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APPLYING SAFE FLOORING IN HOUSING ENVIRONMENTS RELATED TO THE INDEPENDENT ELDERLY

EVALUATING SUITABILITY FLOORING TECHNOLOGY TO ABSORB IMPACT IN THE EVENT OF A FALL

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DOCTORAL DEGREE IN ARCHITECTURAL, BUILDING CONSTRUCTION, AND URBANISM TECHNOLOGY

Ph.D. THESIS

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ABSTRACT

This research has formed intending to investigate a different generation of flooring. Most flooring has the same basic and standard features that make living conditions comfortable, safe, and beautiful. But a group of floors is designed with a specific purpose and for particular spaces and users, whose role is fully integrated with the user conditions. The Compliant Flooring (CF) system, designed to reduce fall-related injuries focusing on resilient behavior. Therefore, a detailed study of CF systems helps to achieve features to maintain environmental security, especially for vulnerable groups such as the elderly.

This study is set out in six main chapters. The first chapter mainly has been addressed the bibliographical studies and statistical data from official and international websites. In this section, the importance of increasing the elderly population, life expectancy, and threats to the safety and health of the elderly especially fall, and their side effects are evaluated. The scope of research has been done internationally, in Europe and within Spain, and finally, Catalonia.

The second chapter studied a brief history of the formation of flooring., which has also considered the comfort and safety of the flooring. Due to the importance and direct relationship between the foot sole and the mechanism of walking with the type of flooring. Many factors include the physics and biomechanics of the body when walking, the kinematic of falls, and impact dynamics have been investigated. In addition, an overview of materials behavior has been conducted to better understand CF systems' behavior. Furthermore, the strategies in dealing with falls and reduce injuries are discussed. Examining other products with energy damping and impact reduction capabilities has been a great help in the proposed designs, all of which have been done by analyzing and presenting related formulas and standards.

The third chapter is devoted to technology and research on CF systems, and the like includes studies in academic, commercial, and architectural departments. This section deals with standard tests related to the matter and studies several examples of similar products.

The fourth chapter includes field research (on-site) and case study analysis. In correspondence with several flooring companies worldwide, we examined products whose manufacturers claimed to be shock-absorber. This part of the research took a long time to send some products to Barcelona. In this section, we needed a real space where we could seek the opinion of the elderly and staff of the center. Therefore, this chapter of the study and all the practice tests were performed at a nursing home in Barcelona for about two months focusing on practical tests, studying the center, and users' related current problems. All this process was completed via interviews with predefined questionnaires. This step also involves modeling and simulating the impact on examples of CF systems. It must be noted that the theoretical features of the quantitative study are used in combination with the practical elements of qualitative research.

Chapter Five also refers to the results, discussions, suggestions for installation, and improving the security of the flooring in risky areas. Simulations were also performed about a possible structure of the tiles with the Finite Element (FE) method.

Chapter Six offers suggestions for future plans. The author investigated related material and structure and present it as initial research for the future work plans. According to the author, with more detailed studies, it is possible to use other natural and recycled materials based on agricultural products (agro-based materials). This point of view can affect products diversity and sustainable architecture.

This study has shown that despite the importance of the issue, there is no standard measurement unit to define a validation in borders of a norm. Corresponding to the findings, we hope this study creates a spark to start the generation and use of such products in industry and trade, and it may open up a new argument for architects and designers, students, and manufacturers.

Principal Keywords: Aging, Life Expectancy, Risk of Fall, Elderly, Fall-Related Injury, Nursing Home, Long-term care (LTC), Compliant Flooring System, Comfort and Safety, Shock Absorption, Force Attenuation, Biomechanical, Hyperelastic material, Rubber, Simulation, Geometry and Structure.

* Keywords associated with each chapter with regard to its contents individually defined before the beginning of the chapter.

RESUMEN

Esta investigación se ha desarrollado con la intención de investigar una generación diferente de pavimentos. La mayoría de los actuales pavimentos tienen las mismas características básicas estándar y ello garantiza que las condiciones de vida sean cómodas, seguras y agradables para la mayoría de los ciudadanos. Pero un grupo reducido de pavimentos está diseñado con un propósito específico: reducir las lesiones relacionadas con las caídas al suelo de las personas; son los denominados CF (compliant flooring en inglés). Un estudio detallado de los sistemas de pavimentos CF está justificado para evaluar su posibilidad de uso para grupos vulnerables como los ancianos.

Este estudio se estructura en seis capítulos. En el primer capítulo se han abordado principalmente los estudios bibliográficos y datos estadísticos consultados en sitios web oficiales e internacionales. En esta sección se evalúa la importancia del aumento de la población anciana, la esperanza de vida y las amenazas a la seguridad y salud de las personas mayores, especialmente, y sus efectos secundarios. El ámbito de la investigación se ha realizado a nivel internacional, en Europa y dentro de España, y finalmente, específicamente para Cataluña.

El segundo capítulo se presenta una breve panorámica del pavimento interior, considerado específicamente su comodidad y seguridad durante el uso. Se ha constatado la importancia y relación directa entre la planta del pie y el mecanismo de andar con respecto al tipo de pavimento. Se han investigado muchos factores que influyen en ello, como la física y la biomecánica del cuerpo al caminar, la cinemática de las caídas y la dinámica del impacto. Además, se ha realizado una descripción general del comportamiento de los materiales al uso en pavimentos para comprender mejor el comportamiento de los sistemas de CF. Además, se discuten las estrategias más idóneas para hacer frente a las caídas y reducir las lesiones. Examinar otros productos con apreciables capacidades de amortiguación de energía y reducción de impactos ha sido de gran ayuda en los prediseños propuestos, todos los cuales se han realizado sobre la base de análisis numérico y los estándares relacionados.

El tercer capítulo está dedicado ya al estudio de la tecnología y la investigación sobre los sistemas de C más idóneos; se incluyen estudios procedentes de departamentos académicos, comerciales y de arquitectura en general. En esta sección se desarrollan algunas pruebas estándar relacionadas con los diversos materiales seleccionados y se estudian varios ejemplos de productos similares.

El cuarto capítulo incluye investigación de campo (in situ) y análisis de estudios de casos. Se contactó por correo con varias empresas notables de pavimentos en todo el mundo, y se examinaron específicamente aquellos productos cuyos fabricantes afirmaban ser amortiguadores. Esta parte de la investigación se vio ralentizada por la demora en los envíos. Una vez llegados se buscó un ámbito real donde poder recabar la opinión de las personas mayores y del personal adscrito a su cuidado. Todas las pruebas prácticas se realizaron en una residencia de ancianos de Barcelona durante unos dos meses, centrándose en el estudio de los actuales pavimentos del centro y los problemas actuales derivados relacionados con los usuarios. Todo este proceso se completó mediante entrevistas a usuarios y cuidadores con cuestionarios predefinidos. Cabe señalar que ello permitió contrastar las características cuantitativas del estudio en combinación con los elementos propios de la investigación cualitativa.

El Capítulo Cinco se refiere a los resultados, discusiones, sugerencias para la instalación y mejora de la seguridad del pavimento en áreas de riesgo. También se realizaron simulaciones sobre una posible estructura base de los pavimentos con el método elemento finito (FEM).

El capítulo seis presenta directrices para desarrollos futuros. El autor investigó más a fondo sobre los materiales y su estructura, y se presenta como una base para desarrollos técnicos futuros.

El autor considera que, con estudios más detallados, sería posible utilizar como CF otros materiales, bien naturales o reciclados a base de productos agrícolas, lo cual aumentaría la diversidad de la oferta de CF y fomentaría la arquitectura más sostenible.

Principales Palabras Clave: Envejecimiento, Esperanza de vida, Riesgo de caída, Ancianos, Lesiones relacionadas con caídas, Residencia de ancianos, Cuidado a Largo Plazo (LTC), Sistema de pisos complaciente, Confort y seguridad, Absorción de impactos, Atenuación de fuerzas, Biomecánica, Material hiperelástico, Caucho, Simulación, Geometría y estructura.

* Palabras clave asociadas a cada capítulo en cuanto a su contenido definido individualmente antes del inicio del capítulo.

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And eventually, thanks to God for a beautiful life and challenges to allow me to grow!

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INTRODUCTION

INTRODUCTION-FOUNDATION OF THE STUDY

Fall and fall-related injuries at buildings have become a public health problem. They are exceedingly becoming more dangerous with increasing age. Fall is the most common event among the elderly getting hurt (Burns, 2018). Reducing muscle strength and joints function is regular with age. Loss of balance occurs due to many intrinsic and extrinsic risk factors, and a possible fall is inevitable.

The results of a fall can be critical, severe, and even irreversible. The most common serious consequence of a fall is a hip fracture, and brain damage as physical injuries, dependence on others causes the individual to become isolated because of severe psychological damage. Besides that, long-term hospitalization and treatment cost society a large amount of money every year.

An estimated 646,000 fatal falls occur each year globally, making it the second reason for unintentional hurt death after road traffic injuries. Adults older than 65 years of age have the highest risk of death or serious injury arising from a fall; also, the risk increases with age. About 37.3 million require medical attention each year because of falls (WHO, 2018). 50% of patients over 65 years of age with hip surgery never recover completely, and the mortality is high as it is hard to regain their mobility from the surgery (Reiner & Frisch, 2009). Fall and fall-related injuries cost society a significant number of fees every year.

Therefore, reducing falls in the elderly is a challenge for many institutions, professionals, and researchers in primary health care. Various preventive interventions have developed in parallel with the increase in the problem. The effectiveness of preventative measures regarding identifying the elderly who present variables related to the risk of falls. Elderly people in this study refers to people who are independent and can do their daily activities in their apartments without the help of others. This includes the elderly who also belong to nursing homes in rented apartments. the

However, we have to understand that the main reason to avoid and prevent falls is to prevent injury and even later death in older adults. Thanks to all the forecasts and studies carried out in prevention, it was possible to reduce falls and injuries. Still, according to the statistics, these solutions do not seem enough to reduce the rate of injuries or even death. There is still a percentage of adults who fall due to intrinsic or extrinsic factors. It is challenging to prevent falls, which means it is necessary to secure the elderly living environment against the threat of falls. Solutions must be made to reduce injuries in older adults after a fall. Safety floorings are known as Novel compliant floorings (NCF) or Shock Absorbing Flooring (SHAF)[1]. They are a passive intervention method that may protect an individual from many types of fall-related injuries. The compliant flooring strategy aims to reduce fall-related injuries by decreasing the severity of damage caused by falls and, hopefully, diminish the occurrence of fractures.

