THE CENTER FOR HEALTH DESIGN®

Achieving EBD Goals through Flooring Selection & Design

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Tandus Flooring creates innovative floorcovering solutions through our unique product line of hybrid resilient, modular, broadloom and woven products that work in tandem to enhance spaces for learning, working, healing and living. Through inspired design and leading-edge technology, Tandus Flooring offers its customers a single-source for innovative product design and technology, comprehensive services, and environmental leadership. For more than 40 years, Tandus Flooring has been examining all the ways to be a better corporate citizen and environmental steward — and then taking actions that lead to demonstrable, meaningful, quantifiable results.

About The Center for Health Design

The Center for Health Design (CHD) formed in 1993, is a nonprofit research, education, and advocacy organization of forward-thinking healthcare, elder care, design and construction professionals, and product manufacturers who are leading the quest to improve the quality of healthcare facilities and create new environments for healthy aging. The CHD Research Coalition promotes the dissemination of evidence-based design research that contributes to therapeutic, safe, efficient, and effective healthcare settings. The group is comprised of experienced researchers, design practitioners, and healthcare administrators. They help develop requests for proposals, select appropriate teams to conduct each research study, monitor the progress of research studies, and critique the drafts of the final reports.

CHD's Research Coalition funds exist to support cutting edge research in evidence-based design (EBD) that fills critical gaps in the field. Also, by rewarding funds to EBD research, the group strives to grow the network of researchers who are engaged in EBD. All research studies funded by the Research Coalition are put through a peer-review process.

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Published by The Center for Health Design
www.healthdesign.org

How to cite this paper:
Nanda, U., Malone, E., and Joseph, A. (2012). Achieving EBD Goals through Flooring Selection & Design. Concord, CA: The Center for Health Design.

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Keywords: Floorcoverings, Flooring, Performance Characteristics, Evidence-based Design, Health Outcomes

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Executive Summary

Flooring sets the stage for all healthcare activities. It contributes to a first impression as people enter and move about a healthcare facility, shaping their opinions about the organization's ability to provide safe, quality and comfortable care. Flooring is a complex, integrated system that consists of the sub-floor for support and the floorcovering and surface finish, which together create the walking and rolling surface for a vast range of care delivery activities and equipment. Contributing both to the building's structural integrity and healing aesthetic, flooring occupies every square inch of measured healthcare facility space, providing a major lifecycle investment opportunity to help realize positive healthcare outcomes, especially those now linked to healthcare reimbursement through the enactment of the 2010 Patient Protection and Affordable Care Act.

In this paper, research findings, industry standards and best practices related to floorcoverings, the floor's most visible component that provides the final walking surface, were examined. Using an evidence-based design approach, how flooring/floorcoverings can contribute to the following performance improvement goals were explored:

1. Reduce slips, trips and falls
2. Reduce patient and staff injuries associated with falls
3. Reduce noise levels
4. Reduce staff fatigue
5. Reduce surface contamination and potential risk of Healthcare-Associated Infections (HAI)
6. Improve Indoor Air Quality (IAQ)
7. Improve patient and family satisfaction
8. Represent the best return on investment

A surprisingly small, but compelling body of knowledge was found that revealed how flooring could impact healthcare outcomes, which is summarized for each of the goals above, distilling the findings into a list of performance characteristics for floorcoverings (Table 1). It was learned that there are trade-offs associated with each desired performance characteristic that may conflict with other EBD goals; these trade-offs are annotated in the list. Finally, the density of the evidence for each goal was qualified, noting whether the source of the information was peer-reviewed research (r), industry standards (s), or best practice articles (p), to facilitate the evaluation process. Where evidence is missing the case for urgent research is made, providing a list of recommended topics. The key insights from the literature review provide a road map for flooring design and selection and can be summarized as follows:

1. **Understand evidence-limitations**. The level of evidence is limited due to the lack of standards, lack of replication of lab-base studies in real life settings, lack of commonly used metrics and tools for data collection, absence of a reporting process that tracks extrinsic factors (such as flooring conditions) alongside the outcomes of interest (such as falls), and the challenge of changing flooring conditions due to maintenance issues regarding cleaning and surface coating. A great deal of the research was conducted in a laboratory setting, not in the complex healthcare delivery environment with endless intervening variables. Once a flooring is installed, there can be many changes in surface conditions due to variation in cleaning protocols, different surface finishing products (such as wax), and the wear and tear over time, which make it challenging to study flooring comprehensively. Additionally the challenge is that while flooring has been a component of some of the health outcome focused research, it has been part of a "bundled" approach (for example studies on sound may look at all the surface finishes, or simply old vs. renovated rooms). In such studies the presence of too many confounding variables makes it difficult to isolate the impact of flooring. Finally, there is a lack of understanding about tools and metrics available to test flooring characteristics, which is compounded by the lack of industry standards regarding floor performance as well as human performance (ergonomics). The business case for flooring has not been made beyond comparison of lifecycle costs to rigorously evaluating the impact flooring can have on health outcomes and how that is translated to return on investment (ROI). The evidence limitations suggest that it is premature to compare flooring types in their entirety and make decisions about design. There is no evidence to support the selection of a specific flooring type as the ideal across the healthcare facility.

2. **Focus on the characteristics for each individual flooring product**. Within the industry's broad flooring categories – Hard/Soft/Resilient – there is a significant variation in the characteristics of the products found within each. With new technology and advances in material sciences the lines between these broad categories is getting blurred. The evidence favoring one broad category of flooring over the other is inconclusive. Rather than using a generalized flooring category, the design team must evaluate individual products based on their performance against each EBD goal before deciding on the right flooring material and design for a particular area.

3. **Consider the trade-offs for each product.** In aiming for desired healthcare outcomes, trade-offs need to be considered during flooring selection. A one-size-fits-all approach cannot be used to select flooring types since different flooring characteristics and properties impact different outcomes. For example a harder floor can reduce staff fatigue associated with pushing heavy equipment whereas a softer floor can reduce staff fatigue associated with extended period of standing. Each product should be analyzed for its individual properties, which can then be evaluated in the context of desired outcomes for a particular healthcare space, carefully weighing the trade-offs associated with each option.

4. **Use a flooring-system approach.** Flooring is an integrated system that consists of the sub-floor for support, and the floorcovering and surface finish that create the walking surface. Additionally, careful consideration has to be paid to adhesives, underlays and surface treatments. Any decisions regarding floorcoverings must also consider how the system comes together, and works together over time as an integrated system.

The recommendations in this paper are not specific to type of healthcare organization (long-term care, acute-care, outpatient care etc.), or within specific areas found within an organization (inpatient room, procedure room, waiting room, OR etc.). Each area in a healthcare organization has a unique flooring requirement based on the clinical mission, the population served, the team caring for them and the equipment used. By emphasizing EBD goals, the findings can be used by designers to prioritize the goals that are most important for a specific area, and/or organization, and identify a list floorcovering properties and characteristics best suited to achieve these outcomes. Rather than offering a prescription for floorcovering selection, instead an evidence-based tool that designers can use to inform their design decisions is provided.

These findings represent the first step in a journey to better understand how floorcoverings contribute as an important, but often unconsidered, design element in the achievement of desired healthcare outcomes. This limited evidence has been translated into an evidence-based list of performance characteristics for floorcoverings that can be used to evaluate different floorcovering types in support of facility lifecycle activities. This list now needs to be tested for clarity, usefulness and practicality by its intended users – the multidisciplinary members of the design team - to create a tool that can aid design decision making based upon the best available evidence.

Many research opportunities for healthcare interdisciplinary, industry and academic teams to collaborate and expand the science, in order to further our understanding, have been identified. In spite of the crucial role flooring can and does play, the attention it has received in research is minimal and this need to be remedied in an initiative that has industry, academia, and research-practitioners working side by side to create research projects. In addition to more focused research, more attention is needed to the development of floorcovering standards specific to the complex, healthcare environment. Floorcoverings are more than just the stage for the healthcare experience, something upon which to walk or move equipment or even just an expensive surface to purchase and maintain, but that rather, floorcoverings are an important piece of the quality care puzzle.

An Annotated Evidence-Based List for the Performance Characteristics of Floorcoverings

The following is a list of performance characteristics for flooring/floorcoverings organized thematically under eight evidence-based design goals. The left column provides the source for information identified as peer-reviewed research (r), industry standards (s), or from best practice (p). The middle column provides the performance characteristics based on the literature review. The right column provides space to assess these characteristics as Present (P), Absent (A), Not Applicable (NA), or Cannot be Determined (?).

Trade-offs associated with each characteristic (which may conflict with other EBD goals), along with additional insights, are annotated in the list and should be carefully considered.

1	REDUCE SLIPS, TRIPS, AND FALLS	P/A/?/NA
s	Flooring material is stable, firm, and slip resistant* (ADAAG - U.S. Dept. of Justice, 2010).	
s	In areas where spillage is likely (like bathrooms, suites, sink areas, lab areas, etc.) flooring is impermeable, easily cleaned and textured (OSHA, 2003; NHS - Healey, 2007).	
p	Depending on flooring type, flooring is tested for optimal performance under different conditions (wet/dry/greasy).	
r	Contrast in flooring patterns is low (Perritt et al., 2005; Calkins, 2012).**	
r	Finish has low reflectance value to prevent glare (Wilmott, 1986; Dvorsky, 2007).	
s	Flooring thresholds are less than ¼ inch vertical, or between ¼” & ½ inch, beveled (ADAAG, 2010).	
s	If carpet is used, pile height is 1/2 inch (13 mm) maximum (ADAAG, 2010).	
s	Exposed edges of carpet are fastened to floor surfaces and have trim on the entire length of the exposed edge (ADAAG, 2010).	
p	Joints and seams are minimized to ensure that sharp edged objects like walking sticks or heels do not cause trips.	
p	Area rugs, walk off mats at building entry and floor mats, if used, have beveled edges and are firmly anchored to facilitate ADA transition guidelines.	
p	Appropriate finishes and cleaning procedures are used in accordance with standards and manufacturer recommendations.***	
OVERALL LEVEL OF EVIDENCE LINKING FLOORING PROPERTIES TO SLIPS, TRIPS AND FALLS		*LOW*
RESEARCH NEEDED LEVEL		*URGENT*

*Note that increasing slip resistance through textured finish can create maintenance/ cleanability issues. These must be balanced during the selection of the flooring. Also note that a standard for COF is not available right now because slip-resistance can vary from surface to surface, or even on the same surface, depending upon surface conditions and employee footwear (OSHA, 2003). The industry norm is between 0.5 and 0.6.

**Note that high contrast patterns may be used for way finding in public areas where patients are not unaccompanied. Also, patterns pose a larger concern for older populations and are used more commonly in pediatric settings. More research is needed on the effect of contrast on age.

*** Note that the floor finish is the final contact surface. Finishing products and cleaning protocols can significantly impact the performance of the floor in terms of slips and trips.

2	REDUCE PATIENT AND STAFF INJURIES ASSOCIATED WITH FALLS	P/A/?/NA
r	Floor has a balance of energy-absorbent properties (to absorb the force of impact that causes injury) and firmness (to reduce the risk of falling due to poor balance) (Wright, 2011; Redfern, 2000).*	
r	If rigid materials are used, then underlays can be used to provide adequate cushioning to reduce the impact of the fall (Laing, 2009; Sran & Robinoviych, 2008).**	
OVERALL LEVEL OF EVIDENCE LINKING FLOOR FINISH TO TRIPS AND FALLS		*MEDIUM*
RESEARCH NEEDED LEVEL		*HIGH*

*Note that impact due to a fall can depend on the sub-floor, underlay, as well as the floorcovering material. While deciding on the impact on injuries, make sure you consider the property of the entire flooring system.
**Make sure the underlay does not create an increase in effort for mobility (see EBD Goal 4).

3	REDUCE NOISE LEVELS	P/A/?/NA
p	Flooring with high footfall noise (such as corridors) should have high sound absorbing properties and low sound transmitting properties while accommodating roller mobility and balance.	
s	The floor finish and the sub-floor structure in healthcare facilities should mitigate noise levels transmitted by an impact in an adjacent space, such as footfall or cart rolling (GG Technical Report, 2007).	
p	Resilient/acoustic underlays should be used to lessen footfall and other traffic noise, for floorcoverings with low IIC.	
OVERALL LEVEL OF EVIDENCE LINKING FLOOR PROPERTIES TO NOISE LEVELS		*MEDIUM*
RESEARCH NEEDED LEVEL		*URGENT*

Note that there is no evidence that currently links flooring property to reduction of airborne sounds. The acoustical benefit of flooring is primarily on impact noise reduction. Standards are currently lacking on ideal NRC levels since these differ greatly between different flooring materials.

4	REDUCE STAFF FATIGUE	P/A/?/NA
r	Provide more cushioning for areas that require standing for extended periods of time. For areas where infection control is a key issue (such as OR), non-porous/impermeable flooring materials should be used with anti-fatigue mats to provide cushioning where surgeons/staff stand for long durations. If anti-fatigue mats are used, surface should have an anti-skid finish and edges should be tapered to reduce risk of trips (Hughes, 2011).*	
p	Cushioning properties should be balanced with roller mobility for walking areas used for equipment transfer (Gray, 2009).**	
p	Greater roller mobility for high traffic areas like corridors.	
OVERALL LEVEL OF EVIDENCE LINKING FLOOR PROPERTIES TO STAFF FATIGUE		*LOW*
RESEARCH NEEDED LEVEL		*URGENT*

*Note that while there is some evidence on the impact of floor mats on underfoot comfort, the research that investigates this across an entire flooring type is minimal. Additionally effects on fatigue are only seen after an extended period of standing. In the design of healthcare environments cushioning (under-foot comfort) and roller mobility must be balanced, based on the activities performed in an area.
**Note that cushioning properties are also associated with injury reduction and the reduction of impact sound.

5	REDUCE FLOOR SURFACE CONTAMINATION AND POTENTIAL RISK OF HAI	P/A/?/NA
s	Carpet is avoided in areas where spills are likely to occur (e.g., laboratories, sinks, and janitor closets) or where patients may be at greater risk of infection from airborne pathogens (e.g., burn units, ICUs, and operating rooms) (CDC - Sehulster & Chinn, 2003).	
s	Do not use carpeting in hallways and patient rooms in areas housing immunosuppressed patients (CDC, 2003).	
p	Surface material is compatible with the sanitizing methods as outlined in the CDC 2003 recommendations for general cleaning strategies of patient care areas.	
p	Surfaces (and joints) are nonporous and impermeable to the extent possible without increasing slipperiness.	
p	Right angles joints between walls and floors are coved to facilitate effective cleaning.*	
s	In facilities electing to use carpet for high activity patient-care areas with risk of spillage, carpet-tiles can be considered to allow contaminated tiles to be removed, properly sanitized or discarded and replaced (CDC, 2003).**	
OVERALL LEVEL OF EVIDENCE LINKING FLOOR PROPERTIES TO HAI		*LOW*
RESEARCH NEEDED LEVEL		*URGENT*

* For hard/resilient flooring only.
**Note that while it is possible to create moisture barrier backings for the carpet tile, currently there is no method to effectively seal the seams that can act as a moisture barrier without welding the seams together (in which case the tile cannot be replaced). If wall-to-wall moisture impermeability is preferred, then the flooring selected should be both impermeable and welded at the seams following industry standards. Also note that in cases where a spill permeates to the sub-floor, the sub-floor would need to be treated as well and the cost associated with removing, cleaning and replacing tiles, and if needed treating the subfloor can become extensive.

