300	12,000-49,999	"	"	Floor finisher	Flooring manufacturer	Flooring manufacturer	"	Often[3&4]	Varnish	.41½	.50
K[1]	N.A.		N.A.	N.A.	N.A.	N.A.	Flooring sub-contractor			Rarely[3&4]	"	.52	.50

[1]Building contractor

[2]Flooring contractor or finisher

[3]Use of filler

[4]Use of stain

N.A. = Information not available

APPENDIX C

TYPE OF FINISHES USED ON RED OAK STRIP FLOORING

(Number of building contractors and floor finishers responding)

Finish	Number of users
Varnish	8
Shellac	1
Penetrating seal	6
Lacquer	1
Epoxy	
Amino resin	
Vinyl	1
Polyurethane	7
Other	
Lignophol	2