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[1] Variations of each flooring term were as follows:
Compliant flooring—Compliant floor(ing), Compliant surface(s), more compliant floors and subfloors, Novel compliant flooring, novel compliant flooring systems;
Safety flooring—Safety floor(ing/s), Novel safety flooring systems, Safety flooring systems;
Soft flooring —Soft(er) floor(ing/s), Soft-surface flooring, Softer surface(s), Softer floor surfaces, Softer floor types, Softer ground;
Impact absorbing flooring—Impact absorbent flooring, Impact-absorbing flooring;
Energy absorbing flooring—Energy absorbing flooring, Energy-absorbing materials, Energy absorbent flooring;
Dual-stiffness flooring—Dual-stiffness floor(ing), Dual stiffness flooring, Dually stiff floor;
Absorptive Surfaces—Absorptive surfaces, Absorbent floor`ing;

The focus of this study is on nursing homes and care centers and indoor areas. But the results of the study and the CF system is one of the products derived from architectural elements that can be used as a suitable flooring in all spaces with a high risk (These spaces have been studied and identified) of collapse and injury in the elderly. These include senior living residences, hospitals, specialized clinics for the elderly, and health centers.

RESEARCH MOTIVATION

I am an architect from Iran. The desire to be creative and present a new design is a characteristic of an architect. Because of the direct connection between architecture and human practice and daily behavior, an architect must delve into the depths of various sciences and know every science to a depth of 10 cm, from computational and medical sciences to social sciences and psychology with little knowledge. Attention to the design's creativity and needs is always a priority and can justify their overlap. Of course, creativity was always mixed with the materials in nature or the commercial market and formed to meet the user's needs. Sometimes the problem exists, and it is observed, academic studies and research are done about the problem, but there is still no effective solution, and the problem is experienced permanently.

The current research is a manifest example of this issue, which is a clear interdisciplinary experience and tries to focus on a problem that requires the cooperation and science of other specialized disciplines. An issue called fall in the elderly and the vulnerable group and concentrate on optimizing the flooring as one of the architectural elements can be part of an architect's responsibilities.

In general, when it comes to safety flooring, people focus on the non-slip surface feature of the floors. Few numbers think about the shock resistance property, except in exceptional cases, such as children's playgrounds, which must be safe enough in both non-slip and shock absorption property of the pavements for children during play. The situation is the same in sports fields or industrial factories. But with a bit of focus on crash statistics, the cost of the fall, and the vulnerable group with high fall death rates, the elderly are the biggest victims. My personal experience is with my late grandmother. Unfortunately, we saw her fall and bruises on her body and face several times. Fortunately, she never suffered a bone fracture due to her appropriate physical condition. Finally, these events and evidence prompted me to research and pursue the study about shock absorption flooring (CF system) in spaces such as nursing homes or medical centers related to the elderly. A CF system may present an improved quality of life among the elderly. It may encourage older to a more active lifestyle, with no fear of falling to the same extent. As CF systems provides equal protection condition to everyone, elderly who, for example, suffer dementia or do not like to put on hip protectors, do not have to rely or dependent on other people as much.

During the research, I found out that many research and methods were presented to control or reduce the risk of falls. Except for three products (in the US and New Zealand), there is no other product in the current market with the purpose of shock absorption. It must be mentioned that of these three products, only one is active in the United States. In our opinion, European countries, especially Spain, with a large elderly population, need to pursue this issue more seriously to provide a solution to reduce treatment costs and the suffering of the elderly.

AIM AND OBJECTIVES

Main Objectives

- Reducing injuries such as fractures caused by the elderly falling indoors by modifying the design and revising the products used in the flooring;
- Feasibility study of using different standard methods to detect and validate the performance of shock-absorption floorings;

Specific Objectives of the study

- Validate the performance and efficiency of the CF system;
- Identify the specific characteristics of the flooring required in daycare centers and nursing homes, which are often antithetical;
- Assess the performance and behavior of flooring in dissipating the applied energy after the fall through software simulation;
- Assess the performance and behavior of flooring by changing the geometry, array, and layout of the sub-unit structure via software simulation;
- Research on the optimization and implementation of tile installation on the current floors of a center;
- Identify risky spaces with a high probability of falling according to available statistics and interviews.
- Assess the possibility of using floor tiles based on recycled materials;

HYPOTHESIS AND RESEARCH QUESTION

Studies and evidence show that the type of flooring system played an essential role in impact reduction after falls (Lachance C. C., 2016) (Laing AC T. I., 2006) (Laing A. C., 2009). Despite the shock-absorption flooring on the market used for sports areas, kid's playground, and industrial purposes, these floorings are not used in spaces with a high risk of falls, such as nursing homes or residential areas. To this end, the questions arise here are:

1. Why there is no norms, building technologies, or safety flooring provided for the elderly environment?
2. What are the essential characteristics of safety flooring with a focus on older users?
3. Why are the products on the market not capable of being installed in nursing homes? Are they not adequately optimized for such spaces?
4. Given the examples of existing architectural designs, why do architects consider the importance of this matter, and why do they not make any difference in the design of the floor according to the user! Are architects not aware of the existence of such products?
5. How to secure the floor of the currently built spaces?

The hypothesis used in this research was formed in response to the above questions. It includes several variables and factors that are thought to affect each other. Apart from conventional technologies to reduce damage in the event of a collision, this research focuses on factors that can change the performance of flooring (Figure 0-1).

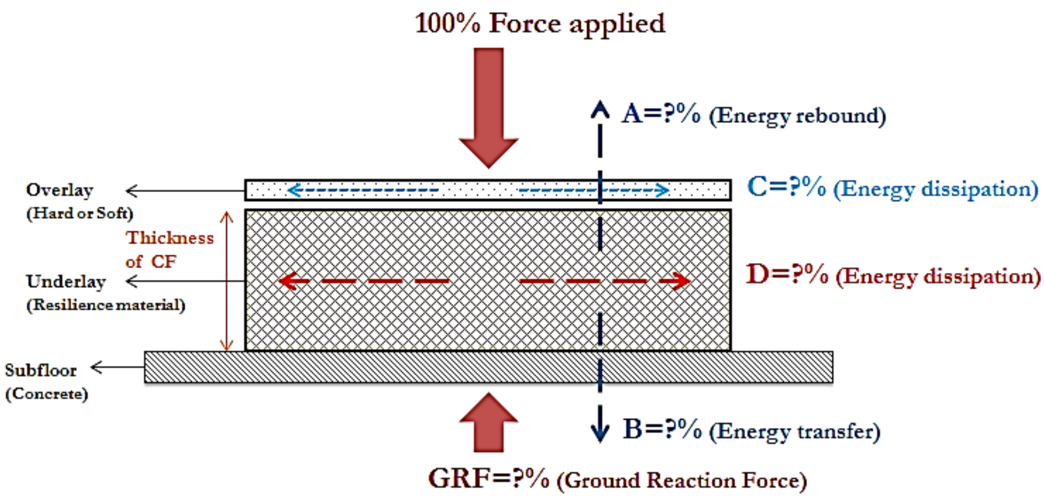


Figure 0-1 Energy transfer/dissipation in Compliant flooring system-By Author

To this end, we started researching similar products in the market. We came to a series of hypotheses based on conducted studies and the biology of the elderly body. By examining them, we can achieve relationships that result in predicting and reducing damage.

- Phenomena or technology used in energy dissipation of CF floorings
- Use the right and appropriate materials
- The thickness of flooring tiles
- Structure, the geometry of cell unit, and layers of tiles
- Overlay (finish layer-hard or soft surface) and underlay (CF)

- Defined force range for energy reduction (impact acceleration-velocity, weight, applied force)
- Behavior and performance of the CF surface in the face of falling (curvature)

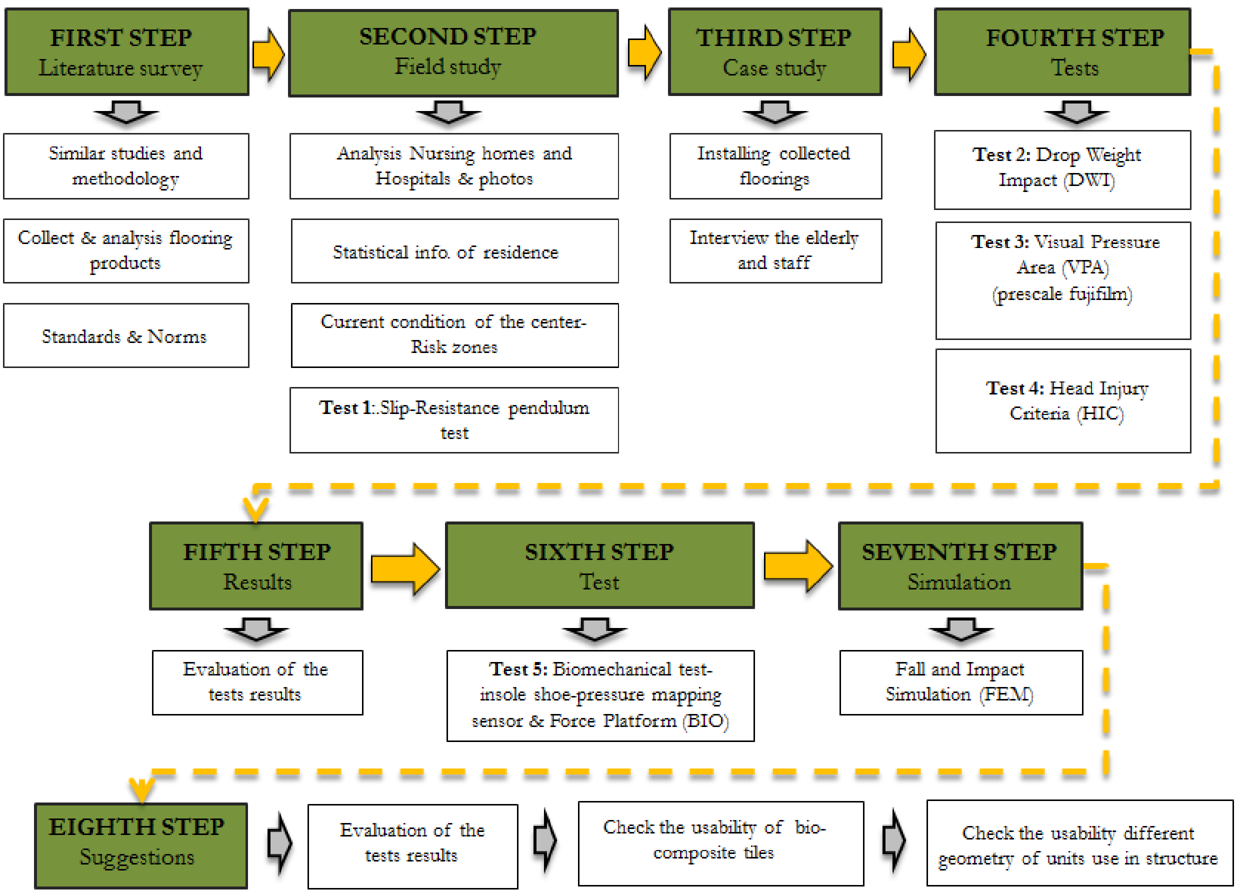
We assumed that the items mentioned are interdependent, and a change in each of them alters or even destroys the flooring performance.