Note that currently there is no evidence linking flooring to HAI, and no causal links between use of antimicrobial treatments and HAI. Additionally there are environmental concerns with using antimicrobial products from an IAQ perspective (See EBD Goal 7).

6	IMPROVE THE PATIENT EXPERIENCE	P/A/?/NA
p	Use floor design to support wayfinding by using colors and patterns in line with the overall design scheme.*	
p	Use flooring materials that are visually appealing and “non-institutional”.	
p	Use thermally insulating material to improve thermal comfort (see EBD Goal 8).**	
p	Use non-glare finishes to avoid strain on sensitive eyes.	
p	Maintain visual appeal by durable surfaces that do not scratch or scuff easily.*	
OVERALL LEVEL OF EVIDENCE LINKING FLOOR PROPERTIES TO STAFF FATIGUE		*LIMITED*
RESEARCH NEEDED LEVEL		*URGENT*

*Use of high contrast patterns must be weighed against perceptual issues that may impair balance, especially in areas where patients may have impaired vision (see EBD Goal 1).
**Use of thermal insulation suggests use of thicker material that can trap air, which in turn may increase risk of surface contamination.

Note that all the recommendations in this section are based on best practices and have not been empirically tested.

7	IMPROVE INDOOR AIR QUALITY (IAQ)	P/A/?/NA
s	Floorcovering should have minimum emission of VOCs and meet the requirements of the California Department of Public Health Standard Method for testing and evaluation of VOC emission (LEED, 2009).	
s	All carpet and carpet cushion should meet the Carpet and Rug Institutes (CRI) Green Label Plus (LEED, 2009).	
s	All adhesives and sealants for seams and joints should meet USGBC LEED for Healthcare standards (LEED, 2009).	
s	Tile setting adhesives must meet USGBC's LEED for Healthcare IEQ standards (LEED, 2009).	
s	Cleaning products specified should met Green Seal GS-37 and GS-40 standards (Green Seal, 2011).	
s	Minimize need for surface coating (EPA, 2007).	
p	Use permanent walk-off mats at entry ways to capture dirt and particulates entering the building. • If used, the mats should be maintained regularly by a contracted service organization. • If used, mats should be firmly anchored, and at least 10 feet in length in the primary direction of travel.*	
OVERALL LEVEL OF EVIDENCE LINKING FLOOR PROPERTIES TO IAQ		*MEDIUM*
RESEARCH NEEDED LEVEL		*MEDIUM*

*See EBD Goal about minimize risk of slips, trips and falls.
Note that while there are excellent standards in place that make the selection of materials easier, there remains a lack of empirical research which must be conducted to advance the field.
Please refer to LEED Guidelines for Healthcare for more information.

8	REPRESENT BEST RETURN ON INVESTMENT	P/A/?/NA
p	Balance first time costs with life-cycle costs before making flooring selection First-time cost (materials and installation) balanced with life-cycle costs (maintenance, repairs and replacement) (including the initial maintenance required to prep the flooring (if any) after installation and prior to occupancy)	
p	Carefully evaluate results of safety and durability testing	
p	Ensure that the flooring supports the organizational mission, branding and strategic goals of the organization	
p	Calculate energy savings (if any) based on material properties of thermal insulation	
p	Estimate the extent to which the flooring aids in improving safety and quality outcomes (Goals 1-7) to calculate Return on Investment	
Calculating return on investment is a complex calculation which is based on projected costs and returns. It should be carefully conducted with the right team of experts and a financial analyst.		

Introduction

In the healthcare environment, flooring is a surface that experiences the most use, covers the most square footage, and defines ease of transferability (movement of people and equipment). Yet it is one of the least researched environmental features in healthcare design. Growing scrutiny of healthcare investments, costs and consequent patient outcomes coupled with the enactment of the 2010 Patient Protection and Affordable Care Act demand a more complete understanding about how all of the elements in the healthcare environment – including flooring – contribute to patient, staff and resource outcomes. This document will reveal how flooring impacts multiple health-related outcomes, and share a set of evidence-based design criteria that can be used to evaluate characteristics of different flooring materials in order to make flooring selections that support the strategic goals of the healthcare organization. Areas where there is a lack of evidence and standards will also be identified, and topics for future research suggested.

Scope & Limitations

Flooring is an integrated system that consists of the sub-floor for support, and the floorcovering and surface finish that create the walking surface. How these elements come together is a key consideration in the selection of materials, curing and installation procedures, and overall maintenance. For this document, the scope will be limited to floorcoverings, though relevant information regarding sub-floors will be mentioned. Processes regarding preparation of floor and installation of coverings will not be considered, though these are additional considerations that practitioners must keep in mind. Also, flooring across levels (such as on steps, stairways, or ramps) will not be considered. Level differences discussed will be in the context of a single floor.

In the industry today, there are three recognized, broad categories of floorcovering – hard, soft and resilient. Hybrid floors are a new category that is gaining popularity. This paper will not address the debate between different categories of flooring on a generic level. Each of these broad categories includes a varied assortment of floorcovering options. This paper focuses on the flooring characteristics as opposed to the broad categories. Appendix 1 provides an overview of the different types of flooring materials and floorcovering options as a reference.

A challenge in the literature has been the interchangeable use of the terms flooring and floorcovering. Wikipedia defines flooring as the "general term for a permanent covering of a floor", including wood, ceramic tile, stone and terrazzo. Floorcovering on the other hand is defined as "a term to generically describe any finish material applied over a floor structure to provide a walking surface," referring more to loose-laid materials such as carpet, area rugs, and resilient flooring such as linoleum or vinyl. This subtle distinction between terminologies, and the use of the term "flooring" for floorcovering characteristics in much of the literature reviewed in this paper made it challenging to use one single term. Therefore, in this paper, the terms flooring and floorcovering have been used interchangeably as well, with the stipulation that the focus is on the material that covers the structural floor and provides the final walking and visible surface.

Another challenge in the paper is the lack of clear metrics and definitions in the literature. This is often the case when the majority of the literature is in the industry, one that is rapidly changing and expanding with new science and technology. Additionally there are multiple testing organizations for each different kind of flooring material (see Appendix 2) without a central repository that tracks performance across flooring types. It has been a challenge to look at information available in industry sources and trace it to the original unbiased research source (if any) and put it in the context of other flooring types, which may be subjected to a completely different set of testing protocols. In this paper peer reviewed research was given the first priority, but given the paucity of evidence, technical reports and best practice documents were included in the review.

A comparison across flooring types or materials was not undertaken due to the current state of the evidence that does not allow a common platform for comparison based on common metrics, standard tests, and clear definitions of performance. Although such comparisons are valuable tools for designers (see Appendix 3 for some useful examples), they cannot be considered evidence-based within the context of health outcomes. This paper takes the first step towards a performance based comparison of flooring/floorcoverings by linking specific flooring characteristics to specific evidence-based design goals.

The purpose of this paper was to examine research findings, industry standards and best practices related to individual types of floorcoverings, and understand the potential links between the performance characteristics of the floorcoverings and desired healthcare outcomes. Eight healthcare outcomes of interest were emergent from the initial scan of the literature and identified as EBD goals:

1. Reduce slips, trips and falls
2. Reduce patient and staff injuries associated with falls
3. Reduce noise levels
4. Reduce staff fatigue
5. Reduce surface contamination and potential risk of Healthcare-Associated Infections (HAI)
6. Improve Indoor Air Quality (IAQ)
7. Improve patient and family satisfaction
8. Represent the best return on investment

A more fine-tuned and modified set of criteria may be needed for each broad category of flooring (hard/soft/resilient). As a first step though, there is a need for to create umbrella categories for Evidence-Based Design (EBD) goals that work across different flooring types to help designers and facilitators weigh salient issues relating to flooring as they make flooring decisions. This paper is contained within this scope.

Recommendations are not specific to type of healthcare organization (long-term care, acute-care, outpatient care etc.), or within a specific areas found within an organization (inpatient room, procedure room, waiting room, OR, etc.). Each area in a healthcare organization has a unique flooring requirement based on the clinical mission, the population served, the team caring for them and the equipment used. By emphasizing EBD goals, the findings can be used by designers to prioritize the goals that are most important for a specific area and/or organization, and identify a list floorcovering properties and characteristics best suited to achieve these outcomes. Rather than providing a prescription for floorcovering selection, an evidence-based tool that designers can use to inform their decisions is provided instead.

Structure

This paper was developed using a three-step process, including input from various industry experts:

1. First, a broad scan of the literature was conducted, using key words for flooring and the different health outcomes found in The Center for Health Design article repository, PUBMED, and Google Scholar. Additional keyword searches on the internet were used to identify industry standards and norms.
2. A core advisory group was established including researchers, interior designers, vendors and healthcare administrators, which met biweekly. Experts from the flooring industry, or other experts who may have input on specific areas of the checklist, were asked to join the calls as needed. Additional resources suggested by the team of experts were also reviewed.
3. The draft of the paper was developed and sent to research experts, and subject area experts (see acknowledgments section) for review. Feedback from the experts was incorporated in the final draft of the paper.

In this paper, key EBD goals and the current literature, linking floorcovering properties to each of the goals are outlined. A set of recommendations are then provided in a condensed list of floorcovering performance characteristics, which are annotated to reflect the source of the evidence with *r (research studies*), *s (standards), and p (best practice)* and help designers weigh the evidence. Where evidence is missing, a case is made for the need for urgent research by topic. Each EBD goal has a set of annotated recommendations, with a column on the side for a practitioner to check Present/Absent/Cannot Determine/Not Applicable. It also has two qualifiers at the bottom: one that outlines the current level of evidence with causal links between floor properties and EBD goals, and the second qualifier that outlines the need for further research. Notes are added to each EBD goal calling out any trade-offs or additional considerations. This list is summarized at the end of the Executive Summary on page 4.

EBD GOAL 1: Reduce Slips, Trips and Falls

Context: Patient falls and associated injuries represent the number-one hospital adverse incident (Joint Commission, 2009); with 6.4 percent of those occurrences resulting in death or physical or psychological injury, referred to as sentinel events (The Joint Commission, 2005; 2009). Falls are defined as a sudden, unintended, uncontrolled downward displacement of a patient's body toward the ground or other object. This includes situations where a patient falls while being assisted by another person but excludes falls resulting from a purposeful action or violent blow (NQF, 2009). Falls are dependent on the ability of a person to maintain balance. Falls while standing or walking on a flooring surface may occur due to slips, trips or stumbles. According to the Environmental Health and Safety unit at Carnegie Mellon (n.d.), slips occur when there is too little friction of traction between the feet and the walking surface. Trips occur when the foot strikes an object (or obstruction), and the momentum throws one off balance. Alternately, material on the sole of the footwear may catch on the flooring surface and cause the foot-swing to be abruptly halted, which could impair balance.

The Agency for Healthcare Research and Quality (AHRQ) summarized additional key statistics associated with patient falls and associated injuries in its Evidence-based Handbook for Nurses (Hughes, 2008) provided below:

- 1.7 to 25 falls per 1,000 inpatient days, depending on the care area, with geropsychiatric patients having the highest risk
- The overall risk of a patient falling is approximately 1.9-3% of all acute care hospitalizations, 6-44% of acute inpatient falls result in injury
- 2-8% of injuries are serious and include head injuries and fractures
- There are approximately 90,000 serious injuries across the United States each year
- There are 11,000 fatal falls in the hospital environment per year
- Long-term care settings report 29-55% of patients fall during their stays, with injury rates up to 20%

The Joint Commission requires healthcare organizations to track patient falls and injuries and devise programs to reduce the number of occurrences. However, there is no standard methodology used across the healthcare industry to identify and analyze the variables associated with each fall. Unlike healthcare-associated infections, there is no federal patient fall and associated injury reporting system to collect information about the circumstances surrounding each fall, including details about environmental variables, such as flooring characteristics. This gap is in part due to the lack of clear distinctions between intrinsic and extrinsic factors that lead to falls.

According to the AHRQ Evidence-based Handbook for Nurses (Hughes, 2008), intrinsic factors are those that have a physiologic origin, whereas extrinsic factors precipitate from environmental or other hazards. Extrinsic risk factors for falls, injury and mortality (fall-related deaths) in the community include environmental hazards, non-supportive footwear, recent hospitalization, and reckless wheelchair use. They report that there is no data to evaluate the injury or mortality risk caused by the extrinsic factors. For acute-care and long-term care settings the paper does not mention any environmental hazards at all. In her work to create a tool to evaluate the contribution of the designed environment to fall risk in hospitals, Calkins (2012) points out that 1) the majority of hospital adult falls are related to intrinsic causes, and 2) while there is some research that addresses extrinsic risk factors in healthcare settings, they frequently use a multi-model approach making it difficult to isolate the impact of a single environmental variable. Additionally very few studies look at the "designed" environment (fixed elements such as flooring and lighting) rather than temporary characteristics (such as clutter or spills etc.).

Given that environmental factors have only been dealt with cursory fashion in the medical literature, it is not surprising that so little is known about flooring and its relationship with falls and injury. The challenge is compounded by the fact that often each organization develops its own patient falls prevention and data collection system, within the context of a performance improvement program. As a result, it is difficult to create a national database that could aid benchmarking efforts to help understand the role of environmental features with fall and injury prevention. A notable exception can be found in the Department of Veterans Affairs' National Center for Patient Safety with its Falls Toolkit (2004), which includes a comprehensive post-fall assessment with questions about the location of the fall and flooring status. Solving the pernicious falls problem will require careful scrutiny of all contributing variables, both intrinsic factors that pertain to the patient such as age, illness, strength and medications and extrinsic variables that include environmental features like flooring (Tzeng, 2008). Calkins' "Falls Environment Evaluation Tool" (FEET) will be one of the first steps in creating a set of metrics to evaluate the incidence of falls in the context of the physical environment, and help isolate the impact of individual elements of the designed environment, including flooring/floorcoverings.

Cost of Falls: Why We Can't Afford Them

Enactment of the 2010 Patient Protection and Affordable Care Act will significantly change the healthcare industry's interest in solving patient falls. The Centers for Medicare & Medicaid Services' (CMS) Partnership for Patients Program has identified injuries associated with falls and immobility as one of nine areas of focus to make care safer. CMS estimates that approximately 25% of fall injuries are preventable and have set the goal for hospitals to reduce the number of preventable fall injuries in half and increase patient mobility by 2013. This initiative is expected to prevent a total of 43,750 injuries over three years (CMS, 2012).