RESEARCH METHODOLOGY AND STRUCTURE

This research aims to focus on safe indoor flooring for the elderly, and the methodology used in this study is developed in several stages (Table 0-1)

1. Study about similar researches and experiences, Analysis of different types of shock-absorbing pavements from some companies around the world and study about the norms that are important in collected floorings and even study other products and methods used with the aim of damping applied force (Quantitative data);

Table 0-1 Steps of the investigation- By Author



2. Analyze the high-risk areas and the flooring currently used in a residential center in Catalonia (Qualitative data) and evaluate the history and statistical information of the elderly fall in the last three years (Quantitative data), and measure the slip resistance floorings with pendulum slip test device. This machine calculates the dynamic coefficient of friction (CoF);
3. Install the collected flooring from the first stage in the residence center to study the opinion of the center's residents and staff (Qualitative data);
4. Carry out different tests on collected floorings to evaluate the performance of the floorings in energy absorption and validation of tests (Quantitative data);
5. Compare the results obtained from tests (step 4) and interviews (step 3) and select the best ones in shock absorption;
6. Use biomechanical devices and techniques to tests on four last choose floorings with the best shock absorption obtained from step “5” (with and without finishing overlay);

7. Use the Finite Element Method (FEM) to simulate the function of the material and the units/cells or geometry used in the structure of compliant floorings and the proposed designs;

8. Investigate the possibility of using agro-based industries raw materials as an option for recycling waste materials, in addition to the use of rubber, and investigate the case of other geometric shapes being applicable as units/cells of structure;

ASSUMPTIONS, DISCLAIMER, AND LIMITATIONS

There are different types of Compliant Flooring in the market dedicated only to sports clubs, fitness, children's playgrounds, factories, and industries. We came across three products (Smartcells, Kradal, Sorbashock) suitable for nursing homes, residences, and health care during the research. But, except for one product (Smartcells) currently available in the market, the other two are inactive and no longer produced (Figure 0-2).

1: SATEC[2], US	4: Supreme[5], Spain	6: Nora[8], Germany
2: SnapSports[3], US	5: Amorim[6]-Wicanders[7], Portugal	7: Sofsurface[9] (softile), Canada
3: Gerflor[4], France		

Figure 0-2 Location of flooring companies from which flooring products are received - By Author

Safe floorings include some specifications. We researched with the assumption that the type of flooring theory has a significant effect on reducing damage in the event of a fall. The softer and more elastic the floor, the less impact it will hit the body from the ground. However, the softness and elasticity of the floor surface cause wheelchairs or trolleys to move hard and causes fatigue of employees' ankles during daily activities. However, evidence suggests that if the vertical deformation of the floor surface is more than standard due to its elasticity feature, floors with low stiffness surfaces could impair balance maintenance, thereby increasing the risk of falls (D. Wright & C. Laing, 2012). In this order, the finishing layer (overlay) must be anti-slip and hard enough to maintain balance, and the sub-structure must be resilient enough to reduce energy. For this purpose, by placing some overlays (Carpet, Ceramic, Parquet, and PVC[10] or linoleum) on the compliant floorings, their efficiency in absorbing and reducing force was re-evaluated.

[2] https://www.smartcellsusa.com/
[3] https://www.snapsports.com
[4] https://www.gerflor.com
[5] http://www.floors-supreme.com/
[6] https://www.amorim.com/en/
[7] https://wicanders.com/en/
[8] https://www.nora.com/
[9] https://www.sofsurfaces.com/
[10] Polyvinyl chloride

- Corresponding with flooring companies and other research-related companies and requesting cooperation with them was sometimes time-consuming.
- The lack of a standard and legal reference to validate the research results causes relative uncertainty. regarding the type of sport and height of playground equipment, numbers of standards are available that make it easy for architects to choose the product they want. In this case, the architect will be greatly relieved that the designed environment is sufficiently safe.
- Due to several jumps, there is a possibility of displaying errors in the value of the force or pressure received by sensors of the IPS[11] system during the biomechanical test. The producer of the IPS system has not presented them with a specific lifespan.
- The number and size of the sample floorings sent by flooring companies were not the same. For this purpose, the tests had to be designed so that the flooring capability was evaluated with minimum error. But in some cases, due to the small size of the tile, there is a possibility of error.

EXPECTED RESULTS

- Reduce treatment and maintenance costs applied to health care centers and the society;
- Open the door to more research on current flooring and give rise to innovations in future trends in pavement layers to create a safe area for the elderly.

[11] Insole Pressure Sensor

CHAPTER 1

BACKGROUND AND DEFINITION OF THE PROBLEM - STATISTICAL DATA AND INFORMATION

CHAPTER 1

1 BACKGROUND AND DEFINITION OF THE PROBLEM - STATISTICAL DATA AND RESEARCH

Keywords: Aging, Life expectancy, Risk of Fall, Elderly, Environmental and Home Safety, Intrinsic and Extrinsic Fall factors, Novel Compliant flooring (NCF).

1.1 AGING AND LIFE EXPECTANCY

The world is faced with an — "**age-quake**[12]"— phenomenon. The demographic curve has transformed because of the declining birth rate, the rate of the child population, and the increase in the rate of the senior population. Many developed and developing countries, such as Japan, Italy, China, Switzerland, and Spain, are becoming aging societies (Figure 1-1). Estimates of life expectancy are an essential issue that depends on indicators of the health and well-being of populations. The increase in life expectancy reflects the improvement of public health and well-being of the populations, medical science, social conditions, and improvement of lifestyles, which leads to control of the disease, prevention of injury. Globally, the population over 65 years of age is growing faster than the rest of the population segments.

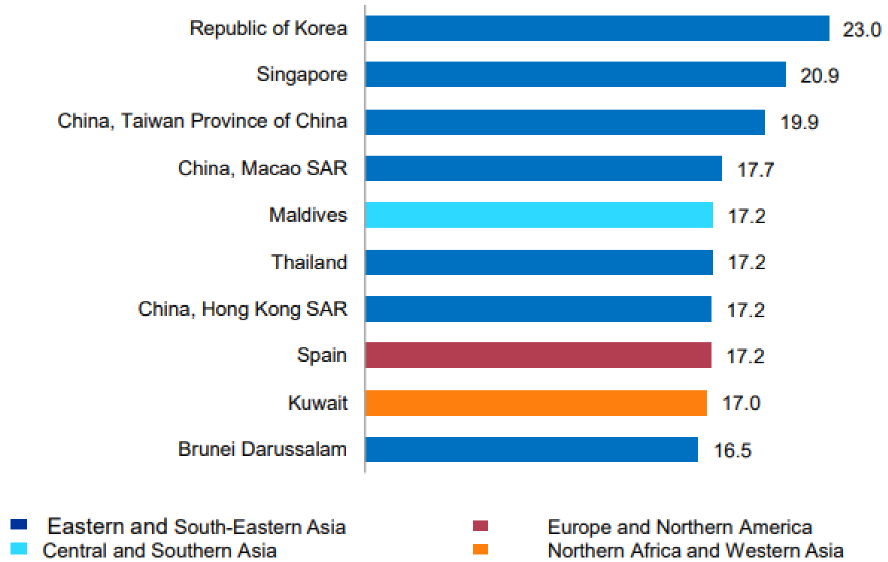


Figure 1-1 Countries or areas with the largest projected increase in the share of persons aged 65 years or over, 2019-2050 (percentage points)[13]

According to the last news received from the report "World Population Outlook 2019", By 2050, one-sixth of the world's population will be over 65 (16%), more than 2019 proportion about 703 million persons aged 65 years or over that is one in 11 (9%) in 2019. By 2050, this rate is projected to double to 1.5 billion. About one in four of the population in Europe and North America could be 65 or older.

[12] Is the term used by Paul Wallace in his book" Age quake: Riding the Demographic Rollercoaster Shaking Business, Finance and our World ", 1999

[13] Source: United Nations Department of Economic and Social Affairs, Population Division (2019). World Population Prospects 2019. 1 Macao is designated as a Special Administrative Region of the People's Republic of China.

In 2018, for the first time in history, persons aged 65 or above outnumbered children under five years of age globally. The number of persons aged 80 years or over is projected to triple, from 143 million to 426 million between 2019- 2050 (UN, 2019) (Nations-UN, 2020).

Spain is the only European country among the ten countries of the world with the largest projected increase in the share of aged persons by 2050. As can be seen in (Figure 1-1, Figure 1-2), by 2050, Spain is ranked eighth globally in terms of aging population growth. Spain's population is 46,755,287 due to the world meter last data of 2020. The life expectancy in Spain in both genders is around 84.0 years.

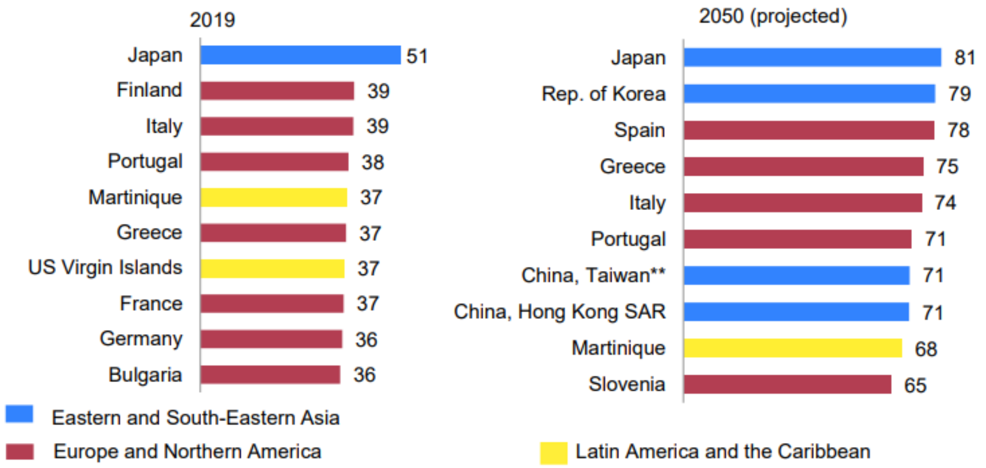


Figure 1-2 Ten countries or areas with the highest old-age dependency ratios, 2019 and 2050[14]

The rate of age for females is 86.7 years old and for males is 81.3 years old (Worldometers, 2020). Figure 1-2 shows the European country's condition of aging and life expectancy. Spain's elderly population over 65 years old is projected almost to double between 2015 and 2050. In 2019, the population aged 65 years and more for Spain was 19.6 %, and it is estimated to be 36.6% by 2050 (Figure 1-3).

According to the population pyramid of Spain, approximately 24% of the Spanish population is 65 and over the years old. The of people aged women are more than men, about 13.5% (INE, 2019).

It was predicted in the report presented by Eurostat organization in 2019, that between 2018 and 2050, the old-age dependency ratio of Slovakia, Ireland, Poland, and Spain will grow at an exclusively rapid speed, at least doubling. (Figure 1-4) France, Spain, Greece, and Italy have the highest shares of very old people (Eurostat, Sept 2019).

[14] Source: United Nations, Department of Economic and Social Affairs, Population Division (2019). World Population Prospects 2019.

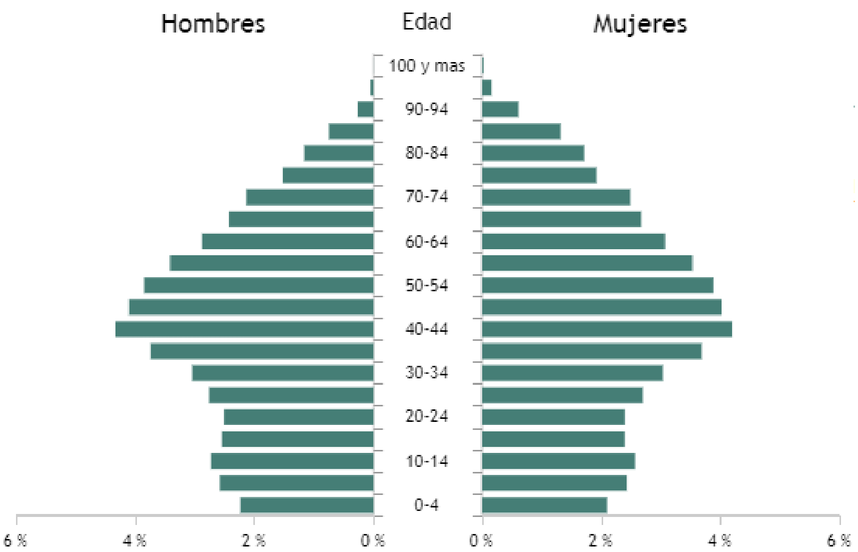


Figure 1-3 Pyramids of the registered population. National, CCAA, provinces, and municipalities-Spain[15]

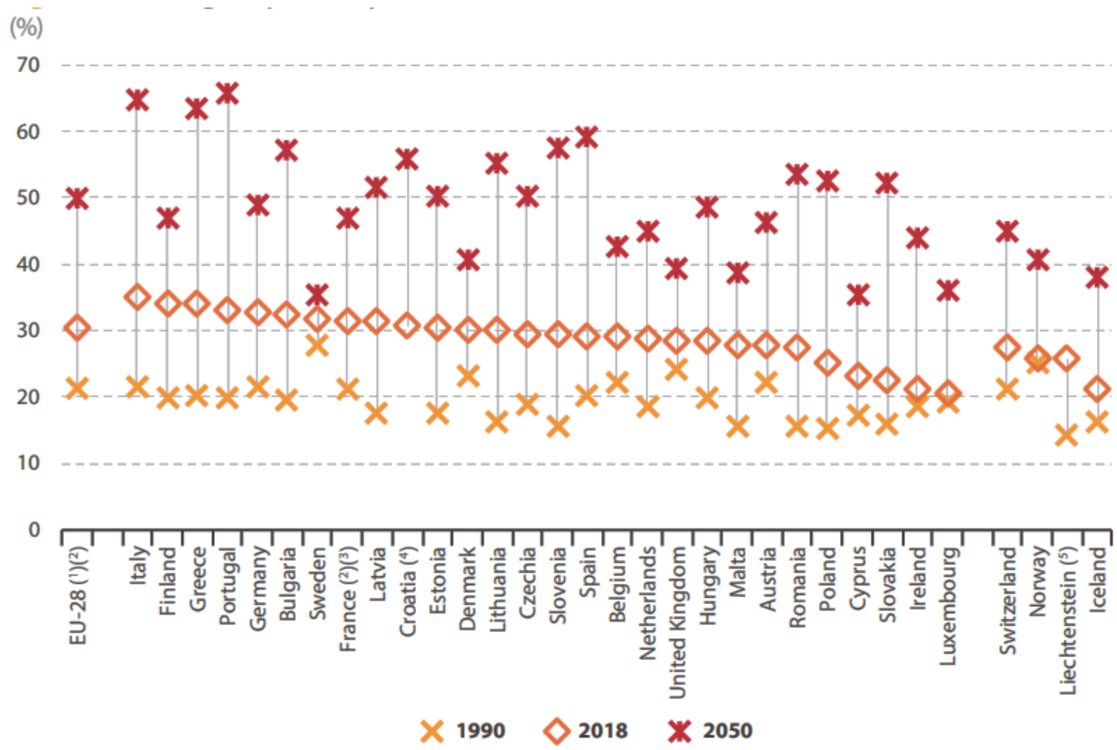


Figure 1-4 Old-age dependency ratio[16], 1990, 2018 and 2050 (Eurostat, Sept 2019)

[15] Source: Continuous Register Statistics

[16] Note: the old-age dependency ratio is calculated as the number of people aged ≥65 years divided by the number of people aged 15-64 years, expressed as a percentage. 2050: population according to the 2018 projections, baseline variant (EUROPOP2018).

1.2 FALL AMONG ELDERLY

Fall among old individuals often terminates in lesions, and limited activity, isolation, or mortality may be likely consequences. A fall is an unintentional event, and the significant injury reason resulting in accidental death among persons over the age of 65. As the age increases in both male and female age groups, the mortality from falling increases dramatically. Statistics show that 70 percent of accidental mortality caused by falls happens for 75 years of age and over. There are various physical, mental, or environmental reasons for falls. More than 90 percent of hip fractures arise due to falls, most of them over 70 years of age. Most of the elderly suffer from immobilization due to physical weakness or acute and chronic health impairment, which causes increasing weakness in function and falls. Injuries caused by falling, in turn, reduce the role, activity limitations, fear of falling, and loss of mobility. Most injuries in the elderly result from falls; fractures of the hip, forearm, femurs, and pelvis are generally a consequence of the composing effect of falls and osteoporosis. Inherent risk factors for falls have been detected in controlled studies, which able to identify those at risk and offer preventive interpositions. Elderly individuals with multiple health problems are at higher risk, but many healthy older ones fall accidents each year as well. There is currently little information and perception about the etiology of postural instability and the falling effectiveness of interventions to prevent falls.

Generally, One-third of community-dwelling elderly persons and 60 percent of nursing home residents fall each year (Fuller, 2000). Falls are serious and costly. One out of five falls results in a severe injury such as broken bones or a head injury (Alexander BH, 1992) (Sterling DA, 2001). Each year, about 2.8 million elderlies are treated in emergency centers for fall injuries, and over 800,000 patients are hospitalized which at least 300,000 of them for hip fractures, and more than 95% of hip fractures are caused by falling sideways. Falls are the most common reason for traumatic brain injuries (TBI). (Jager TE, 2000)

The World Health Organization (WHO) defines the fall as the consequence of any event that precipitated the patient to the ground against her/his will. This precipitation is usually sudden and involuntary. It can be referred by the patient or by a witness. More than a third of adults aged 65 years or older fall each year, and of those who fall, 20% to 30% suffer moderate to severe injuries that reduce mobility and independence and increase the risk of premature death. Most (95%) injurious falls among residents in residential homes occur indoors (Nurmi I, 2002). But the compensation of injury for older adults is brutal, painful, long-term, or sometimes even irreparable. More than 90% of hip fracture patients are over 65 years. 40% of them usually require nursing-home care, 50% need to get help from the cane or walker, and 24% of those over age 50 will pass out within one year because of factors related to the injury and the convalescence period (Daniel A. Sterling, Jan 2001). Approximately 50% of older adults over 60 falls at least once a year, this rate is about 40% in nursing homes, and it is about 1.5 falls per bed annually. Among people over 85, 20% of fall-related deaths happen in residential care settings (Todd, 2004). It is reported that about 93% of the older adults live in private homes, among which 29% live alone (Rougier, 2011). The pieces of evidence demonstrated that 50% of the seniors who lay on the floor after a fall for more than one hour died within six months after the fall without direct injuries (Lord, 2010). Rates of falls in nursing homes and hospitals approximately 3x the rates of falls among community-dwelling elderly.