Financial incentives have been designed to spur innovation. Since 2008, CMS no longer pays hospitals at a higher rate for the increased cost of care consequent to an injury associated with a fall. The estimated average 2009 payment associated with injuries sustained by a patient falling from bed were $24,962 per patient (Hart, Chen, Rashidee, & Kumar, 2009). The new Hospital Value-Based Purchasing program further realigns hospital financial incentives by shifting payment for volume to a quality care reimbursement model that requires a reduction in patient falls and injuries in order for hospitals to receive the maximum Medicare and Medicaid payments (CMS, 2012).

The CDC & NIOSH document on slips, trips and falls incidence outlines two categories of falls (Bell et al., 2010):

1. Falls from an elevation (such as while standing on a chair, from ladders or stairs, from a non-moving vehicle, etc.)
2. Same-level falls (such as while walking or working, from a chair while sitting, tripping up stairs, etc.)

Same-level falls can be prevented by minimizing slips and trips based on the design, selection and maintenance of the flooring. The United Kingdom's National Health Service (NHS) has identified four main causes of slips and trips accidents in healthcare, each of which is related directly to flooring (Healey, 2007):

1. Slippery/wet surfaces: caused by water and other fluids
2. Slippery surfaces caused by dry or dusty floor contamination, such as plastic, link or talcum
3. Obstructions (both temporary and permanent)
4. Uneven surfaces and changes of level, such as unmarked ramps

The NHS also makes a clear distinction between environmental factors (which relate to the flooring property, spillages, contamination and maintenance etc.), footwear factors (contamination, material, pattern, and fit of shoes), individual factors (related to staff awareness and vigilance), and organizational factors (the safety culture of the institute and the nature of the tasks themselves to organize flow such that work can be handled to minimize obstructions). It is obvious in the NHS report that slips, trips and falls occur due to a complex systemic dynamic; however as designers, the need to select flooring that minimizes these occurrences from an environmental stand point is an important piece of the solution.

In a review of the literature on the impact of environmental design on patient falls, Gulwadi and Calkins (2008) identified four characteristics of flooring that may impact fall risk:

1. Floor material (resilient versus soft) which can impact postural sway and balance, based on research by Dickinson et al (2001) that showed low-pile, tightly woven carpet may not be a fall risk,
2. Floor pattern; based on research by Perritt et al. (2005) that showed high contrast patterns relate to higher incidence of falls,
3. Floor transitions, based on work by Theodos (2003) that showed transitions in flooring could be a risk factor but did not cite specific studies, and
4. Coefficient of friction that relates to the slipperiness of the floor as a factor of surface resistance related to the interaction of the flooring with what is on the foot; no conclusive research was cited.

There is a growing body of literature on the subject of falls and injuries in the healthcare context. It is not necessary, however, that all falls result in injuries, and therefore injuries are addressed as a standalone goal in the next section.

Material

Perhaps the biggest debate in flooring today is whether the type of material (hard/soft/resilient) has a direct impact on falls and injuries. This is a complex question given the extensive varieties of flooring/floorcovering options that are available today, including new composite and hybrid materials. Appendix 1 provides a basic list of different types of flooring, which continues to evolve.

In a recent review of the literature by Choi et al (2011) to create a multi-systemic fall prevention model, Choi identified a study by Donald (2000) as the only "single intervention study" in a hospital setting. This means that a study made a direct link between a single environmental variable – flooring type (either carpet or vinyl) and falls. This study was based on a randomized control trial) design, and showed that vinyl floors decreased the risk of falls as compared to carpet. However, the sample size of this study was limited and thus the findings need to be accepted with caution (Choi, 2011). In contrast to Donald's findings, research by Dickinson showed that low-pile and tightly woven carpet is not a fall risk (Dickinson, 2001). Calkins' (2012) correlational study found that linoleum flooring was associated with more falls than vinyl-composite tile (VCT), especially in the bathroom where the rate of the falls was 10 times higher for linoleum than VCT and ceramic tile. This could be attributed to the increased probability of wet surfaces in bathrooms. Unfortunately, no study or literature review was identified that provided a comprehensive analysis of flooring types and falls.

In theory, the impact of flooring material on falls relates to how the firmness of the floor (also understood as floor compliance or hardness/softness) can impact postural sway and balance in a person standing or walking on it. Choi and colleagues (2011) noted support for the impact of floor compliance (softness) on postural sway (Redfern, 1997), but remarked that the evidence was not conclusive. It is possible that floor compliance and softness may have a larger impact on injuries resulting from falls, rather than on the incidence of falls, which will be addressed in the next section.

Slip Resistance or Coefficient of Friction of Flooring Surface Finish

A key component of the flooring that contributes to falls is the "slipperiness" on the surface of the floor. To counter this characteristic, floorcoverings must have an ideal amount of slip resistance. It is important to realize however, that multiple factors contribute to the slip resistance of a floor. The Health and Safety Executive (2007) lists the following environmental factors that relate to the slip resistance of floors:

1. Friction between the floor and the shoe

2. Presence of suitable micro-roughness (calculated as a mean of several peak to valley measurements)

3. Hardness of the floor

4. Applications for sealing floors during installation

5. Later modifications on the floor surface such as inappropriate varnishing/sealing/polishing

In the U.S., slip resistance is defined most commonly by the Coefficient of Friction (COF), which relates to the ratio of normal force holding two materials together and the maximum force necessary in shear to reduce sliding (Miller, 1982). OSHA cites Miller's work from 1982 as a guide to achieve proper slip resistance, and recommends a static COF of 0.5 in its appendix material. In fact, OSHA expressly states that an absolute value for static COF cannot be recommended across the board (OSHA, 2003). It provides the caveat that:

> "A higher COF may be necessary for certain work tasks, such as carrying objects, pushing or pulling objects, or walking up or down ramps. Slip-resistance can vary from surface to surface, or even on the same surface, depending upon surface conditions and employee footwear. Slip-resistant flooring material such as textured, serrated, or punched surfaces and steel grating may offer additional slip-resistance. These types of floor surfaces should be installed in work areas that are generally slippery because of wet, oily, or dirty operations. Slip-resistant type footwear may also be useful in reducing slipping hazards."

The prevalent practice in the industry is to select an anti-slip floorcovering with a COF of 0.6 (Byrd, 2009). However, given the lack of research and adoption by different standards association, this number should not be considered an absolute recommendation. Since COF can only be measured as a factor of two surfaces coming in contact, there are many confounding variables that impact this state, such as type of footwear as well as a lack of standardized tests, both of which pose a challenge in establishing a firm standard. In fact, the U.S. Department of Justice's Americans with Disabilities Act Accessibility Guidelines (ADAAG, 2010) are very generic do not give a number and state that a "slip-resistant surface provides sufficient frictional counterforce to the forces exerted in walking to permit safe ambulation."

Today, there is no national standard for slip resistance for floorings in different types of buildings and work areas. The American National Standards Institute (ANSI) and National Floor Safety Institute (NFSI) are working on the development of test methods for flooring materials, including Wet and Static COF of common hard-surface materials. According to ANSI/NFSI B101.1-2009, walkway slip resistance can be measured and categorized in one of three traction ranges: high, moderate, or low. Floors categorized as high-traction present a low risk of a slip and fall, while moderate- and low-traction floors present a higher risk. The standard does not apply to carpeting of any type or mechanically polished tile such as polished porcelain or marble, but addresses common hard-surfaced flooring materials such as ceramic tile, vinyl floorcoverings, and wood laminates, as well as coatings and polishes. Readers should continue to monitor the ANSI/NFSI initiative for updates with regard to the development of national standards for flooring properties that are currently lacking (see Appendix 2 for more information).

It is also important to note that slipperiness is a complex construct that needs to take into account issues of epidemiology, biomechanics, human-centered (psychophysics), roughness and friction. Appendix 4 explains this further in a note from Dr. Chang from the Liberty Mutual Research Institute for Safety. Human locomotion has to be considered alongside surface factors to determine standards for slipperiness/ slip-resistance. Given the complexity of the issues associated with slip resistance, it is not surprising that little research is available regarding how the COF for different types of flooring contributes to falls.

Transitions

In contrast to slips, which are effected by the surface properties of the floor, trips are more of a design issue. Planning ahead for the thickness of different floorcoverings and how transitions are addressed between different types of flooring or over thresholds is a key consideration. The ADAAG (2010) regulation on slips and trips is not specific. It recommends a stable, firm and slip-resistant surface defined as follows:

> "A stable surface is one that remains unchanged by contaminants or applied force, so that when the contaminant or force is removed, the surface returns to its original condition. A firm surface resists deformation by either indentations or particles moving on its surface. A slip-resistant surface provides sufficient frictional counterforce to the forces exerted in walking to permit safe ambulation".

The ADA also sets clear standards for transitions that flooring thresholds should be less than ¼” vertical or between ¼” and ½” beveled. No research that supports these requirements has been identified, but they are established through the Department of Justice as minimum requirements for newly designed and constructed or altered State and local government facilities, public accommodations, and commercial facilities to be readily accessible to and usable by individuals with disabilities (Bunterngchit, Lockhart, Woldstad, & Smith, 2000).

Research on healthcare for the elderly suggests that ideally there should be few changes to flooring types, no thresholds, and no changes from carpet to resilient floors. The argument is that for people using walkers, going from a higher COF to smooth floors can increase the chance that the walker wheels run away, causing a fall (Dvorsky, 2007). Unnecessarily changing flooring surface – especially at a location other than the threshold to a room where people expect flooring to change, may cause more problems, especially in association with footwear. Different soles work better on different surfaces, so changing from one type of surface to another is more likely to make it more difficult for some people-especially those who shuffle (Calkins, 2012). In a recent paper looking at the transitional effects of floor surfaces and obstruction of the immediate field of the floor surface on walking and gait researchers found that transitional floor surfaces (carpet to vinyl and vinyl to carpet), and carrying a light load, can increase slip-induced falls (Bunterngchit et al., 2000).

Appearance

In addition to the mechanical properties of the floor, visual properties such as glare and patterns can also contribute to falls.

Glare: Wilmott and colleagues (1986) argued that shiny/highly reflective floors can cause glare and lead to disorientation, particularly with elderly patients, which impacts gait speed. Floors may appear wet and slippery when shiny, which can contribute to the fall risk. Dvorsky (2007) identified glare as a key issue for seniors who have more sensitive vision and may be blinded temporarily by glare. In their review of the literature, Gulwadi and Calkins (2008) noted that floor finish, specifically a high-gloss surface’s contribution to glare may contribute to falls, but cited a lack of empirical research. Glare intolerance is accepted as a risk factor for falls, especially in the elderly (Fuller, 2000). Glare can be measured as a factor of the surface reflectance in terms of the Light Reflectance Value (LRV) of a surface.

Pattern: Research by Perritt (2005) on carpet patterns showed that that high contrasting patterns were associated with more incidents (stumbles, reaching for handrail, veering, purposeful stepping, pausing, stopping) than carpeting with low color contrast patterns. Bonato and Bubka (2011) found that viewing high contrast static patterns (black and white squares laid out in regular patterns on a rug) can induce motion sickness. In a recent correlation study by Calkins (2012), it was found that vinyl flooring with medium size pattern (1"- 6") was associated with greater falls than no pattern, small pattern (<1") or large pattern (>6"). These few studies suggest that floor glare and pattern may contribute to falls. However, the underlying relationship, and ideal condition for each, demands more research.

Note on Staff Perspective

Slips, trips and falls are a growing concern for healthcare workers as well. In 2002, more U.S. healthcare workers were injured than the workers in construction and mining combined. Slips, trips and falls contribute to the largest proportion of lost time injuries (21%) for healthcare workers (Waters, 2006). Although articles that examine falls from a staff perspective are limited, the information in Table 1 suggests that research on this subject is urgently needed.

Table 1 Causes and Types of Falls in Healthcare Workers. NIOSH – Waters, 2006

Causes and Types of Falls	Percentage of Health Care Workers Who Fell
Slipping or tripping	88
Slipping	53
Tripping	32
Liquid contaminants (e.g., water, cleaning solutions)	36
STF occurred at a transitional area	64
Dry/wet	32
One type of floor to another	22
Uneven surfaces	15
Fell forward	41
Fell to the side	23
Fell backward	21

type characteristics and incidence of falls has not been established. This is an area of inquiry that must be addressed urgently, keeping in mind both the intrinsic properties of the floor and the surface finish, and extrinsic properties like footwear, cleaning protocols and maintenance.

The following table summarizes the insights gleaned from the literature review about flooring design and floorcovering selection considerations to help reduce slips, trips and falls.

1	REDUCE SLIPS, TRIPS, AND FALLS	P/A/?/NA
s	Flooring material is stable, firm, and slip resistant* (ADAAG - U.S. Dept. of Justice, 2010).	
s	In areas where spillage is likely (like bathrooms, suites, sink areas, lab areas, etc.) flooring is impermeable, easily cleaned and textured (OSHA, 2003; NHS - Healey, 2007).	
p	Depending on flooring type, flooring is tested for optimal performance under different conditions (wet/dry/greasy).	
r	Contrast in flooring patterns is low (Perritt et al., 2005; Calkins, 2012).**	
r	Finish has low reflectance value to prevent glare (Wilmott, 1986; Dvorsky, 2007).	
s	Flooring thresholds are less than ¼ inch vertical, or between ¼” & ½ inch, beveled (ADAAG, 2010).	
s	If carpet is used, pile height is 1/2 inch (13 mm) maximum (ADAAG, 2010).	
s	Exposed edges of carpet are fastened to floor surfaces and have trim on the entire length of the exposed edge (ADAAG, 2010).	
p	Joints and seams are minimized to ensure that sharp edged objects like walking sticks or heels do not cause trips.	
p	Area rugs, walk off mats at building entry and floor mats, if used, have beveled edges and are firmly anchored to facilitate ADA transition guidelines.	
p	Appropriate finishes and cleaning procedures are used in accordance with standards and manufacturer recommendations.***	
OVERALL LEVEL OF EVIDENCE LINKING FLOORING PROPERTIES TO SLIPS, TRIPS AND FALLS		*LOW*
RESEARCH NEEDED LEVEL		*URGENT*

*Note that increasing slip resistance through textured finish can create maintenance/ cleanability issues. These must be balanced during the selection of the flooring. Also note that a standard for COF is not available right now because slip-resistance can vary from surface to surface, or even on the same surface, depending upon surface conditions and employee footwear (OSHA, 2003). The industry norm is between 0.5 and 0.6.
**Note that high contrast patterns may be used for way finding in public areas where patients are not unaccompanied. Also, patterns pose a larger concern for older populations and are used more commonly in pediatric settings. More research is needed on the effect of contrast on age.
*** Note that the floor finish is the final contact surface. Finishing products and cleaning protocols can significantly impact the performance of the floor in terms of slips and trips.