Table 1-1 Summary data tables of life expectancy and age in countries[17]

Region, development group, country or area	Population aged 65 years or over (thousands)		Percentage aged 65 years or over		Total fertility rate		Life expectancy at birth for year 2010-2015		Life expectancy at age 65 for year 2010-2015		Males per 100 females aged 65 years or over		Males per 100 females aged 80 years or over		Old-age dependency ratio (65+ /20-64)[a]		Prospective old-age dependency ratio[b]		Economic old-age dependency ratio[c]	
	2019	2050	2019	2050	2019	2050	male	female	male	female	2019	2050	2019	2050	2019	2050	2019	2050	2019	2050
EUROPE	140,410	199,895	18.8	28.1	1.6	1.7	73.6	80.7	16.4	19.7	69.6	78.1	53.1	66.4	31.3	53.7	19.2	27.1	41.5	72.7
Eastern Europe	48,187	66,139	16.4	25.2	1.7	1.8	67.2	77.1	13.3	17.5	55.0	65.6	38.1	47.8	26.5	46.6	20.6	27.8	30.9	55.4
Belarus	1,437	2,072	15.2	24.0	1.7	1.8	66.8	77.9	12.3	17.5	48.5	60.5	30.0	39.6	24.1	43.5	20.1	27.7	24.9	45.9
Bulgaria	1,488	1,542	21.3	28.6	1.6	1.7	70.8	77.8	14.0	17.3	67.3	76.3	54.2	59.2	35.6	54.6	30.1	36.2	39.5	61.8
Czechia	2,117	3,043	19.8	28.9	1.7	1.8	75.1	81.2	15.6	19.1	73.1	88.4	52.0	75.7	33.0	55.9	20.9	27.9	43.6	76.6
Hungary	1,907	2,371	19.7	28.0	1.5	1.7	71.6	78.7	14.3	18.1	61.0	74.3	40.9	57.4	32.4	52.6	22.5	30.0	43.8	72.2
Poland	6,864	10,364	18.1	31.1	1.4	1.6	73.1	81.1	15.5	19.8	65.4	79.3	45.3	63.3	29.2	60.3	16.1	25.9	41.4	88.0
Republic of Moldova*	486	774	12.0	23.0	1.3	1.5	66.7	75.2	11.8	15.8	59.2	62.0	40.7	35.8	17.9	38.5	19.4	30.4	20.1	42.8
Romania	3,639	4,498	18.8	27.7	1.6	1.7	71.5	78.4	14.6	17.8	66.8	76.4	53.1	62.3	31.1	52.2	23.5	32.9	30.7	52.5
Russian Federation	22,019	31,048	15.1	22.9	1.8	1.8	64.5	76.0	12.7	17.2	49.2	58.8	33.0	39.9	24.3	41.7	19.3	26.1	27.3	47.5
Slovakia	883	1,438	16.2	28.9	1.5	1.7	72.5	79.8	14.6	18.4	65.4	79.6	44.5	62.3	25.5	54.6	17.3	29.0	37.1	83.4
Ukraine*	7,349	8,988	16.7	25.5	1.4	1.6	65.8	75.9	12.2	16.4	50.3	59.6	35.7	38.3	26.6	45.9	25.7	33.1	28.6	49.0
Northern Europe	19,845	29,240	18.8	25.4	1.7	1.8	78.2	82.6	18.0	20.7	82.4	88.7	64.8	79.7	32.2	47.3	18.5	23.2	47.6	72.2
Channel Islands*	30	56	17.6	28.1	1.5	1.6	79.8	84.1	18.1	21.7	83.8	87.1	63.8	75.2	28.4	52.9	14.9	24.6	..	..
Denmark*	1,152	1,514	20.0	24.2	1.8	1.8	78.1	82.2	17.5	20.2	85.6	88.7	65.4	80.9	34.6	44.6	20.3	24.3	53.4	72.9
Estonia	265	333	20.0	28.7	1.6	1.7	71.9	81.2	14.9	19.8	52.7	75.7	35.4	57.1	33.9	54.9	21.0	27.4	50.5	86.0
Finland*	1,225	1,512	22.1	27.6	1.5	1.6	77.7	83.7	17.7	21.4	78.5	84.8	56.2	71.8	39.2	51.4	19.2	24.5	57.2	80.3
Iceland	52	95	15.2	25.2	1.7	1.7	80.6	83.8	19.0	21.1	91.3	93.3	72.6	82.5	25.8	46.2	13.2	21.7	40.4	74.6
Ireland	694	1,511	14.2	26.6	1.8	1.7	78.7	82.5	17.9	20.4	88.8	89.0	70.8	82.6	24.4	50.6	12.5	22.0	36.7	78.4
Latvia	388	411	20.3	27.8	1.7	1.8	69.0	78.8	13.8	18.8	49.2	63.1	33.6	46.4	34.5	53.0	24.6	30.5	47.7	76.8
Lithuania	556	615	20.2	29.0	1.7	1.8	68.5	79.3	14.1	19.0	51.1	61.7	37.9	47.1	33.5	55.7	21.8	31.5	51.8	88.2
Norway*	929	1,581	17.3	24.0	1.7	1.7	79.5	83.6	18.3	21.2	86.4	95.8	63.1	84.2	29.1	43.4	15.4	21.2	45.4	69.3
Sweden	2,027	2,800	20.2	24.6	1.8	1.8	80.0	83.8	18.6	21.2	86.8	93.1	66.4	83.2	35.5	45.5	19.2	22.4	52.2	72.8
United Kingdom*	12,499	18,775	18.5	25.3	1.7	1.8	78.9	82.7	18.3	20.8	84.8	89.7	68.9	82.0	31.7	47.1	18.5	23.0	46.5	70.6
Southern Europe	32,111	47,859	21.1	35.0	1.4	1.5	78.5	83.8	18.0	21.4	76.5	82.8	59.7	70.2	35.1	71.7	19.7	32.8	44.2	90.2
Albania	409	617	14.2	25.4	1.6	1.5	75.2	80.0	16.1	18.4	92.3	88.3	84.9	79.0	23.2	43.8	16.7	27.2	28.1	49.0
Bosnia and Herzegovina	568	816	17.2	30.4	1.3	1.4	74.1	78.9	14.7	17.4	74.2	82.9	60.0	67.7	27.4	56.5	20.9	32.8	34.2	66.6
Croatia	862	1,039	20.9	30.9	1.4	1.6	74.2	80.6	15.2	18.7	67.0	80.0	45.7	64.6	35.0	59.2	25.0	32.0	50.2	85.1
Greece	2,298	3,271	21.9	36.2	1.3	1.5	78.5	83.7	18.4	21.2	79.6	85.4	70.4	75.7	37.1	75.0	20.9	32.2	51.2	104.0
Italy	13,934	19,585	23.0	36.0	1.3	1.5	79.9	84.7	18.6	22.0	76.9	83.9	59.2	71.8	39.0	74.4	20.9	34.6	50.1	97.5
Malta	92	130	20.8	30.4	1.5	1.7	79.4	83.3	18.3	20.9	83.7	95.0	60.0	82.5	34.7	58.0	17.5	24.9	50.5	92.3
Montenegro	97	140	15.4	23.8	1.7	1.7	73.6	78.5	14.6	17.2	74.2	79.7	61.1	66.9	25.6	42.8	21.3	26.3	31.3	51.0
North Macedonia	293	476	14.1	25.7	1.5	1.6	73.1	77.2	14.0	16.0	80.4	85.6	65.8	71.8	22.1	45.4	20.1	30.8	..	..
Portugal	2,286	3,162	22.4	34.8	1.3	1.6	77.4	83.7	17.6	21.3	72.3	75.5	57.0	63.3	37.8	71.4	21.1	33.2	43.9	79.8
Serbia*	1,644	1,887	18.7	26.6	1.4	1.6	72.1	77.4	13.8	16.4	75.5	78.2	60.9	63.0	31.3	47.9	27.1	31.6	35.4	53.0
Slovenia	420	623	20.2	32.1	1.6	1.7	77.1	83.1	17.0	20.8	75.2	89.4	49.5	73.2	33.5	65.0	18.5	30.3	46.7	92.9
Spain*	9,183	16,062	19.6	36.8	1.3	1.6	79.6	85.3	18.7	22.6	76.8	82.6	59.1	68.9	32.2	78.4	16.9	31.8	37.8	92.8
Western Europe	40,267	56,658	20.6	28.8	1.7	1.7	78.4	83.7	18.1	21.6	78.0	84.8	59.9	75.0	35.3	55.7	19.4	27.3	52.7	85.0
Austria	1,708	2,684	19.1	29.4	1.5	1.7	78.4	83.5	18.0	21.2	76.7	87.1	59.0	78.8	31.0	56.0	18.7	27.8	40.4	74.6
Belgium	2,193	3,290	19.0	26.9	1.7	1.8	78.0	83.0	17.7	21.1	78.2	89.1	59.1	79.5	32.5	51.3	18.0	24.8	50.5	82.0
France*	13,281	18,810	20.4	27.8	1.8	1.8	78.7	85.0	19.0	23.0	75.8	78.7	56.5	67.1	36.5	54.5	17.0	24.7	54.5	81.6
Germany	18,009	24,040	21.6	30.0	1.6	1.7	77.9	82.9	17.6	20.8	78.0	87.2	61.6	78.3	36.1	58.1	21.9	29.6	54.4	89.2
Luxembourg	88	194	14.3	24.5	1.4	1.6	78.8	83.5	18.0	21.3	83.1	93.8	61.5	85.0	22.2	43.8	12.3	20.6	35.1	71.9
Netherlands*	3,352	4,806	19.6	28.0	1.7	1.7	79.4	83.1	17.9	21.1	86.1	90.5	64.6	83.7	33.5	53.3	17.9	28.0	50.4	85.4
Switzerland	1,618	2,813	18.8	28.6	1.5	1.6	80.5	84.7	19.1	22.2	82.1	89.3	62.9	80.2	30.8	54.4	15.5	25.0	47.7	88.0

The reason for a fall is rarely unique, and most of the time, the cause is multifactorial, constituting a clinical syndrome. It is estimated that the annual incidence of falls in the young elderly (65-70 years) is 25% and reaches 35-45% when reaching an older age (80-85 years). Still, the number exceeded 85 years of reported falls decrease, possibly due to restriction of physical activity (Table 1-1)

[17] Source: United Nations, Department of Economic and Social Affairs, Population Division (2019). World Population Prospects 2019.

1.3 SIDE EFFECT OF THE FALL

In general, fractures are the most common serious injury resulting from falls in older persons. Specifically, fractures of the hip, wrist, humerus, and pelvis in this age group result from the combined effects of falls, osteoporosis, and other factors that increase susceptibility to injury (Fuller, 2000).

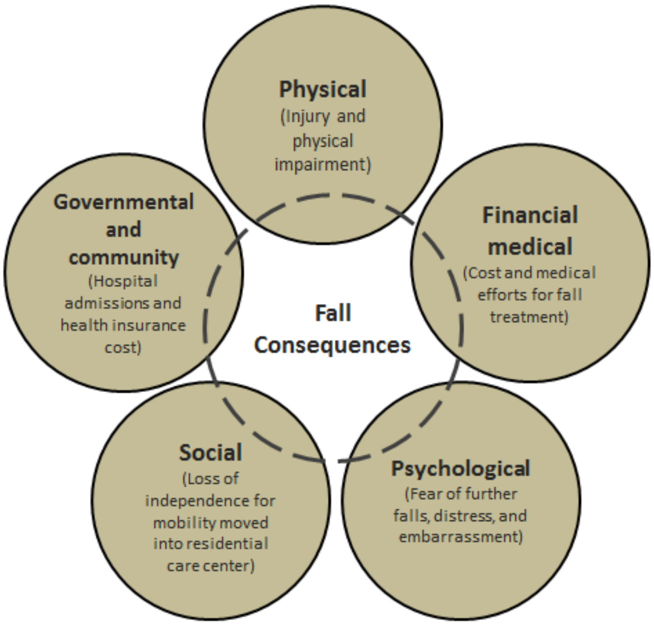


Figure 1-5 The main consequences related to elderly falling (El-Bendary N. Q., 2013)

Complications of fractures involve the economic impacts to family and society and include isolation and psychological effects, in the long run, cause depression and severe dependence on the elderly. Direct expenses include health care expenses such as medication services, treatment, and rehabilitation consultations—the fall Impact on social relations and reduction of activity. Fall events make dependent her/him on others, which in turn causes loss of income and spending more due to dependence. (WHO W. H., 2007). In the following (Figure 1-5), the main consequences of elderly falling have been shown (El-Bendary N. Q., 2013). Falls in the elderly may have adverse physical, psychological, social, financial, medical, governmental, and community consequences and even cause death.

Physical consequences:

Physical consequences are shown in a broken bone or soft tissue injury, pain and bruising, mobility reduction, and feasible long-term inability, and generally lead to dependence and will need the help of others.

Psychological consequences:

Fear of falling again overwhelms him/her and reduces his/her daily activities. It causes embarrassment and isolation, and loss of self-confidence.

Social consequences:

Lack of regular social activity reduces independence and increases dependence, which becomes a reason for possible transfer to residential centers or nursing care.

Financial and medical consequences:

Fall injuries are the single most considerable cost of a personal injury accident. That is why slip and fall prevention has been recognized as a national health priority area. This evidences showed that falls are a common event of injury and a relevant economic burden to society (Heinrich, 2010). Fall-related injuries are leading to high healthcare consumption, and financial costs from injuries are considerable. The cost of long-term care and nursing, both at home and in the nursing home, is very high. For some patients, the Injuries resulted in difficulty to heal, chronic leg wounds requiring a constant change of dressing at the health center (James K. , 2007). Studies have shown that 54% of these costs are related to falls injuries in the elderly. Between 2007 and 2009, about 3% of people aged 65 and over were referred to the emergency department due to a fall. Related medical expenses are estimated at an average of €675.4 million per year. Eighty percent of medical care costs (€540 million) associated with a fracture are due to falls. The average price of fall-related injury is about €9370 per fall depended on fall severity, which increases with age from around €3900 at ages 65–69 years to €14,600 at ages over 85 years. The cost for women is about €9990, and for men is €7510 (Hartholt K. A., 2012). Pelvic fractures (€14,000) have the highest rate among other fall injuries. However, other injuries caused by recurrent falls are costly, Hip and femoral fractures cost (approximately €22,000 per case) the healthcare system and the society the most (Hartholt K. A., 2012) (Hartholt K. A., 2011).

The accidents that people over 65 years of age usually suffer in Spain generate a health expense of about 423.8 million euros per year, representing an average of 1,431 euros per accident. Of this amount, 90% corresponds to the direct costs of health care and rehabilitation, and 10% to absences and work permits, caregiver contracts, and transport.

The Mapfre Foundation, with the collaboration of IMSERSO[18], the General Directorate of the Elderly of the Community of Madrid, and the Spanish Society of Geriatrics and Gerontology, carry out the "Economic evaluation study of the accessibility of the elderly in Spain." To determine the economic cost of accidents that require healthcare in those over 65 years of age, know the socio-demographic characteristics of this group and analyze the clinical consequences of such accidents. (Del Campo Martín, 2011).

In this sense, the study has reported that the main consequences of these accidents are injuries, although, as it has qualified, these are not the ones that generate the most cost. Thus, they have warned that hip fractures are the ones that represent the highest health expenditure (149,907,720 euros), followed by fractures of the femur (65,695,155 euros) and fractures of the tibia and fibula (46,866,925 euros). Also, the report has highlighted that 78 percent of the injured have needed diagnostic tests - resonances and analytics - and that 63 percent have required pharmacological treatment. In fact, out of every ten people, seven went to a hospital, one in four older people was hospitalized, and two out of ten required surgeries (Table 1-2).

[18] Instituto de Mayores y Servicios Sociales

Table 1-2 Breakdown of the economic cost of accidents in the elderly (Del Campo Martín, Estudio de evaluación económica de la accidentabilidad de las personas mayores en España., 2011).

TYPE OF COST	€	%
DIRECT COSTS	381,261,626	90.0
Attendance	344,456,068	81.3
Rehabilitation	36,805,558	8.7
INDIRECT COSTS	42,589,474	10
Family work absences	3.052.155	0.7
Hired caregivers	21,953,934	5.2
transport	16,103,415	3.8
Aids, crutches…	1,479,970	0.3
TOTAL COSTS	423,851,100	100.0

Regarding indirect costs, the expert has highlighted that they are much lower since it has been taken into account that people over 65 are already retired. However, they have warned that if the law changes and the retirement age is set at 67 years will also increase these costs due to the sick leave that these accidents entail. In absolute terms, 423 million euros/year can be considered as a possible magnitude to be reduced, which represents approximately 0.04% of Spanish GDP[19] and 0.5% of total healthcare spending in Spain. But the need to reduce the figure should not be motivated solely by financial savings but by saving the suffering and human losses that this reality implies. In the same way, to reduce this number, the most reasonable method is prevention, but even more important is the measures are taken to relieve injuries after a fall.

Death and Incidence Rates

Reviews showed in 2017, 13 840 per 100 000 (uncertainty interval (UI) 11 837–16 113) elderly received medical treatment because of a fall-related injury in the Western European zone. In 2017, 8.4 million of 11.7 million injured adults aged 70 and older were due to fall-related injury. In 2017, 54 504 elderly died due to falls. Death rates due to a fall in 2017, ranging from 18 per 100 000 in the age group of 70–74 years and 705 per 100 000 in the ages over 95 years (Haagsma, 2020). Table 1-3 shows the incidence and death rates due to falls in the elderly by the European country.

[19] Gross Domestic Product

Table 1-3 In older adults (70+ years) per 100 000 by country with 95% uncertainty intervals, 2017 (Haagsma, 2020).

Country	Incidence rate* (per 100 000)	Rank number incidence rate†	Death rate* (per 100 000)	Rank number death rate†	Total deaths (%)‡	Case fatality rate§
Andorra	15 556 (12 964–18 709)	7	88.6 (71.8–107.8)	12	1.7	0.006
Austria	14 863 (12 617–17 445)	9	96.8 (89.0–105.1)	10	1.8	0.007
Belgium	19 634 (16 498–23 644)	2	118.4 (108.3–128.9)	6	2.1	0.006
Cyprus	9964 (8260–12 017)	19	54.9 (47.3–62.8)	17	1.2	0.006
Denmark	13 620 (11 496–16 188)	13	97.2 (89.7–106.1)	9	1.8	0.007
Finland	18 808 (15 864–22 068)	4	132.5 (123.2–142.6)	5	2.5	0.007
France	17 682 (14 941–20 963)	6	133.5 (122.1–145.4)	4	2.7	0.008
Germany	14 962 (12 556–17 604)	8	95.3 (85.8–105.9)	11	1.6	0.006
Greece	7594 (6326–9032)	22	29.0 (26.7–31.5)	22	0.5	0.004
Iceland	13 312 (11 266–15 555)	14	87.6 (80.8–95.0)	13	1.7	0.007
Ireland	10 489 (8826–12 502)	17	54.2 (49.6–59.6)	18	1.1	0.005
Israel	8811 (7438–10 453)	20	44.4 (40.5–48.7)	20	0.9	0.005
Italy	12 850 (10 899–15 215)	15	69.0 (63.3–75.2)	16	1.3	0.005
Luxembourg	17 713 (14 791–21 045)	5	113.6 (101.1–127.7)	7	2.0	0.006
Malta	13 654 (11 630–16 059)	11	77.2 (70.8–85.0)	15	1.5	0.006
Netherlands	13 623 (11 756–15 894)	12	145.5 (133.8–157.8)	3	2.7	0.011
Norway	19 796 (15 536–24 233)	1	152.6 (146.6–158.8)	2	2.8%	0.008
Portugal	8086 (6790–9659)	21	35.9 (32.8–38.9)	21	0.6	0.004
Spain	10 161 (8571—12 003)	18	50.1 (46.1–54.6)	19	1.0	0.005
Sweden	14 835 (11 751–18 249)	10	103.1 (95.8–110.5)	8	2.0%	0.007
Switzerland	19 431 (17 099–22 400)	3	153.2 (141.3–165.9)	1	3.3	0.008
UK	12 099 (9814–14585)	16	78.6 (77.0–80.4)	14	1.4	0.006

In this regard, to reduce the costs imposed on the healthcare system and society, basic programs should be further implemented to prevent falls and fractures (Heinrich, 2010) (Hartholt K. A., 2012).

<u>Governmental and community consequences:</u>

As evidence and statistics show, falls can have devastating effects on people's health and the level of hospital admissions and health insurance costs. since the world population gets older, a concerted drive from the national to the local level requires. Every government must prioritize the reduction of such imposed costs in its programs and fall prevention. That would be more effective to organize the legal conditions and financial incentives via the collaboration of social care and the government (El-Bendary N. Q., 2013).

1.4 ENVIRONMENTAL AND HOME SAFETY FOR AGING ADULTS

1.4.1 GENERAL RISK FACTORS INVOLVED IN FALL

After a fall, the elderly is generally afraid of falling again. For this reason, they reduce their daily activity, and this inactivity reduces the strength and strength of their muscles and provides a basis for them to fall again. Falls are possible for any reason, and the causes of falls must be identified to control and avoid falls. The risk of suffering an injury from a fall depends on the patient's readiness or disorders and environmental conditions and rises with the number of risk factors. (Tinetti, Sep 1994). Also, a significant number of older individuals have more than one problem simultaneously, making the risk of a fall even greater.

The main risk factors reflect the multitude of health determinants that directly or indirectly affect well-being. These risk factors that lead to falls can be intrinsic (that is, physiological developments, diseases, and age-related medications) or extrinsic (that is, environmental risks). It is necessary to remember that a single fall can have many reasons, and frequent falls can have a different etiology. Therefore, it is not recommended to evaluate each risk factor separately. Many factors affect the balance and gait (ability to walk), resulting in the fall, but only rarely are all of the causes fully reversible. Physical factors or intrinsic factors may cause older people to fall quickly. Biological risk factors are related to the body, habit, or lifestyle. Aging develops long-term physical or mental conditions or any illnesses that have an impact on gait and balance. Weakness, pharmacologic factors, dizziness, Central nervous system disorder, Heart attack or stroke, syncope, visual problem, etc. (Pfortmueller, 2014), and many similar cases are examples of factors that inadvertently upset the balance and cause a fall. It is helpful to conduct a walk-through of the spaces to identify possible problems that may lead to falling. There may be various indoor or outdoor factors in the environment that can increase the likelihood of falling. Environmental hazards or extrinsic factors include threshold door, Different levels, Fall from the bed, Slippery Floor (especially at night), poor light, furniture, loose rugs, Stairways.