EBD GOAL 2: Reduce Patient and Staff Injuries Associated with Falls

Injuries sustained during a fall are costly to the patient and the healthcare organization. In a study that evaluated the characteristics and circumstances of falls that occur in the hospital setting, Hitcho and colleagues (2004) found that the rate of inpatient falls ranged from 2.7 to 7 falls per 1,000 patient days, with approximately 30 percent resulting in injury. Chang and colleagues (2004) estimated that healthcare costs associated with falls were approximately $20.2B in 1994 and expected to grow to $32.4B by 2020. None of these statistics capture the quality of life impacts that a fall resulting in an injury has on patients and family members.

In a systematic review of the literature from the Cochran Foundation investigating the link between flooring and injuries resulting from falls, Drahota et al (2007) found that, while appropriate flooring in healthcare settings appears to be a viable option to reduce injuries, current findings are largely inconclusive because of weak study designs and a lack of specificity describing the type of floor and floor properties. The team concluded that tests conducted in a laboratory setting, which evaluated the shock-absorbency properties of floorcovering, lacked validation in real world conditions. They strongly recommended assessing both clinical outcomes and cost effectiveness before making flooring investments.

In research linking flooring type to injuries resulting from falls, Laing et al. (2009) and Sran & Robinovitch (2008) found that softer floors may reduce the severity of injuries (e.g. hip fractures) by applying lower forces to the hip during a fall. A retrospective study by Healey (1994) that included a sample of 225 fall accident forms in an elderly care unit over 4 years, selected at random, found that patients who fell on carpeted floors were less likely to sustain injury than those who fell on vinyl flooring. Healey also found that while 46% of patients who fell on vinyl floors sustained injuries, only 17% of patients who fell on carpeted floors sustained injuries. Simpson's et al. (2004) 2-year prospective cohort study conducted at 34 residential care homes showed that carpeted floors with wooden sub-flooring were associated with the lowest number of fractures per 100 falls compared to other floor types evaluated (i.e. uncarpeted with wooden sub-floors, carpeted with concrete sub-floors and uncarpeted with concrete sub-floors). This research shows that it is the assembly of the floorcovering and the structural sub-floor that impacts injuries.

Hip fractures are one of the most common injuries incurred in environments where there is a high density of frail elderly persons, such as residential care facilities, hospitals, and senior centers (Laing, 2009). Laing's study describes how lowering the stiffness of the ground surface can reduce the force applied to the proximal femur in the event of a fall. Laing cites different studies that show that falling into padded carpet, grass or loose dirt, reduces hip fracture risk compared to falling on concrete/linoleum. He makes a case for the role of the flooring underlay in reducing injury, and warns the reader that reducing the floor stiffness too much can impair mobility and balance and lead to increased risk for falls. Laing's research compared four energy-absorbing floors (with different heights ranging from 2.5 cm to 11 cm and different densities) to a rigid floor (slip-resistant dense natural rubber 2 mm thick). The tests were conducted in a lab setting and measured balance impairment (which relates to falls) as well as force attenuation (which relates to injury). The two conditions can represent competing demands on flooring, so the ability to measure both simultaneously is valuable. Their results indicated that low stiffness floors can substantially attenuate impact force with only minimal coincident impairments in balance. Laing's findings are in contradiction to earlier work by Redfern (1997) who argued that force attenuation properties of energy absorbent floors may be outweighed by an increase in fall risk. The trade-off between fall risk and injury requires careful evaluation.

In his research Laing (2009) found that force attenuation (ability of the floor to attenuate impact force sufficiently) can range between 7% for wood floors, to 15% for carpets, and 24% for carpet with common under-paddings. Thus a careful consideration of the specific product is warranted. Laing also reported studies that showed more than a 50% force reduction by using PVC foams under carpet and vinyl, but again cautioned that purely mechanical tests do not account for the natural compliance of the human body.

Selecting the type of flooring (hard/soft/resilient) depends on the flooring function and can vary extensively between areas that are prone to slips (like bathrooms) versus areas that are for more sedentary activity such as bedrooms, offices etc., or high traffic areas such as corridors and walkways. The trade-off between maintaining balance (fall risk) and reducing injury is a key consideration that must be evaluated when selecting flooring/floorcovering properties as well as usage and maintenance. Use of new materials for underlays that provide cushioning for more rigid materials (such as foam, SmartCell cushion, polyurethane etc.) is a solution that has been tested, but not yet standardized. Again it is important to consider the entire flooring system — floorcovering, underlay, and sub-floor — to determine how injury can be minimized without increasing risk of falls. More research is needed to understand the ideal relationship between all flooring system components to reduce falls and associated injuries.

The following table summarizes the insights gleaned from the literature review about flooring design and selection recommendations to help reduce patient and staff injuries associated with falls.

2	REDUCE PATIENT AND STAFF INJURIES ASSOCIATED WITH FALLS	P/A/?/NA
r	Floor has a balance of energy-absorbent properties (to absorb the force of impact that causes injury) and firmness (to reduce the risk of falling due to poor balance) (Wright, 2011; Redfern, 2000).*	
r	If rigid materials are used, then underlays can be used to provide adequate cushioning to reduce the impact of the fall (Laing, 2009; Sran & Robinoviych, 2008).**	
OVERALL LEVEL OF EVIDENCE LINKING FLOOR FINISH TO TRIPS AND FALLS		*MEDIUM*
RESEARCH NEEDED LEVEL		*HIGH*

*Note that impact due to a fall can depend on the sub-floor, underlay, as well as the floorcovering material. While deciding on the impact on injuries, make sure you consider the property of the entire flooring system.
**Make sure the underlay does not create an increase in effort for mobility (see EBD Goal 4).

EBD GOAL 3: Reduce Noise Levels

In an issue paper on sound in the healthcare environment, Joseph and Ulrich (2007) made a case for acoustic design based on the high hospital noise levels, which often exceeds 85 dB(A) to 90 dB(A) which is far in excess if the World Health Organization guidelines for 35 dB(A) during daytime and 30 dB(A) at night within patient rooms. The authors provide an overview of factors contributing to noise in the healthcare environment, and the dire consequences it can have including annoyance, sleep disruption and awakening, decreased rate of wound healing and increased incidence of rehospitalization. In the case of NICU patients the authors cite research linking noise to decrease in oxygen saturation, and increase in blood pressure, heart and respiration rate. In a recent study published by The Center for Health Design, Solet and colleagues (2010) explained the importance of noise and the detrimental effect it can have on patient satisfaction, as well as stress, medical errors, lost privacy (interference with speech privacy), and sleep deprivation.

The Hospital Consumer Assessment of Healthcare Providers and Systems, otherwise known as HCAHPS, survey collects information about the patient's perception of and satisfaction with their hospital experience. One of the questions on the 27-item survey is "During this hospital stay, how often was the area around your room quiet at night?" Healthcare leaders now have additional incentive to reduce hospital noise since, under the Hospital Value-Based Purchasing program, patient satisfaction with the care experience is linked to a portion of the hospital's payment from The Centers for Medicaid and Medicare (CMS, 2012).

According to Joseph and Ulrich (2007) the two main reasons for why hospitals are noisy are: 1) too many noise sources; and 2) sound reflecting, rather than sound absorbing, environmental surfaces (walls, floors and ceiling).

Additional noise sources may include sound transmitting across walls, floors and other barriers since no area in the hospital can be considered truly sound-proof. The FGI Guidelines for Design and Construction of Healthcare Facilities published a white paper (FGI, 2010) on sound & vibration design guidelines which is available as a reference to understand the acceptable sound and vibration levels in a healthcare setting. However, the design recommendations do not take into consideration the multiple factors that go into controlling sound absorption and transmission by flooring. Floor noise is generated by foot traffic, movement of carts and equipment (surface-generated noise due to impact), as well as reflectance of airborne sounds like conversations and overhead paging and intercom systems. Sound attenuating and absorbing properties can vary significantly between different floorcoverings, including the construction of the subfloor. The Green Guide for Healthcare (GGHC, 2007) technical brief for the acoustic environment in hospital argues that in health care facilities traditional solutions to infection control concerns, such as removing carpeting, work against creating a healthy acoustic environment. Surfaces are often covered with hard materials designed for easy cleaning and disinfection, which may reflect and amplify rather than absorb sound. Commercial office buildings that do not have this problem can use porous finishes to improve sound absorption in the space (GGHC, 2007).

Davenny (2010) suggests that among common healthcare flooring surfaces, rubber generally produces the least impact noise, and vinyl composition tile placed directly on concrete and terrazzo produces more impact noise. Carpet provides the highest level of impact noise reduction of all flooring types used in the healthcare setting. However, he warns that flooring material should not be relied upon to provide all the airborne sound absorption to control noise sources such as alarms, overhead paging, etc. These insights, while valuable, must be considered carefully since the claims are not supported by any research cited by the author. It is important to understand that flooring can contribute to noise levels through sound absorption, sound transmission, and impact noise, which are measured as follows:

1. Sound absorption can be measured by the noise reduction coefficient (NRC) rate
2. Sound transmission can be measured by the sound transmission class rating (STC) which measures the reverberation between two rooms (in the case of flooring one below the other)
3. Impact noise (transmission of impact sound through a floor) can be measured in terms of the impact insulation class (IIC). Additionally impact noise can be measured by impact noise rating (INR)

NRC ratings are frequently shared by vendors as one of the floorcovering properties. Typically, carpet has the higher NRC ratings (more sound absorbing properties) compared to resilient floors, which in turn have higher NRC ratings compared to hard finishes such as stone, terrazzo and vinyl. For rigid floors, acoustic underlays can be used to reduce impact noise. Frequently, the resiliency in the flooring that provides sound absorbency can also contribute to the cushioning effect that can reduce staff fatigue from standing for long periods of time. There are no current industry standards for appropriate NRC values for floorcoverings in a healthcare setting. Such standards will need to consider the room location and function, specifying the equipment used and moved, the amount of foot traffic as well as the number of individuals present who may be speaking. Acoustic modeling of each area could provide a valuable assessment tool as a first step to determining floorcovering solutions.

The technical brief for Acoustic Environments by the Green Guide for Healthcare (2007) provides a standard for room noise levels which is organized by room type. The paper suggests that the floor finish and sub-floor structure in healthcare settings are most effective in mitigating noise levels by transmitted by an impact. The paper states that rubber produces the least impact noise followed by VCT (among smooth, cleanable flooring surfaces used in hospitals); whereas terrazzo produces the most impact noise. It also states that carpet is a mediocre finish to absorb airborne sound, and that most carpeting used in healthcare spaces have a NRC performance ranging from 0.2 to 0.3. The report emphasizes that the acoustical benefit of carpeting is to reduce impact, rather than airborne noise. Currently carpet provides the highest level of impact noise reduction of all flooring types.

Noise Attenuation Trade-offs

Noise profoundly impacts patients and staff in a healthcare setting, with deleterious consequences for all. When selecting the right flooring for a healthcare environment, the noise absorbance properties of the floor must be balanced against concerns of cleanability, balance, and roller mobility. Currently no research links flooring properties to reduction in healthcare environment airborne noise. Research in this area has been less than ideal because ceilings, floors and walls collectively contribute to noise together, making the isolation of variables difficult. In a recent publication, authors found that hard floors with acoustical grade ceiling tile are comparable to carpeted floors with standard (existing) ceiling tile in terms of noise levels (Frederick et al., 2012). The study was conducted on two inpatient nursing units at the current Palomar Medical Center. Prior to the study, both units had carpeted corridors and standard acoustical ceiling tile. As part of the study, new hard surface flooring (a resilient tile) was installed in one unit. Subsequently, high-performance acoustical ceiling tile (a mineral fiber tile) was installed on the unit. The other nursing unit received new carpet tiles (a low, dense, loop construction designed for heavy traffic areas, with a nylon face that has a pile height of 0.187 inches, or 4.7 mm, and 9.4 stitches per inch). The noise data results suggested that hard floors with acoustical grade ceiling tile are comparable to carpeted floors with standard (existing) ceiling tile. The only difference was that hard floors with acoustical grade ceiling tiles may be more effective at reducing maximum noise levels than is carpeting. It is important to bear in mind that the study only examined airborne sound and not impact sound.

Further research is needed to understand the precise impact of flooring types in combination with other environmental design strategies on both the creation and attenuation of noise. It is also important to focus the research on sound transmission due to impact, which is where flooring can be the key contributor to noise levels, especially in public/staff areas that may have a lot of foot traffic and equipment transfer.

The following table summarizes the insights gleaned from the literature review about flooring design and selection considerations to help reduce noise levels.

3	REDUCE NOISE LEVELS	P/A/?/NA
p	Flooring with high footfall noise (such as corridors) should have high sound absorbing properties and low sound transmitting properties while accommodating roller mobility and balance.	
s	The floor finish and the sub-floor structure in healthcare facilities should mitigate noise levels transmitted by an impact in an adjacent space, such as footfall or cart rolling (GG Technical Report, 2007).	
p	Resilient/acoustic underlays should be used to lessen footfall and other traffic noise, for floorcoverings with low IIC.	
OVERALL LEVEL OF EVIDENCE LINKING FLOOR PROPERTIES TO NOISE LEVELS		*MEDIUM*
RESEARCH NEEDED LEVEL		*URGENT*

Note that there is no evidence that currently links flooring property to reduction of airborne sounds. The acoustical benefit of flooring is primarily on impact noise reduction. Standards are currently lacking on ideal NRC levels since these differ greatly between different flooring materials.

EBD GOAL 4: Reduce Staff Fatigue

Fatigue associated with standing

In a healthcare setting, staff members spend extended periods of time engaged in activities that require them to be on their feet. Complaints of musculoskeletal fatigue and discomfort are common, especially associated with long-term standing (Redfern et al., 1997). In a review of the literature, Redfern and Cham (2000) described the ergonomic and epidemiological evidence of the problems associated with long-term standing. The authors provided a comprehensive analysis of the literature comparing different types of floor mats, healthcare activities, as well as the research setting (lab/practice) and the impact on staff fatigue. They found a lack of consensus stating that while some studies found a relationship between flooring and fatigue, others did not. The authors warn that only a few studies investigated the relationship between floor material characteristics and subjective/objective measures of fatigue. However, as a general rule of thumb the authors suggest that for extended periods of standing there is a beneficial effect to having a softer floor, compared to hard floor, primarily in the lower extremities (leg, ankle, foot), as well as the lower back. No descriptions about the specific characteristics that define "softness" are defined.

A follow up study by Cham and Redfern (2001) measured fatigue associated with standing for more than four hours on different types of floor mats compared to a hard floor covered with vinyl tile. Analysis of subjective criteria showed that standing on the hard surface consistently yielded the highest (worst) discomfort/fatigue ratings. Differences in other ratings such as upper back discomfort and overall fatigue were not significant. In a follow up study (Cham & Redfern, 2001) the researchers found that in general, floor mats that had the characteristics of more elasticity, less energy absorption, and more stiffness resulted in less discomfort and fatigue. Because the material properties were compared only across six mats authors of the paper caution readers that the findings are not conclusive in terms of desired material properties. They concluded that flooring properties can affect low-back and lower-leg discomfort/fatigue, but also cautioned that the results may be detected only after a long period of standing (three hours).