Table 1-4 Gross Mortality Rate due to the fall per 100,000 inhabitants over 65 from 2000-2018-Spain[20]

	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
65-69 años	4,13	4,31	3,43	4,09	4,31	4,30	4,39	4,62	4,70	3,80	3,69	4,42	4,89	4,35	5,42	5,44	6,19	5,61	6,53
70-74 años	6,46	6,66	6,57	6,78	7,10	7,79	6,63	7,28	7,09	7,92	8,04	7,07	7,01	8,57	9,42	9,28	10,57	9,28	10,49
75-79 años	12,60	10,74	12,69	12,26	12,47	12,66	12,08	11,65	12,36	14,66	14,83	16,05	15,86	16,89	17,68	18,26	17,85	17,01	17,89
80-84 años	22,91	23,39	22,32	24,12	25,81	29,07	22,22	22,54	25,71	25,58	27,41	27,25	32,16	35,67	33,70	34,61	37,20	36,50	34,65
85 y más años	65,70	61,36	66,89	69,06	60,03	61,76	60,79	62,70	59,04	66,40	64,05	73,34	91,51	98,42	95,29	95,85	97,63	98,59	101,40

According to the information available in Statistical Portal Management Intelligence Area[21] (Ministerio de Sanidad, 2019) of Spain website (MSSSI)[22], statistics of deaths due to falls in Spain are classified and presented by state, age, gender and year. Table 1-4 and Table 1-5show statistics on the number of mortality from fall per 100,000 inhabitants in the entire states of Spain and ages in the recent two decades. In the last five years, the state of Catalonia has been ranked almost tenth on the list (Table 1-4). The rate of death caused by fall at age 65 and over have constantly been increasing from 2000 to 2018 (Table 1-5).

[20] Source: Ministerio de Sanidad, Servicios Sociales e Igualdad. Instituto de Información Sanitaria. Mortalidad por causa de muerte. http://pestadistico.inteligenciadegestion.msssi.es/publicosns/Comun/DefaultPublico.aspx
[21] Interactive Consultation of the National Health System
[22] Spanish Ministry of Health, Social Services and Equality–https://www.mscbs.gob.es/

Table 1-5 Adjusted Mortality Rate due to the fall per 100,000 inhabitants over 65 from 2000-2018 by States (Ministerio de Sanidad, 2019).

	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
Total nacional	2,75	2,68	2,80	2,74	2,78	2,81	2,55	2,63	2,71	2,64	2,63	2,65	2,83	3,05	3,14	3,04	3,29	3,29	3,30
ANDALUCIA	2,85	2,31	2,77	2,90	3,12	2,99	2,85	2,75	2,93	2,81	2,96	2,30	2,58	2,06	2,08	1,66	2,03	2,69	2,93
ARAGON	2,17	3,34	2,51	2,71	2,81	2,45	2,89	2,07	3,37	2,55	2,23	2,55	2,37	2,72	4,65	3,77	4,34	4,67	4,58
ASTURIAS (PRINCIPADO DE)	4,56	5,63	5,12	5,15	5,00	5,01	5,52	3,69	5,42	5,76	5,24	6,21	7,76	7,24	7,17	6,86	7,34	7,98	6,18
BALEARS (ILLES)	3,35	2,99	2,10	2,00	2,50	2,62	2,95	2,37	2,51	2,86	3,24	3,95	3,21	2,67	3,21	3,25	3,04	3,81	4,26
CANARIAS	2,27	2,68	2,09	1,87	2,24	3,53	2,55	2,90	2,83	2,81	2,69	2,39	2,59	3,61	2,97	2,63	1,96	1,65	2,28
CANTABRIA	2,10	1,83	3,38	1,78	1,72	1,84	1,29	1,79	1,78	1,92	2,57	1,48	2,93	6,51	5,27	2,54	2,52	1,86	3,95
CASTILLA Y LEON	2,21	2,11	2,33	1,70	1,91	1,63	2,76	2,27	1,89	1,76	0,88	1,31	0,86	1,20	1,78	1,83	2,30	2,34	2,65
CASTILLA - LA MANCHA	1,45	1,46	1,34	1,33	1,42	2,18	0,98	1,76	1,33	1,87	3,22	3,78	5,16	5,61	4,89	5,15	6,12	4,67	4,92
CATALUNA	2,84	3,00	3,16	2,62	2,41	2,43	2,08	2,20	2,33	2,13	1,80	1,87	2,12	2,01	2,64	2,38	2,40	2,59	2,54
COMUNIDAD VALENCIANA	2,46	2,08	2,18	2,33	2,85	2,79	2,53	2,90	2,39	3,12	3,35	2,72	2,89	2,80	2,64	3,25	3,37	2,53	2,54
EXTREMADURA	0,61	0,91	1,06	1,53	0,74	1,22	1,07	1,36	1,23	1,09	1,11	1,32	0,96	1,26	1,46	1,80	1,57	1,83	1,18
GALICIA	3,35	3,30	3,36	3,77	3,34	3,69	2,77	2,51	3,22	2,81	2,90	3,72	4,06	4,78	4,56	4,76	5,44	5,13	4,96
MADRID (COMUNIDAD DE)	2,04	1,92	2,13	2,30	2,15	1,65	1,80	2,03	1,87	1,97	1,52	1,84	1,48	2,57	2,27	2,22	2,49	2,30	2,19
MURCIA (REGION DE)	4,36	2,96	3,49	3,09	3,80	3,16	2,45	3,42	3,03	2,49	2,96	3,27	3,17	3,75	3,74	4,04	3,83	4,38	3,84
NAVARRA (COMUNIDAD FORAL DE)	4,18	3,62	4,73	4,79	5,11	5,47	5,72	5,23	5,66	6,35	5,57	4,71	5,64	4,99	5,69	6,21	5,74	5,11	5,77
PAIS VASCO	3,30	3,61	3,29	3,55	3,24	3,82	2,46	3,47	3,84	2,71	3,29	3,24	2,63	2,91	3,04	3,01	3,64	4,00	3,43
RIOJA (LA)	5,59	4,39	5,73	3,80	6,24	4,99	3,61	4,14	5,18	4,02	5,16	5,63	4,59	4,90	3,45	4,07	3,20	4,20	6,54
CEUTA	1,38	1,31				1,87	5,14	1,39		3,98	2,54	1,25		1,78	1,18	1,19	5,84	1,15	1,87
MELILLA			1,75	2,29		2,49	1,06	1,46	1,43						1,25	2,42	1,22	2,01	

Some studies show that the most inactive and the most active people are at the highest risk of falls. Specific activities may increase the risk of falls. Fatigue or unsafe practice in exercise sessions are of these factors. Exposure to particular environments and conditions may increase the likelihood of falling. Slippery or uneven floors, cluttered and degraded pavements (Todd, 2004)

The tendency to fall increases with the number of risk factors that are concentrated in each elderly patient. Main factors lead to fall are classified as follow:

1- Intrinsic reasons (Physical factors):

- Increasing age
- Medication use or alcohol
- Arthritis
- Gait disturbance, balance disorders or weakness, pain related to arthritis
- Acute illness
- Chronic pain
- Anemia or other blood disorders
- Thyroid problems
- Foot disorders
- Muscle weakness in the legs
- Diabetes
- Parkinson's disease
- Frailty
- Vertigo (dizziness) or balance difficulties
- Central nervous system disorder, syncope, drop attacks, epilepsy
- Brains, mental or mood conditions, such as dementia, Alzheimer's disease, delirium, depression, or psychotic behavior
- Cognitive impairment and sensory deficits, including vision or hearing difficulties or neuropathy (numbness) in the legs and feet

- Urinary incontinence or frequent urination that needs numerous resort to the bathroom (sometimes too late)
- Dehydration (lack of fluids in your body). Older adults tend to lose water faster. Dehydration causes hypotension (low blood pressure) which can result in a fall. Dehydration can also cause confusion, loss of balance, constipation, and many other undesirable symptoms. They can become dehydrated unconsciously if the weather is warm, use diuretics ("water pills") and other medications, or suffer from specific conditions like diabetes.
- Diuretics and blood pressure medications can decrease blood pressure, which increases the risk of falling
- Certain medications significantly increase the risk of falling. These include medicines such as tranquilizers, sedatives, sleeping pills, antidepressants, or antipsychotics.
- Vitamin D deficiency (that is, not enough vitamin D in the system) (Aging, 2017).
- Cognitive impairment
- Reduced vision, including age-related changes (i.e., the decline in visual acuity, decline in accommodative capacity, glare intolerance, altered depth perception, presbyopia [near vision], decreased night vision, the reduction in peripheral vision)
- Difficulty rising from a chair
- Foot problems
- Neurologic changes, including age-related changes (i.e., postural instability; slowed reaction time; diminished sensory awareness for a light touch, vibration, and temperature; the decline of central integration of visual, vestibular, and proprioceptive senses)
- Decreased hearing, including age-related changes (i.e., presbycusis [increase in pure tone threshold, predominantly high frequency], impaired speech discrimination, excessive cerumen accumulation)
- A history of falling and fear of falling again (Rubenstein LZ. Yoshikawa TT, 1993) (Fuller, 2000).