In the healthcare setting, Hughes and colleagues (2011) identified hazards associated with prolonged standing in the nursing profession, including leg pain, spinal compression, chronic venous insufficiency, increased risk of heart carotid atherosclerosis, and impaired circulation, which in turn can lead to varicose veins, decreased oxygenation, increased fatigue, pain and adverse birth outcomes. The authors recommend various ergonomic tools to reduce the health hazard of standing. Hughes et al. (2011) cite literature that links flooring and shoe features to the side-effects associated with prolonged standing. The dilemma of flooring design decisions is described as follows: "Generally, when a person stands for long periods, softer floors provide less muscle fatigue and more comfort than hard floors, especially for the lower extremities and lower back. Floor material that is too soft, however, will affect stability and may increase muscle demands and fatigue." Authors caution the reader that flexible flooring materials (e.g., wood, cork, carpeting, and rubber) support safer standing than inflexible flooring materials, but may not be feasible in a surgical environment because of infection control issues. Based on the review of the literature, Hughes and colleagues (2011) recommend harder flooring materials in surgical suites covered with anti-fatigue mats with tapered edges to reduce trips, and anti-skid finish to reduce slips.

While there is some evidence to support the use of anti-fatigue mats as discussed above, this is not yet conclusive recommendation. Furthermore, it does not translate to decisions about overall flooring due to the lack of standard tests to measure softness and because different manufacturing companies use different test methods. This makes it is difficult to evaluate the anti-fatigue performance of different flooring materials on human performance in a standardized fashion. One testing method measures cushioning by the density of the flooring surface as a function of foot pressure, and has been used to compare cushioning properties of LVT, rubber and linoleum, as well as carpets with different kinds of cushion underlays. The results show that additional cushioning is not needed for comfort in the use of carpet, and should be avoided due to the negative effect on rolling resistance (Gray 2009).

Balancing cushioning with roller mobility

A NIOSH study (Waters, Collins, Galinsky, & Caruso, 2006), examined the effect of different load weights on full body patient lifting devices (overhead track mounted devices compared with floor-based devices on different floor types - tile, wood and carpet). They found that the force needed to push was higher on carpet compared to wood and tile when considering required pushing, pulling and rotating forces. The study did not give any recommendations for specific floor type due to the large variation in the force attenuation properties within each flooring category. Rather they concluded that ceiling lifts are preferable to floor-based lifts due to the high variability of different flooring types, and the fact that the presence of inclines on the floor increased the push force required. In other words, the difference in the pushing force required to move loads varied so much across different flooring types that ceiling lifts may be preferable.

Another study that compared floor-based and overhead-mounted lifting devices found that during push, pull and particularly rotation movements were significantly less when an overhead-mounted lift was used compared to using floor-based lifts, even when the flooring was optimal- smooth and level flooring, such as the linoleum in the study. The authors cautioned that the required force for patient transfer tasks using wheeled equipment or furniture could exceed acceptable force limits if the floor surfaces were less ideal such as floors comprised of carpet or rough wood (Rice, Woolley, & Waters, 2009). Unfortunately, the study did not compare different flooring types to study the impact with varied flooring characteristics and their effect on roller mobility. Another team of researchers conducted a study analyzing 3D spine forces imposed upon the lumbar spine through various patient handling conditions by manipulating ceiling and floor based patient lifts. Floor based patient lifts included hard surface flooring (polished cement) and short-pile carpet. The results again found that ceiling based lifts are preferable to floor-based lifts. Within the context of floor-based lifts researchers found that conditions operating the system on carpet and operating the system with small wheels, increased the forces on the spine (Marras, Knapik, & Ferguson, 2009).

That said, the push and pull actions associated with the movement of equipment and furniture, with and without the patient, represents a daily requirement for most staff. In addition to flooring lifts, staff members must frequently move hospital beds, IV poles, etc., on a daily basis. So the challenge becomes finding a surface that is smooth, offers minimum roller resistance, while not being slippery, which as previously discussed under EBD Goal 1, can cause falls. Additionally, there is the issue of standing fatigue which can be offset by providing cushioning in the floor, but again, not at the cost of efficient movement of equipment and furniture.

In a white paper that addressed the issue of staff fatigue, Gray (2009) summed up the designers' dilemma in floor selection with the following comment: "Is it possible to choose flooring that will decrease daily fatigue of employees but not increase the difficulty of moving heavy hospital beds?" The biggest challenge regarding staff fatigue is maximizing underfoot comfort while accommodating roller mobility and balance. This challenge is even more difficult because of the lack of ergonomic industry standards related to floor-cushioning and pushing/pulling rolling loads. Gray (2009) investigated the rolling resistance of different flooring products (hard surface- vinyl, rubber, ceramic, and three kinds of carpet), and found that carpet with non-cushioned performance backing can come within a few pounds of the rolling resistance found on hard-surfaces. The author concluded that the ideal flooring system to achieve both anti-fatigue performance and low-rolling resistance is modular or broadloom carpet with a dense, non-cushioned PVC or thermoplastic performance backing. To provide the evidence base for these flooring type recommendations, the valuable insights gleaned from Gray's study need to be repeated in a more controlled research study. Furthermore since the research was conducted by a flooring company (Mohawk), replicating the study in academic or independent industry settings is required. Other research cited in the industry supports the use of firm but cushioned performance backings to improve walking comfort (Busch, 2007). However authors still recommend using non-cushion secondary backings for high traffic areas with extensive wear and tear such as hospitals.

The review of the literature suggests that properties of the floor can have a far reaching impact on staff fatigue and health. However, staff comfort and health must balance with the practical reality of roller mobility associated with the movement of equipment and furniture in healthcare delivery. Further research is needed on the subject, on different kinds of flooring products, and cushion and non-cushion underlays. Research also needs to carefully control for the different types of equipment and human traffic that the floor would support. A thorough analysis of foot and equipment traffic must be made prior to flooring selection to understand how staff will use the space.

The following table summarizes the insights gleaned from the literature review about flooring design and selection considerations to help reduce staff fatigue.

4	REDUCE STAFF FATIGUE	P/A/?/NA
r	Provide more cushioning for areas that require standing for extended periods of time. For areas where infection control is a key issue (such as OR), non-porous/impermeable flooring materials should be used with anti-fatigue mats to provide cushioning where surgeons/staff stand for long durations. If anti-fatigue mats are used, surface should have an anti-skid finish and edges should be tapered to reduce risk of trips (Hughes, 2011).*	
p	Cushioning properties should be balanced with roller mobility for walking areas used for equipment transfer (Gray, 2009).**	
p	Greater roller mobility for high traffic areas like corridors.	
OVERALL LEVEL OF EVIDENCE LINKING FLOOR PROPERTIES TO STAFF FATIGUE		*LOW*
RESEARCH NEEDED LEVEL		*URGENT*

*Note that while there is some evidence on the impact of floor mats on underfoot comfort, the research that investigates this across an entire flooring type is minimal. Additionally effects on fatigue are only seen after an extended period of standing. In the design of healthcare environments cushioning (under-foot comfort) and roller mobility must be balanced, based on the activities performed in an area.
**Note that cushioning properties are also associated with injury reduction and the reduction of impact sound.

EBD GOAL 5: Reduce Surface Contamination and Potential Risk of Healthcare-Acquired Infections

Healthcare-associated infections (HAIs) are infections that patients acquire during the course of receiving treatment for other conditions within a healthcare setting (CDC, 2010). The burden associated with these infections is high, with one out of every 20 hospitalized patients contracting an HAI (CDC, 2010). Klevens and colleagues (2007) estimated that 1.7 million HAI incidents and 99,000 associated deaths occurred in American hospitals in 2002. Numerous recent studies have revealed the enormous cost associated with this preventable occurrence. Scott (2009) estimated HAI associated direct hospital costs between $35.7B and $45B annually. Erber and colleagues (2010) examined 600,000 cases and found 2.3 million hospitalization days that accounted for $8.1B in hospital costs and 48,000 preventable deaths that were attributed to HAI sepsis and pneumonia alone.

CMS' Partnership for Patients program (2012) has targeted several types of HAI infection as focus areas in the campaign to make care safer. Catheter-associated urinary tract infections are caused by germs that enter the urinary system through a tube inserted into the bladder to drain urine. Almost 560,000 health-care-associated UTIs have occurred annually in the past. Hospitals are challenged to cut the number of preventable catheter-associated urinary tract infections in half by 2013, preventing 185,000 cases (CMS, 2012). Another common HAI, central line-associated blood stream infection is also an area of focus with 50% of these serious infections thought to be preventable; the target goal for this area of focus. Similar goals have been identified for surgical site infections and ventilator-associated infections, the details for which can be seen at the Partnership for Patients website http://www.healthcare.gov/compare/partnership-for-patients/safety/index.html learn.

Every health design project must complete an Infection Control Risk Assessment (ICRA) required as described in the Facility Guideline Institute's (FGI) Guidelines for the Design and Construction of Health Care Facilities (2010). The assessment requires two types of recommendations: design aspects with long-range implications for infection prevention, and mitigation recommendations which apply during the construction and commissioning processes (Bartley, 2010). The FGI Guidelines state that "when selecting surfaces and furnishings, there is an expectation to ensure that surfaces meet necessary code requirements, while also looking for characteristics that support sustainability and infection prevention"

(Bartley, 2010; p. S7). Ideal features of surfaces that satisfy sustainability, infection prevention, and safe patient outcomes include cleanability, resistance to moisture, and reducing the risk of fungal contamination (Bartley, 2010; based on CDC and HICPAC Guidelines 2003).

Carpet and HAIs

Many factors contribute to HAIs, especially those that relate to surface contamination and cleaning effectiveness. Although there is no existing evidence that links flooring to HAIs, the use of carpet in patient areas is perhaps its most controversial consideration. In an early study by Anderson et al. (1982), epidemiological and microbiological studies were conducted in a hospital room with carpet and in one with no carpet. Microbiological profiles were determined with specimens obtained from patients admitted to these rooms. In each sampling period, higher microbial counts per square inch were measured for the carpet than for the bare floor. Recovery rates of Enterobacter spp., Klebsiella pneumoniae, and Escherichia coli were higher from carpet samples than from bare floor samples. Organisms (such as E. coli, Pseudomonas aeruginosa, K. pneumoniae, and Staphylococcus aureus) obtained from patients were also more frequently recovered from the carpet than from the bare flooring. However, authors did not find disease in patients to be associated with organisms found as contaminants of the carpet or the bare floor. Other studies that establish the role of carpet as a reservoir for fungi and bacteria include Beyer& Belsito (2000), Gerson et al. (1994), and Skoutelis, et al. (1994).

In an issue paper on the impact of the environment on infections in healthcare facilities Joseph (2006) proposes that new carpeting becomes contaminated very quickly, and the effect of cleaning carpet is transient— bacterial levels soon return to pre-cleaning levels. Moreover, bacterial contamination increases with higher levels of activity, and soiled carpet that is damp or wet provides the ideal setting for bacteria to proliferate. However, Joseph cautions that there is little epidemiological evidence linking carpet contamination with incidence of nosocomial infection among immuno-compromised patients. In fact, there is scant evidence linking floors to nosocomial infections in any patient populations. Some authors argue that with hard-surface flooring particulates are kept airborne, whereas with carpet microorganisms are trapped until they are removed by antimicrobial treatments or removed by high-efficiency particulate air (HEPA) filter vacuum cleaners (Marberry, 2006; Mitchell, 2006). Research by Radke (1997) argues that if carpet is properly maintained it can act as a "sink" allowing harmful allergens, dust, and microorganisms to be trapped and removed by vacuuming. In contrast, airborne particles could be redistributed from hard surface flooring into the air by mopping (Radke, 1997). This finding is supported by the doctoral research by Harris (2000), who found that VCT had a higher level of bacteria in the air samples compared to broad loom carpet; thus as long as proper cleaning protocol is followed, carpet is not a high risk surface for HAI.

Currently, CDC and HICPAC guidelines (Sehulster and Chinn, 2003) do not provide any recommendations against the use of carpeting in patient-care areas, but suggest avoiding the use of carpet in areas where spills are likely to occur (e.g., laboratories, sinks, and janitor closets) or where patients may be at greater risk of infection from airborne pathogens (e.g., burn units, ICUs, and operating rooms). In keeping with the OSHA finding that carpeting contaminated with blood or other potentially infectious materials cannot be fully decontaminated, the CDC suggests that in facilities electing to use carpet for high activity patient-care areas with risk of spillage, carpet tiles can be considered to allow contaminated tiles to be removed, discarded and replaced. In all cases where carpet is used, reasonable efforts to clean and sanitize carpet using recommended carpet detergent/cleaner products must be made (Sehulster and Chin, 2003).

In a recent pilot study, Harris et al (2010) compared the presence of potential pathogens on tiled carpets (non-permeable backing consisting of thermoplastic vinyl composite material reinforced with fiberglass and a proprietary antimicrobial preservative integral in the backing), non-tiled carpets (tufted textured loop nylon type 6/6, 71% solution-dyed and 20% yarn-dyed, with a weight of 23oz/yd2 and pile density of 7886), and vinyl flooring found in a Midwestern community hospital. Using a swab sampling protocol over a five-month period and a denaturing gradient gel electrophoresis-16S rDNA molecular analysis, researchers were able to identify 93% of the major components at the genus and species level with the following findings:

- Tiled carpet samples did not present any known bacterial pathogens, though some retrieved sequences were related to bacterial isolates thought to be rare pathogens, such as Psychrobacter organisms, suspected causes of meningitis. The authors suggest the following reasons for why the carpet tiles had no known pathogens present:

- The presence of antimicrobial substances
- The tiled carpet texture functioned as a sink for organisms, making some organisms inaccessible
- The tiled carpet may not have been exposed to known pathogens

- Samples taken at the edge of the carpet had the highest bacterial diversity (most common genera were Bacillus and Psychrobacter) compared to samples taken from the tile surface or backing.
- Tiled carpet contained an abundance of saprophytic bacteria, suggesting a high content of organic material and the need for additional cleaning.
- The non-tiled carpet controls and tiled carpet had a comparable diversity of genera; however the non-tiled carpet had more pathogenic organisms at the genus level.
- Vinyl control locations had a lower number of genera than found in the carpet samples; however a high number of genus and species associated with genera of pathogenic bacteria.

Regardless, even though the most common nosocomial pathogens were not found in this analysis, several genus/species were identified as major bacterial community members that may represent potential pathogenic agents; therefore all precautions should be taken to avoid exposure of immunocompromised patients to these potential sources of contamination. Harris and colleagues (2010) also recommend additional research to investigate the sources and vectors of pathogenic bacteria; viability and variability of bacterial diversity found on carpet tiles; the impact of cleaning on bacterial type and number; the impact that cleaning equipment has on cleaning effectiveness; and how the effect of the outside environment and seasons affect bacterial diversity. They suggest that carpet may support survival of a more complex community of bacteria making it less prone to immediate changes in bacterial composition when a potential pathogen is present in the hospital environment. This is an interesting possibility which warrants more investigation. In a response to the current state of evidence on carpet and risk of HAI, Dickey (2012) states:

> "Non-solid surface flooring such as carpet is a potential concern because (1) it can be a source of mold growth when it gets wet if not promptly dried or removed (2) it may be a source of airborne pathogens if not carefully removed when in clinical areas and (3) vacuum cleaners used to clean carpet are not always well maintained and may aerosolize pathogens during vacuuming. However, agree 100% that flooring types have not been linked to HAIs."

More research is needed before the final verdict on the use of carpet can be provided. Meanwhile it is critical that strict protocols for cleaning be used for carpet found in patient care areas.

HAIs and Other Flooring Types

Lankford and colleagues (2006) assessed six common floorcovering materials, manufacturer recommended disinfectants, and cleaning methods for efficacy. They contaminated each floorcovering with Vancomycin-resistant enterococci (VRE) and Pseudomonas aerunginos (PSAE) in a concentration that simulated the bacterial content of urine found in bacteriuria. Surface contamination was tested at five minutes after inoculation and then each floorcovering was tested using manufacturer recommended disinfectants and cleaning methods. The results are summarized in Table 2 (on next page), revealing that four of the floorcoverings remained contaminated even after using recommended disinfection and cleaning methods. In reviewing this article and the research on carpeting versus other flooring materials in general, Ulrich and Zimring (2008) suggest that serious pathogens such as VRE may survive less well or for shorter periods of time on carpet compared to other flooring materials. They caution that the merits of carpets versus other floorings with respect to infection control are not clear-cut or fully resolved, and further investigation is warranted. Lankford's findings specific to flooring finishes are summarized in Table 2.

Table 2 - Flooring Surfaces as Pathogen Media, Recommended Disinfectants, Cleaning Methods and Results				
Material (Source for sample used.)	**Pathogen Growth 5 minutes After Inoculation**	**Manufacture Recommended Disinfectant**	**Manufacture Recommended Cleaning Method**	**Results after Cleaning**
Synthetic backed carpet	Confluent growth for VRE and PSAE	8% alkyl dimethyl benzyl ammonium chloride, 8% didecyl dimethyl ammonium chloride (Virex II 256)	Quaternary compound, hot water extraction	No growth for either VRE or PSAE
Vinyl backed carpet	Confluent growth for VRE and PSAE	Anionic surfactant, bactericide with terpene hydrocarbons, undiluted (Sylon-5)	1:1 solution of Melaleuca alternifolia (tea tree oil), agitation	No growth for either VRE or PSAE
Vinyl composition tile	Confluent growth for VRE and PSAE	5% dipropylene glycol methyl ether (Armstrong S-485 Floor Cleaner)	Detergent recommended	*Non-confluent growth for VRE and PSAE*
Linoleum	Confluent growth for VRE and PSAE	8% alkyl dimethyl benzyl ammonium chloride, 8% didecyl dimethyl ammonium chloride (Virex II 256)	Quaternary compound	*Non confluent growth for VRE;* no growth for PSAE
Vinyl Sheet Goods	Confluent growth for VRE and PSAE	5% dipropylene glycol methyl ether (Armstrong S-485 Floor Cleaner)	Quaternary compound	*Non-confluent growth for VRE and PSAE*
Rubber Tile Flooring	Confluent growth for VRE and PSAE	8% alkyl dimethyl benzyl ammonium chloride, 8% didecyl dimethyl ammonium chloride (Virex II 256)	Quaternary compound	*Non-confluent growth for VRE and PSAE*

VRE, Vancomycin-resistant enterococci; PSAE, Pseudomonas aeruginosa
Confluent growth – heavy contamination such that organism growth merges into one mass
Non-confluent growth – less contamination such that organisms form individual colonies
No growth – no organism contamination
Table information adapted from tables found in, Lankford, M. G., Collins, S., Youngberg, L., Rooney, D. M., Warren, J. R. & Noskin, G. A. (2006). Assessment of materials commonly utilized in healthcare: Implications for bacterial survival and transmission. *American Journal of Infection Control 34*(5), 260. The original article includes information about the specific vendors for each flooring material.

An issue paper by Gray (2010) completed a review of the literature with regard to flooring and infection control issues, and concluded the following:

- There is no evidence that floorcovering of any type is a source of healthcare-associated infections.
- Although some anti-microbial environmental additives were shown to reduce the number of microbes in laboratory tests and on treated surfaces but did not inhibit cross-transmission, there was no evidence that this actually reduced the rate of in-hospital acquired infections.

In the UK, recommendations for flooring include smooth, impermeable surfaces for floors, and appropriate skirtings (Healey, 2007). Scottish guidance stated that the right angle joints between walls, floors, and ceilings should have coving for ease of cleaning, and that surface joints should be kept to a minimum; and where they exist, surface joints should be sealed effectively (McDonald, 2010).

The review of the literature suggests that properties of the floor can have far reaching impact on surface contamination. However, until issues of cleaning and maintenance are isolated from the intrinsic properties of the floor itself, results will remain inconclusive. Further research is needed with different types of flooring products, while controlling for surface finish, and cleaning protocols.

The following table summarizes the insights gleaned from the literature review about flooring design and selection considerations to help reduce floor surface contamination.

5	REDUCE FLOOR SURFACE CONTAMINATION AND POTENTIAL RISK OF HAI	P/A/?/NA
s	Carpet is avoided in areas where spills are likely to occur (e.g., laboratories, sinks, and janitor closets) or where patients may be at greater risk of infection from airborne pathogens (e.g., burn units, ICUs, and operating rooms) (CDC - Sehulster & Chinn, 2003).	
s	Do not use carpeting in hallways and patient rooms in areas housing immunosuppressed patients (CDC, 2003).	
p	Surface material is compatible with the sanitizing methods as outlined in the CDC 2003 recommendations for general cleaning strategies of patient care areas.	
p	Surfaces (and joints) are nonporous and impermeable to the extent possible without increasing slipperiness.	
p	Right angles joints between walls and floors are coved to facilitate effective cleaning.*	
s	In facilities electing to use carpet for high activity patient-care areas with risk of spillage, carpet-tiles can be considered to allow contaminated tiles to be removed, properly sanitized or discarded and replaced (CDC, 2003).**	
OVERALL LEVEL OF EVIDENCE LINKING FLOOR PROPERTIES TO HAI		*LOW*
RESEARCH NEEDED LEVEL		*URGENT*

* For hard/resilient flooring only.
**Note that while it is possible to create moisture barrier backings for the carpet tile, currently there is no method to effectively seal the seams that can act as a moisture barrier without welding the seams together (in which case the tile cannot be replaced). If wall-to-wall moisture impermeability is preferred, then the flooring selected should be both impermeable and welded at the seams following industry standards. Also note that in cases where a spill permeates to the sub-floor, the sub-floor would need to be treated as well and the cost associated with removing, cleaning and replacing tiles, and if needed treating the subfloor can become extensive.

Note that currently there is no evidence linking flooring to HAI, and no causal links between use of antimicrobial treatments and HAI. Additionally there are environmental concerns with using antimicrobial products from an IAQ perspective (See EBD Goal 7).

EBD GOAL 6: Improve the Patient Experience

Wayfinding

The experience of a patient and their family begins at the very first threshold of the hospital. Providing a clear path for patients to move from each point of entry to all major destinations is a significant factor in reducing patient and family stress. Flooring choices can be a subtle, yet effective means to improve wayfinding (Malkin, 1992). Color schemes that differentiate departments, floors or wings can aid in wayfinding. Accent colors, such as inlays and borders, can also be effective. The use of varying floor materials can help define public, visitor-only and private areas in the hospital. Moreover, flooring can define transitional, in-between spaces that signal a change to a more private space (HFM, 2007). That said, there is a challenge in varying flooring material linked to falls (see EBD Goal 1). Varying flooring materials without appropriate transitions, or in unexpected areas (such as within a waiting room), can increase risk of falls. High contrast patterns may impair balance, especially amongst older adults with impaired vision. Thus issues about flooring patterns must be weighed carefully against the perception related issues related to stumbles and trips.

Visual Appeal

Because of the large square footage covered by flooring, it is one of the most visible areas of the interior environment. Flooring that is ill-maintained, scratches easily or shows scuff marks, will be noticed immediately. As a result, durability and visual appeal becomes a key concern that links to patient satisfaction. Additionally, flooring (in the choice of colors, patterns and textures) must support the overall aesthetic of the environment to add to the element of "attractiveness" which has been linked to increased patient satisfaction and perception of quality of care (Becker, 2008).

Shine/Reflectiveness/ Glare

Another common approach in hospitals has been to promote a perceived clean, institutional look achieved with waxed and shiny floors. Research now shows that too much waxing can make the floor slippery, and the shine can add to glare, which can both increase risk of falls, as described earlier under EBD Goal 1. Joh et al. (2006) reported that "shine" was the most frequently mentioned response when participants were asked: "By only looking at it, how would you tell if the floor was slippery?" Additional experiments demonstrated that people rely on "shine" information in forming judgments of slipperiness despite variations as a function of surface color, viewing distance, and lighting conditions. Lesch and colleagues (2008) conducted a study asking participants to rate 38 different floor surfaces in terms of slipperiness, reflectiveness, light/dark, traction, texture and likelihood of slipping. The participants were asked first to rate the slipperiness of the surfaces, then asked a set of questions in a randomized order, and ended the test session by going back to the first question to rate the slipperiness. Participants reported that reflectiveness had the strongest correlation with perceived slipperiness. The issue of glare has been discussed in EBD Goal 1 in terms of the impact on slips and trips. Increased *perception* of slipperiness due to glare or high reflectiveness can potentially reduce patient satisfaction.

Patient Satisfaction and Overall Comfort

Although empirical research is lacking on the precise role flooring plays with regard to patient satisfaction, there are many best practice examples that link the visual appearance and appeal to patient satisfaction. More attention will be given to the role that flooring plays in influencing patient responses to two of CMS' patient satisfaction survey - HCAPHS – questions. The first question is "During this hospital stay, how often were your rooms and bathroom kept clean?" Stained and smelly flooring may influence a patient's response to this question. The second question addressed previously under EBD Goal 3, "During this hospital stay, how often was the area around your room quiet at night." As previously discussed, carpet helps to reduce impact generated noise, and healthcare leaders have more incentive to reduce noise since reimbursement will be tied to HCAHP results. The choice of flooring also goes a long way for help with patient comfort – both physical and psychological. Harris (2000) found in her research examining the impact of flooring in a telemetry unit that, while staff perceived patient rooms with VCT to be cleaner, have better odor, ventilation and air movement, they found rooms with carpet to be more comfortable, have less noise and glare, and have better temperature with fewer temperature shifts. Similarly, patients perceived patient rooms with VCT to be cleaner, with better ventilation and fresher air, but rooms with carpet to have more comfortable temperatures. One of the most significant findings of the Harris (2000) study was that the amount of time visitors spent in rooms with carpet was higher compared to rooms with VCT; perhaps an indication of how environmental quality can influence behaviors which may be beneficial to patients (Harris, 2011).

Thermal Comfort

Thermal comfort, or acceptable thermal conditions, depend on a combination of air temperature and mean radiant temperature (Olesen, 2002). Keeping walls, ceilings and floors within a reasonable thermal range is a key component of thermal comfort. The ASHRAE 55P Standards (2010) on thermal environment conditions for human occupancy provide some insight into desired ranges of thermal comfort. The ASHRAE standards acknowledge the subjectivity of thermal comfort by including the following factors in their comfort considerations: metabolic rate, clothing insulation, air temperature, radiant temperature, air speed and humidity. Floor surface is related to radiant temperature. In its section on floor surface temperature, the document determines that for people wearing shoes the temperature of the floor is more important than the material of the floorcovering. There are no recommendations made for floor surface temperature in healthcare environments, probably because of the complex nature of thermal comfort, as well as the lack of research. Hedge (2003) suggests that a material like carpet, because of its fibrous construction, traps a layer of air close to the floor, which acts as an insulator. He also suggests that an additional pad under the carpet can add to the thermal insulation. How flooring contributes to the overall thermal comfort is a much needed area of research. The subject of surface temperature and radiation is closely linked to the materials' ability to provide thermal insulation, which is also an energy saving benefit discussed in EBD Goal 8.

In thinking about the patient experience from a perception standpoint it is evident that different flooring finishes offer different advantages, and a designer must be mindful of minimum performance requirements and the trade-offs. What is important is that the design be thoughtful and tailored to the intended use of the space.

The review of the literature suggests that floor design can improve the overall patient, and potentially family experience; but more research is needed to provide an evidence-based approach.

The following table summarizes the insights gleaned from the literature review about flooring design and selection considerations to help improve the patient experience.

6	IMPROVE THE PATIENT EXPERIENCE	P/A/?/NA
p	Use floor design to support wayfinding by using colors and patterns in line with the overall design scheme.*	
p	Use flooring materials that are visually appealing and "non-institutional".	
p	Use thermally insulating material to improve thermal comfort (see EBD Goal 8).**	
p	Use non-glare finishes to avoid strain on sensitive eyes.	
p	Maintain visual appeal by durable surfaces that do not scratch or scuff easily.*	
OVERALL LEVEL OF EVIDENCE LINKING FLOOR PROPERTIES TO STAFF FATIGUE		*LIMITED*
RESEARCH NEEDED LEVEL		*URGENT*

*Use of high contrast patterns must be weighed against perceptual issues that may impair balance, especially in areas where patients may have impaired vision (see EBD Goal 1).
**Use of thermal insulation suggests use of thicker material that can trap air, which in turn may increase risk of surface contamination.

Note that all the recommendations in this section are based on best practices and have not been empirically tested.

EBD GOAL 7: Improve Indoor Air Quality (IAQ)

According to the Environmental Protection Agency (EPA), building materials can have a large impact on air quality, which in turn can affect the occupants (EPA, 2007). Due to the great advances made in the field of sustainability, there is a significant body of work that can guide designers and practitioners on the environmental impact of flooring selections. This paper does not cover this this goal in detail. Readers should access additional resources from the U.S.Green Building Council website. More empirical research is needed making causal links between the flooring properties and environmental outcomes, and linking the environmental outcomes to health outcomes. The following design features are recommended based from a cursory review of some of the current industry standards (Green Guide for Healthcare, 2007; LEED, 2009; EPA, 2007; Healthy Building Network, 2008; Green Seal, 2011) summarized below:

7	IMPROVE INDOOR AIR QUALITY (IAQ)	P/A/?/NA
s	Floorcovering should have minimum emission of VOCs and meet the requirements of the California Department of Public Health Standard Method for testing and evaluation of VOC emission (LEED, 2009).	
s	All carpet and carpet cushion should meet the Carpet and Rug Institutes (CRI) Green Label Plus (LEED, 2009).	
s	All adhesives and sealants for seams and joints should meet USGBC LEED for Healthcare standards (LEED, 2009).	
s	Tile setting adhesives must meet USGBC's LEED for Healthcare IEQ standards (LEED, 2009).	
s	Cleaning products specified should met Green Seal GS-37 and GS-40 standards (Green Seal, 2011).	
s	Minimize need for surface coating (EPA, 2007).	
p	Use permanent walk-off mats at entry ways to capture dirt and particulates entering the building. • If used, the mats should be maintained regularly by a contracted service organization. • If used, mats should be firmly anchored, and at least 10 feet in length in the primary direction of travel.*	
OVERALL LEVEL OF EVIDENCE LINKING FLOOR PROPERTIES TO IAQ		*MEDIUM*
RESEARCH NEEDED LEVEL		*MEDIUM*

*See EBD Goal about minimize risk of slips, trips and falls.
Note that while there are excellent standards in place that make the selection of materials easier, there remains a lack of empirical research which must be conducted to advance the field.
Please refer to LEED Guidelines for Healthcare for more information.

EBD GOAL 8: Represent the Best Return on Investment

In healthcare organizations, flooring represents a significant investment over the lifecycle of the facility, literally underpinning all healthcare delivery activities and covering thousands of square feet. As a first step, it is imperative that before making any flooring decisions, a comprehensive analysis of both first time and life-cycle costs associated with flooring options is conducted, and then evaluated within the context of a return on investment (ROI) analysis, providing leaders with a value-based, bottom-line driven framework for decision-making. Central to the business case is the need to balance one-time construction costs against ongoing operational costs and revenue enhancements over the 30-plus years that most healthcare facilities exist (Sadler et al., 2008). In the case of flooring, first-time costs need to be offset with lifecycle costs, which include consideration of the financial impacts associated with patient and staff outcomes, such as those that were discussed in the first seven EBD goals found in this paper, coupled with linked financial reimbursements. Calculating these true costs represents an critical strategic consideration, which should be conducted early in the planning process – one rarely performed in the healthcare industry.

Calculating Cost: First Time + Lifecycle Costs

Bishop (2002) provides a comprehensive analysis of life-cycle cost for floorcoverings in school facilities, which includes the initial purchase cost, installation charges, maintenance requirements and associated costs, plus the cost of maintaining the floor, to include cleaning chemicals over a predetermined period of time, in order to understand the total expenses associated with a flooring investment. Bishop cautions the reader that life cycle costing does not necessarily mean that the longer something lasts, the less the cost over time. This case is proved by his comparison of the life-cycle costs of carpet and VCT, over a 22 year period, which is the expected usable life of VCT in schools. The usable life of carpet is 11 years and so replacement costs, accounting for inflation, have been included in the analysis. In this case, the author found that at the end of the 22 year time period, carpet expenditures were more cost effective than VCT, even though carpet had the higher purchase and installation cost. The cost of cleaning and maintenance was calculated over the school calendar year, for each material, using the following template:

FLOOR TYPE	FREQUENCY	MINUTES/ 1000 SQ.FT.	TOTAL MINS./ 1000 SQ. FT	TOTAL COST
CLEANING ACTIVITY				

A different calculation was made for light-medium traffic areas, compared to heavy traffic areas, a method that is valuable for healthcare facilities as well.

It is not uncommon for flooring manufacturers to provide life-cycle cost analysis for their product compared to other popular products in the industry. However, since the detailed calculations are rarely shared and the data is biased due to issues of vested interest, it becomes tough for a client to make decisions on this information alone. Adapting Bishop's template to the healthcare environment, including the cost of the cleaning solutions and materials used, provides a research formula to compare life cycle costs of commonly used floorcovering materials in healthcare institutions, and establish standard benchmarks, which can be used by the industry to evaluate flooring and floorcovering investments. See Appendix 3 to see some examples of lifecycle assessment across different flooring types.

Energy savings represents another important variable to consider. LEED standards should be referenced before making such determinations. In particular the role of thermal insulation is important, since it is tied back to the issue of thermal comfort discussed in EBD Goal 6 (improving patient experience). Thermal insulation properties of finishes, including floorcoverings, are measured in terms of R-value (which indicates the resistance to heat flow). According to the Oak Ridge National Laboratory (ORNL, 2008), the higher the R-value the greater the insulating effectiveness. R-value depends on the type of material, its thickness and density, and in the case of multi-layered installations, R-values of each layer have to be considered independently.

Evaluating Return on Investment

Once a comprehensive understanding of flooring costs over the lifecycle is conducted, the next step is to consider the impact of this investment on healthcare outcome associated costs and revenue. To our knowledge, this complex, multivariant calculation has never been performed in a healthcare setting. However, given the changes in reimbursement practices associated with hospital-acquired conditions and patient satisfaction consequent to the enactment of the 2010 Patient Protection and Affordable Care Act, as have been described in the various EBD goals in this paper, there are new incentives to understand the role various environmental features, including flooring play in achieving desired healthcare outcomes and estimate the impact on costs, revenue and reimbursement. Sadler et al (2008) provides a model that can be used to compute the costs, and estimate the best return on flooring investments. Healthcare specific comprehensive flooring investment ROIs are needed to better understand the inherent cost and benefit associated with each flooring design decision.

The following recommendations relate to the overall process of flooring selection rather than specific performance characteristics.

8	REPRESENT BEST RETURN ON INVESTMENT	P/A/?/NA
p	Balance first time costs with life-cycle costs before making flooring selection First-time cost (materials and installation) balanced with life-cycle costs (maintenance, repairs and replacement) (including the initial maintenance required to prep the flooring (if any) after installation and prior to occupancy)	
p	Carefully evaluate results of safety and durability testing	
p	Ensure that the flooring supports the organizational mission, branding and strategic goals of the organization	
p	Calculate energy savings (if any) based on material properties of thermal insulation	
p	Estimate the extent to which the flooring aids in improving safety and quality outcomes (Goals 1-7) to calculate Return on Investment	
Calculating return on investment is a complex calculation which is based on projected costs and returns. It should be carefully conducted with the right team of experts and a financial analyst.		

Discussion

Floorcoverings occupy every square inch of measured healthcare facility space, representing a major investment opportunity to help shape positive healthcare outcomes. Floorcoverings are part of a flooring system/assembly that consists of the sub-floor for support, the floorcovering (which may have underlays), and the surface finish that forms the final walking and rolling surface. When making decisions about flooring it is important to first make sure that the system, as a whole, works. Although structural issues and issues of floor preparation and installation have not been covered in this document, they too may play an important role in mitigating adverse health or environmental outcomes. No floorcovering, regardless of how thoughtfully it has been selected, can be effective if it is not installed properly, or subsequently cleaned and maintained as per its unique requirements.

In this paper, the literature has been reviewed to provide an evidence-based set of criteria based on research findings, industry standards, and best-practices. This can be used to evaluate different flooring options, fully acknowledging that each floorcovering comes with its own unique considerations. Although there are many studies that address flooring or include flooring as part of the set of design solutions, the causal link between a specific flooring property and specific outcomes of interest is low. Eight EBD goals of interest were identified in this study, and prioritized based on the current level of evidence available, as listed below:

1. Reduce slips, trips and falls
2. Reduce patient and staff injuries, associated with falls
3. Reduce noise levels
4. Reduce staff fatigue
5. Reduce floor contamination
6. Improve the patient experience

7. Improve indoor air quality

8. Represent best return on investment

When evaluating the research for each EBD goal, it was evident early on that floor selection is complex and frequently trade-offs must be considered carefully in the flooring design decision-making process. Where this is true, criteria were annotated with notes indicating the trade-off to be considered. To use the Flooring Considerations List found on page 5-9 it is important to carefully examine the annotations. It is also important to understand if the recommendation is based on peer-reviewed research (r), existing standards (s), or best practice sources (p).

A surprisingly small, but compelling body of that knowledge was found that revealed how flooring could impact healthcare outcomes, which is summarized for each of the goals above, the findings of which were distilled into an evidence-annotated list of floorcovering characteristics. The complexity of floorcovering decision-making was explored in the context of the many trade-offs that must be evaluated with each option, such as whether to specify a softer floor to cushion patient falls and minimize patient injuries, as well as to reduce staff fatigue versus providing roller mobility for equipment movement. Where evidence is missing, the case was made for urgent research, providing a list of recommended topics. A great deal of the research that was examined was conducted in a laboratory setting, not in the complex healthcare delivery environment with endless intervening variables. Once flooring is installed, there can be many changes in surface conditions due to variation in cleaning protocols, different surface finishing products (such as wax), and the wear and tear over time, which make it challenging to study flooring comprehensively. The key insights include:

1. **Understand evidence-limitations**. The level of evidence is limited due to the lack of standards, lack of replication of lab-base studies in real life settings, lack of metrics and tools for data collection, absence of a reporting process that tracks extrinsic factors such as flooring conditions alongside the outcomes of interest (such as falls), and the challenge of changing flooring conditions due to maintenance issues regarding cleaning and surface coating. The highest level of evidence is found for falls and injuries, followed by noise, fatigue, infection prevention, overall patient experience and indoor air quality. Additionally the challenge is that while flooring has been a component of the research that has looked at these issues, its impact has

not been teased apart due to a "bundled" approach to the intervention, and too many confounding variables. Additionally there is a lack of understanding about tools and metrics available to test flooring characteristics, which is compounded by the lack of industry standards. The business case for flooring has not been made beyond the comparison of lifecycle costs.

2. **Focus on the characteristics for each individual flooring product**. Within the industry's broad flooring categories — hard/soft/resilient — there is a significant variation of the products. The research shows that the evidence is inconclusive for any broad category of flooring having an advantage over another. Rather than using a generalized flooring category, the design team must evaluate individual products based on their performance against each EBD goal before deciding on the right flooring material and design for a particular area.
3. **Consider the trade-offs for each product in the context of intended use.** In aiming for desired healthcare outcomes, trade-offs need to be made between different flooring characteristics. A one-size-fits-all approach cannot be used to select flooring types since different flooring characteristics and properties impact different outcomes. For example a harder floor can reduce staff fatigue but increase risk of injury from falls, whereas a softer floor can reduce risk of injury but increase staff fatigue. Similarly a thicker and fibrous material such as carpet can aid thermal insulation but increase risk of surface contamination. The same property of the floor that aids underfoot comfort can inversely affect roller mobility. Each product should be analyzed for its individual properties, which can then be evaluated in the context of desired outcomes for a particular healthcare space, carefully weighing the trade-offs associated with each option.

4. **Use a flooring-system approach.** Flooring is a complex system comprising of the assembly of sub-floor support, the adhesives and underlays, the floorcoverings, and the surface finish. Any decisions regarding floorcoverings must also consider how the system comes together, and works together over time as an integrated system. Additionally, considerations of cleaning protocols or added finishes (like an additional coating of wax) need to be considered carefully. Some outcomes are linked to just the flooring finish, such as falls, and this finish can be impacted by the surface coating, cleaning protocol and the wear and tear to the finish as installed over time. It is important to maintain a performance check protocol on the floor finish to ensure that the floor is still

functioning as intended at install. Outcomes such as fatigue, noise absorption and roller mobility are a function of the floorcovering as well as the underlay. Other outcomes linked to impact, such as injuries and sound transmission, are a function of the entire assembly. Careful consideration must be paid not just to the floorcovering (which has been the primary focus of this paper), but also the underlay and the subfloor. Considerations of how the slab is treated before install and use of adhesives is linked to the efficacy and lifecycle of the flooring as well as sustainability issues. Although these issues are not considered in detail in this paper, each flooring product adheres to strict industry standards on both these issues which must be taken into consideration while selecting flooring.

Urgent Call for Research

In undertaking this literature review, it was surprising to learn how little was published about the flooring and its role in healthcare. Thankfully, several healthcare-flooring-focused papers will be published in the near future that should begin to fill this gap:

- A systematic review of the literature on flooring by Debra Harris, PhD, will be published in HERD in the coming spring (Harris, in press)
- An industry resource developed by Whitney Gray, PhD, comparing different types of flooring is soon to be published
- A new“Falls Environment Evaluation Tool” (FEET) by Maggie Calkins, PhD, soon to be available at the Center for Health Design website.

In addition, what is urgently needed is a nexus between industry, academia and healthcare operations to conduct basic and applied research on how specific flooring and floorcovering characteristics can impact health outcomes. A common framework needs to be created that facilitates the comparison of the myriad of flooring products that are in the market today. For most EBD goals it is apparent that research is urgently needed and each section ends with some ideas on potential research topics which are tabulated below:

EBD GOAL	RESEARCH NEEDED
1 **REDUCING SLIPS, TRIPS & FALLS**	1. Replication of lab-based studies in real life settings 2. Longitudinal study (over multiple years) examining floor surface characteristics and impact on slip resistance 3. Studies on the impact of floor transitions (changing flooring materials and use of high contrast patterns) on trips and falls. 4. Development of tools to match floor characteristics and situational conditions to health outcomes of interest 5. Development of clear definitions of flooring characteristics (such as slip resistance, Coefficient of Friction, Shine or Light Reflectiveness etc.) and the metrics/ testing methods to measure these. 6. Multiple outcome studies that look at impact of flooring on slips, trips, falls, vis-à-vis surface contamination and risk of infection, and carefully evaluate trade-offs.

(Continued from previous page)

EBD GOAL	RESEARCH NEEDED
2 **REDUCING INJURY**	1. Replication of lab-based studies in real life settings including patient fall and injury outcome data. 2. Studies that isolate the various elements of the flooring assembly to better understand the role of each separately and together on fall impact and associated injuries. 3. Multiple outcome studies that look at impact of flooring on injury, sound transmission, roller mobility and staff fatigue and carefully evaluate trade-offs.
3 **REDUCING NOISE LEVELS**	1. Lab-based and real-life studies on the impact of different types of flooring on airborne noise as well as impact noise and sound transmission. 2. Studies on environmental noise that tease apart the effect of flooring, from the effect of other interior materials and finishes (like ceilings and walls). 3. Developing and using tools that measure sound absorption and transmission (objective) alongside perception of noise (subjective) to get a comprehensive understanding about the impact of flooring. 4. Multiple outcome studies that look at the impact of floorcoverings on noise reduction, thermal comfort and surface contamination, and evaluate trade-offs.
4 **REDUCING STAFF FATIGUE**	1. Studies that evaluate functional requirements across various settings associated with human and equipment traffic needs (standing: underfoot comfort, pushing equipment: roller mobility, walking: cushioning and balance etc.). 2. Comparison of the ability of different flooring types to meet comfort requirements described above (while carefully controlling for the ergonomics of the equipment). 3. Studies comparing underfoot comfort vis-a-vis push/pull forces on cushion versus non cushion secondary backings. 4. Multi-variable studies that evaluate floors with underfoot comfort and roller mobility in the context of patient falls and associated injuries.
5 **REDUCE SURFACE CONTAMINATION & RISK OF HAI**	1. Laboratory-based studies on surface contamination by common healthcare pathogens for a variety of floorcoverings. Evaluation of whether floors contaminated with these organisms result in transmission to patients, resulting in documented HAI. 2. Investigation of the role of flooring such as carpet to act as a “particulate sink” with the ability to trap microorganisms until they are removed by HEPA filter vacuum cleaners. 3. Investigation of the differences between flooring types and their recommended cleaning products to learn more about the extent to which cleaning protocols can effect surface contamination by combining design and process improvement outcomes. 4. Studies on moisture permeability across different flooring types, and the trade-off between impermeability and ease of replacement. 5. Multi-outcome studies that look at the business case of trade-offs associated with cleanability vis-à-vis outcomes associated with falls, injury, comfort, noise and fatigue.
6 **IMPROVE THE PATIENT EXPERIENCE**	1. Patient satisfaction surveys that ask questions (direct and indirect) related to flooring appearance, comfort, and convenience. 2. Lab-based and real-life (on site) studies on the visual appearance and visual and physical comfort over the lifecycle of a flooring material. 3. Studies on the use of flooring as a wayfinding aid. 4. Multiple outcome studies comparing quality of care outcomes (comfort, visual appeal, satisfaction, wayfinding etc.) to safety outcomes (slips and trips, falls and injuries, risk of HAI) and evaluating trade-offs.

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EBD GOAL	RESEARCH NEEDED
7 **IMPROVE INDOOR AIR QUALITY**	1. In conjunction with other green initiatives, investigation of VOC emission rates and efficacy of anti-microbial products. 2. Study the use of walk-off mats at entryways, and extent to which recommended maintenance protocols are followed. 3. Study of how use of different flooring materials can impact IAQ, and if the use of “particulate sinks” is beneficial.
8 **REPRESENT BEST RETURN ON INVESTMENT**	1. Studies that develop and test ROI methodology which calculate flooring first-time and life cycle costs, including estimates of flooring impact on healthcare outcomes.

It is important to conduct studies that are collaborations between industry partners, academic researchers and research practitioners to ensure that studies are rigorous, unbiased, and transparent, while staying pertinent and topical to the industry. Additionally it is important to consider human and material/surface properties together. Results of studies conducted within the industry should be shared more openly to inform not just clients, but guidelines and standards.

A note about standards:

In the course of examining the evidence, many missing or ill-defined standards were identified with regard to floorcovering properties, with very few standards that focused specifically on the unique requirements of the healthcare environment. Given the ubiquitous nature of flooring and the high-risk environment of healthcare, standards are needed that specifically address the needs of the vulnerable populations that use healthcare facilities. Many of the standards, such as the CDC 2003, are almost a decade old and the information may not reflect new advances in flooring technology. Additional floorcovering standards that require further development include:

- Defining, measuring and testing floor slipperiness
- Defining, measuring and testing floor cushioning in the context of patient and staff use and roller mobility for equipment movement
- Developing NRC ratings in the healthcare setting
- Cleaning and maintenance requirements to reduce surface contamination
- Ergonomic standards related to human performance such as acceptable push/pull loads which can determine the standards for floor cushioning

Final Thoughts

Many research opportunities have been identified for healthcare interdisciplinary, industry and academic teams to collaborate and expand the science, in order to further our understanding. In spite of the crucial role flooring can, and does, play, the attention it has received in research is minimal and this need to be remedied in an initiative that has industry, academia and research-practitioners working side by side to create projects. In addition to more focused research, more attention is needed to the monitoring and reporting of extrinsic factors such as flooring to allow correlations between health outcomes and flooring types. Additionally there is a need to develop floorcovering standards specific to its performance in the complex, healthcare environment. In the industry, there is a constant pressure to choose between the latest and greatest product- there is an urgent need to create a common evidence based platform upon which these decisions can be made. This paper does not seek to provide prescriptions for design, but rather to provide a tool that can inform designers in their own evaluation of different products, tailored to their unique context of application, within the complex healthcare fabric.

These findings represent the first step in a journey to better understand how floorcoverings contribute as an important, but often unconsidered, design element in the achievement of desired healthcare outcomes. This limited evidence has been translated into an evidence-based list of performance characteristics for floorcoverings that can be used to evaluate different floorcovering types in support of facility lifecycle activities. This list now needs to be tested for clarity, usefulness and practicality by its intended users – the multidisciplinary members of the design team- to create a tool that can aid design decision making based upon the best available evidence.

Appendix 1: List of Flooring Types

Information from: Materials and Assemblies I, Interior Design Program, UTSA. Instructor: Irina Solovyova, Ph.D.

Flooring types

1. Hard Floorcoverings
    a. Tile flooring
        i. Ceramic / glazed or unglazed
        ii. Glass
        iii. Mosaic
        iv. Porcelain
        v. Quarry / glazed or unglazed
        vi. Stone
    b. Concrete and cementitious flooring
        i. Concrete
        ii. Terrazzo
        iii. Poured flooring
            1. Epoxy resin
            2. Methyl methacrylate
            3. Magnesium oxychloride
            4. Latex resin
            5. Fluid-applied athletic
            6. Seamless quartz
    c. Wood flooring
        i. Planks
        ii. Strips
        iii. Engineered wood
        iv. Parquette
    d. Laminate flooring
    e. Bamboo flooring
2. Resilient Flooring
    a. Cork flooring
    b. Linoleum flooring
        i. Linoleum
        ii. Marmoleum
    c. Rubber
    d. Vinyl flooring products
        i. Solid vinyl tile
        ii. Vinyl sheet
        iii. Vinyl composition tile
3. Soft floorcoverings (textile based)
    a. Carpets *: Carpets range tremendously based on fiber composition, construction methods, and carpet pile. Basic categorization is woven or tufted.
    b. Rugs

Appendix 2: Floor Testing Organizations

NFSI:
The National Floor Safety Institute was founded in 1997 as a not-for-profit 501 (c) (3) organization whose mission is to aid in the prevention of slips, trips-and-falls through education, research, and standards development. The NFSI is led by a fifteen-member Board of Directors representing product manufacturers, insurance underwriters, trade associations, and independent consultants. In June 2006, NFSI was designated as a Standards Developer for the American National Standards Institute in developing standards for Safety Requirements for Slip, Trip, and Fall Prevention under the NFSI B101 Standards Committee.

In October 2009, ANSI approved the first NFSI Standard, the ANSI/NFSI B101.1-2009 Testing Method for Measuring Wet SCOF of Common Hard-Surface Materials. Since that time the NFSI B101 Standards Committee has published three additional standards: ANSI/NFSI B101.0-2012 Walkway Surface Auditing Procedure for the Measurement of Walkway Slip Resistance; ANSI/NFSI B101.3-2012 Test Method for Measuring Wet DCOF of Common Hard-Surface Floor Materials (Including Action and Limit Thresholds for the Suitable Assessment of the Measured Values); and ANSI/NFSI B101.5-2012 Standard Guide for Uniform Labeling Method for Identifying the Wet Static Coefficient of Friction (Traction) of Floorcoverings, Floorcoverings with Coatings, and Treated Floorcoverings.

In addition to NFSI, there are various standards organizations for different flooring types. The following is a list of standards for different flooring properties and the associated testing organizations, based upon course material from the "All Materials and Assemblies I course, Interior Design Program, University of Texas at San Antonio. Faculty: Irina Solovyova, Ph.D.

	Carpet	Rubber	Vinyl	Ceramic Tile
Standard Specification			A STM F1700 - 04(2010) ASTM F1303 - 04(2009) ASTM F1066 - 04(2010)e1	ANSI 137.1
Flammability				
Flame spread	ASTM E 84 NFPA 255 UL 992	ASTM E 84 NFPA 258 UL 992	ASTM E 84 NFPA 258 UL 992	
Surface flammability ignition	DCC-FF1-70 DDD-C-95(Rev) ASTM 2859-70T DOC-FF 2-70			
Flooring radiant panel test	ASTM E-162-67 NBS IR-75-950 NFPA 253		ASTM E 648	
Smoke	NBS 708 NFPA A 258/1976		ASTM E 662	
Colorfastness				
To light	AATCC 16E-1982			
To gas	AATCC 23-1975			
To ozone	AATCC 109-1975			
Crocking	AATCC 8-1981			
Shampooing	AATCC 107-1975			
Acoustics				
Airborne sound	AS TM C 423 PBS C.1			
Impact sound	ASTM C 423-66 PBS C.2		ASTM E 492	
Electrostatic	AATCC 134-1979			
Light reflectance	ASTM E 97 IES transaction		ASTM 1347 (color difference)	
Azotic control	AATCC 112/30/90			

	Carpet	Rubber	Vinyl	Ceramic Tile
Durability				
Tuft bind	ASTM D 1335 DD C 0095A			
Delamination	FTMS 191-5100			
Breaking	FTMS 191-5100			
Shrinkage	DOC C 0095 A			
Appearance				
Piling/Fuzz	Dupont TRL 609			
Stain resistant	PBS-F.2			
Crush resistant	FTMS 502A/3231			
Abrasion	ASTM D 1175 641			
Accessibility	ADAAG	ADAAG	ADAAG	ADAAG
	4.5 Ground and Floor Surfaces	4.5 Ground and Floor Surfaces	4.5 Ground and Floor Surfaces	4.5 Ground and Floor Surfaces
Slip resistance			ASTM D 2047	

ASTM E-84 – Steiner Tunnel Test
UL 992 - Chamber test
DOC FF 1-70 – Methenamine Pill Test
NBS IR 75-950 & NFPA 253 – Flooring Radiant Test
NBS 708 – Smoke Density Test

Testing and Standards organizations:

ASTM - American Society for Testing and Materials, http://www.astm.org/
NFPA – National Fire Protection Association, http://www.nfpa.org
UL - Underwriters Laboratories, http://www.ul.com/global/eng/pages/
ANSI – American National Standards Institute, http://www.ansi.org/
ISO – International Organization for Standardization, http://www.iso.org/iso/home.html
NBS – National Bureau of Standards, http://www.nist.gov/index.html
DOC – Department of Commerce, http://www.commerce.gov/

AATCC – American Association of Textile Chemists and Colorists, http://www.aatcc.org/
FTMS - Federal Test Method Standard
IES – Integrated Environmental Solution, http://www.iesve.com/
PBS – Public Building Service, http://www.gsa.gov/portal/content/104444
NALFA – North American Laminate Flooring Association, http://nalfa.com/ansi_standards.php
NWFA – National Wood Flooring Association, http://woodfloors.org/
OSHA – Occupational Safety and Health Administration, http://www.osha.gov/SLTC/walkingworkingsurfaces/index.html
TCNA - the Tile Council of North America, http://www.tileusa.com/
CRI – Carpet and Rug Institute, http://www.carpet-rug.org/
ADAAG – Americans with Disabilities Act Accessibility Guidelines, http://www.access-board.gov/adaag/html/adaag.htm
EverySpec, http://www.everyspec.com/ - Free source for specifications, standards and handbooks

Appendix 3: Floor Type Comparisons by Different Studies (Not Empirical Data)

The following tables have been compiled from different articles that compare flooring types. These have not been included in the main text since they lack empirical data. However, it may be useful to look at this table alongside the set of EBD criteria outlined in the paper.

Table 1 Life Cycle cost comparisons across flooring types

Flooring Type	Life Cycle	Initial Cost	Maintenance
Terrazzo	Long life	High	Very low
Linoleum*	Long life	Above average	Very low
Rubber*	Long life	Above average	Very low
Porcelain tile	Long life	Average	Low
Welded-seam sheet vinyl	Moderate	Average	Moderate
Vinyl planks and tile	Moderate	Average	Moderate
Carpet	Moderate	Average	Moderate to above average
Vinyl composition tile	Moderate	Lowest	Maximum

**Good Leadership in Energy and Environmental Design (LEED) rating.*

Adapted from Byrd, A. (2009). Making the best selections in flooring, walls, hard surfaces and upholstery. *Health Facilities Management Magazine, August 2009 issue*. Retrieved from http://www.hfmmagazine.com/hfmmagazine _ app/jsp/articledisplay.jsp?dcrpath=HFMMAGAZINE/Article/data/08AUG2009/0908HFM _ FEA _ interiors&domain=HFMMAGAZINE

Table 2 Life Cycle Comparison of Resilient Flooring

	Issues	PVC/Vinyl Reference	Synthetic Rubber (SBR)		Polyolefin (Stratica)		Linoleum	
Raw material	Biobased content	None	=	None	=	None	+	High, but ag practices need improvement
	Post consumer recycled content	Virtually none	?	Some have but may be toxic	=	None	=	No PC, highest PI (post industrial)
	POPs, other PBTs, CMRs	Many in petroleum extraction & refining	=	Many - petroleum extraction & refining	=	Many - petroleum extraction & refining	+	Few - pesticides can be eliminated
Manufacturing	POPs	Many, major dioxin source	+	None identified	+	None identified	+	None
	Other PBTs	Many but may be able to be designed out	=	Many but may be able to be designed out	+	None identified	++	None
	CMRs	Many integral	=	Many integral	+	Few - all optional, ex ethylene	++	Many but may be able to eliminate all
Use	Heavy metals & flame retardants	Many but may be able to be designed out	=	Many but may be able to be designed out	++	None	++	None
	Phthalates	Many but may be able to be designed out	++	None	++	None	++	None
	VOC	Many. May reduce but not eliminate	=	Many. May reduce but not eliminate	=	Many. May reduce but not eliminate	=	Many. May reduce but not eliminate
End of Life	Recycling or composting	Small experimental recycling	–	None	–	None	=	Small experimental composting
	POPs	Major dioxin source	+	None identified	+	None identified	+	None identified

Key: Comparison to vinyl

? Unclear	– Worse	= Similar	+ Better	++ Best

POP – Persistent Organic Pollutants; PBT – Persistent and bioaccumulative toxicants; CMRs – carcinogens, mutagens or developmental or reproductive toxicants; VOC – volatile organic compound

Source: Lent, T., Silas, J., Vallette, J. (2009). Resilient Flooring & Chemical Hazards. *Health Care Research Collaborative, April 2009 issue,* 1-54 (Reprinted with permission).

Appendix 4: Note About Slipperiness

To: The Center for Health Design

Thank you for the opportunity to review your proposal about initiatives to reduce fall injuries. Multi-disciplines are involved in fall injuries, so multi-disciplinary approaches are needed. One of the critical issues is about the measurement of slipperiness which could help identify dangerous locations and evaluate potential interventions. Liberty Mutual Research Institute for Safety took the initiative to invite leading world experts to discuss various approaches to measure slipperiness in Hopkinton in July 2000. The approaches included epidemiology, biomechanics, human-centered (psychophysics), roughness and friction. The outcomes of the conference have been published as a book, entitled *Measuring Slipperiness- Human Locomotion and Surface Factors* (ed. Chang, W. R., Courtney, T. K., Grönqvist, R., Redfern, M. S.), Taylor & Francis, London, ISBN 0-415-29828-8, 2003. The consensus of the world experts at this conference was that there has been no single discipline that could completely cover the issue of slipperiness measurements. Friction measurement has been widely used because of convenience and familiarity, but it also has its shortcoming. So, do other approaches. It is very important to keep the limitations of these approaches in mind when utilize them to assess slipperiness.

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Liberty Mutual Insurance

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