Medications, especially the use of four or more prescription drugs (Drugs That May Increase the Risk of Falling):

- (Sedative-hypnotic and anxiolytic drugs (especially long-acting benzodiazepines)
- Tricyclic antidepressants
- Significant tranquilizers (phenothiazines and butyrophenones)
- Antihypertensive drugs
- Cardiac medications
- Corticosteroids
- Nonsteroidal anti-inflammatory drugs
- Anticholinergic drugs
- Hypoglycemic agents
- Any medication that is likely to affect balance (Fuller, 2000)

2- Extrinsic reasons (Environmental hazards and factors):

It is helpful to conduct a walk-through of the spaces to identify possible problems that may lead to falling. There may be various indoor or outdoor factors in the environment that can increase the likelihood of falling. Factors include:

Indoor factors

- The most common hazard for falls is tripping over objects on the floor
- Inappropriate footwear and clothing
- Wrong walking aids or assistive devices
- Extension Cords Across Walkways
- Threshold door
- Uneven surfaces
- Fall from bed
- Bump or dent for any reason on the floor
- Slippery Floor-Bathroom, Kitchen… (water, oil, detergent, etc.)
- poor lighting (especially at night), intensity and reflection of light, loose rugs, wires, lack of grab bars or poorly located/mounted grab bars, and furniture that isn't sturdy.
- Use of inappropriate color in interior design (use contrast in paint, furniture, and carpet colors)
- Use of oversized furniture and objects or unstable chairs or tables
- Improper footwear or shoes with heels.
- Stairways
- Pet movement between legs

Exposure to risk

- Some studies show that the most inactive and the most active people are at the highest risk of falls. Specific activities may increase the risk of falls. Fatigue or unsafe practice in exercise sessions are of these factors.
- Exposure to particular environments and conditions may increase the likelihood of falling. Slippery or uneven floors, cluttered and degraded pavements) (CEREPRI, 2004).
- Lifestyle or Behavioral Risk Factors
- The arbitrary use of medications and over-the-counter doctors.
- In older age, medications take more time to break down and leave your body.
- Some medicines interact with each other, and the result would be unexpected and harmful.
- Some medications have side effects such as dizziness or confusion that can also increase the chance of falling.
- Alcohol consumption while taking medication may cause functional impairment in the medicine and increase the risk of falling.
- Lack of Exercise
- Annual health checkup (Vision, Hearing, Foots, Blood, Bones, and Joints) (Aging N. C., 2018)
- Avoid talking openly with a healthcare provider or doctor and express the problem
- Aging makes muscles weaker, joints ache more, and exercise is more and more challenging. Some common complications like arthritis, dizziness and chronic pain may make it more challenging to exercise.
- Staying indoors is another problem that reduces exposure to the sunshine. And this implying that the lack of vitamin D in the body, which the body needs to keep bones strong.

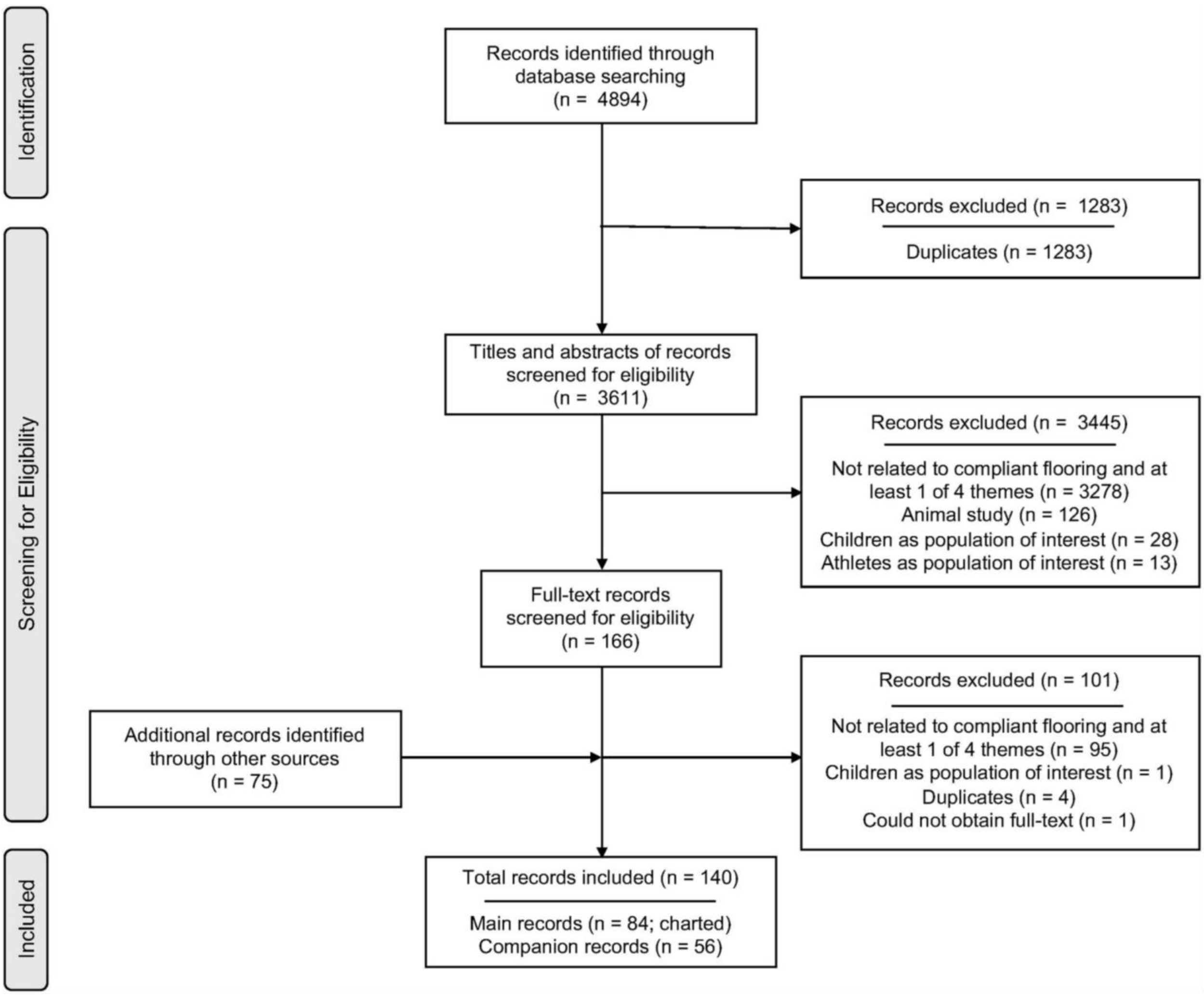
Demographic factors

- Older age (especially ≥ 75 years)
- White race
- Housebound status
- Acute illness
- Historical factors
- Use of cane or walker
- Previous falls
- Living alone (Fuller, 2000)
- Chronic conditions, especially neuromuscular disorders

1.5 NOVEL COMPLIANT FLOORING (NCF)

As mentioned above, many of the factors that lead to falls are environmental factors that may occur indoors. In the following sections, many other methods of reducing post-fall injuries are briefly discussed. One of the measures that can be considered to reduce the vulnerability of the elderly is the installation of shock absorption floorings. Extensive studies have been done in this field due to the products available in the market. In their research, this type of flooring has been mentioned as a Novel Compliant Flooring (NCF) that aims to diminish fall-related injuries in healthcare settings.

Table 1-6 Study flow diagram. Diagram adapted from PRISMA (Moher D L. A., 2009)



Compliant Flooring (CF) system is a passive intervention strategy designed to reduce the surface's stiffness to attenuate the impact forces applied to the body and reduce the severity of the injury in the event of a fall (Laing A. C., 2009).It is an excellent opportunity for high-risk environments such as long-term care (LTC), where fall and injury rates are about three times higher than in older adults living in the community (Rubenstein LZ, 1994) (Tinetti M. E., 1989). So far, a few LTC sites have used the CF system (Lachance C. C., 2016).

An obstacle to implementing the CF system may be the lack of synthesized evidence (Lachance C. C., 2016). A survey was conducted by Chantelle C. Lachance et al. (Lachance C. C., 2017) about the biomechanical efficacy, clinical effectiveness, cost-effectiveness, and workplace safety associated with compliant flooring systems. Their references were based on academic and grey literature databases. They found 3611 titles and abstracts and 166 articles, 84 records, plus 56 companions (supplementary) reports. Biomechanical efficacy records (n = 50) represent CF system can reduce fall-related impact forces with minimal effects on standing and walking balance. Clinical effectiveness records (n = 20) indicate that the CF system may decrease injuries but may grow the risk of falls. Preliminary evidence suggests that the CF system may be a cost-effective strategy (n = 12) but may also lead to physical problems and fatigue for healthcare workers (n = 17) (Table 1-6).

1.6 SIGNIFICANCE OF THE STUDY

In the literature review, the importance of the floors is to take the impact of our daily activities and is generally the first surface to reflect wear and tear. There are hundreds of flooring types to choose from, but it's essential to choose the right one from the start as the wrong floors can practically cause irreparable damage. In any country, specialized laboratories are used to check compliance with standards and product validation. The standard and suitable flooring for sports and leisure should offer an optimal combination of functionality, efficiency, and safety. Also, in sports and fitness, factors like elasticity, fall attenuating, and insulating properties of the flooring (in case of the gym, dumbbell sport, Cross Fit, Martial Arts) is of the uttermost importance. Industrial environments and kid's playgrounds have better conditions for flooring. But what about the elderly! Although falling is not always dangerous, it is always dangerous for the older generation. There are two concerns with the same goal: Prevent falls, fall detection, or prevention of injury in the elderly! Many studies have been conducted to reduce the risk of falling and the rate of damage in the event of a fall. Many of which are in the field of assistive devices for the elderly to prevent falls. But the problem remains.

According to the researcher's observations and studies, most of the floors of hospitals, medical centers, residences, or nursing homes, not only in Spain but also in other countries, are covered by terrazzo, granite, or marble due to their high durability and easy cleaning. Except using vinyl in some cases, all of which have rigid and dangerous surfaces for the elderly. Only in some instances, for research, compliant floorings have been used for a certain period in health centers or pharmacies. And other research has been done in laboratories by simulating impacts or falls.

In this research, despite the limitations, an attempt has been made to use on-site and laboratory methods. Besides risk zones, the opinion of the older adults and staff has been considered about comfort and interests.

CHAPTER 2

THEORETICAL FRAMEWORK FLOORING AND SHOCK ABSORPTION SYSTEMS

CHAPTER 2

2 THEORETICAL FRAMEWORK - FLOORING AND SHOCK ABSORPTION SYSTEMS

Keywords: Flooring, Long-Term Care (LTC), Comfort, Kinematic of Fall, Dynamic of Impact, GRF, Fall-Related Injuries, Fall Prevention, Fall Detection, Fall Protection, Safety Flooring, The CF System, Geometry, Material, Cost Effectiveness, Shock Absorption, Cushion Systems.

Flooring is generally a word used for a permanent coating of a floor or a word to describe any finish material installed over a floor structure to provide a walking surface. The subfloor is a layer under the flooring, supporting the flooring, floating floors, raised floors, or sprung floors. Flooring is one of the essential elements in architectural design. Flooring is the first surface that we are in direct contact with the whole day. Unconsciously, it directly affects the mental and physical performance of human beings. Suitable flooring is significant not only in terms of aesthetics but also in terms of comfort and safety. Comfort means that during daily activities, it does not involve the human foot in fatigue, and to be sound and heat insulation, has the proper color and texture of the space. Safe flooring means flooring that does not have a slippery surface and can absorb energy and reduce damage in the event of a fall. This subject will be thoroughly discussed later. More information about Solid Mechanic, Elastomers, Hyperelastic Material are given in appendix E.

2.1 A BRIEF HISTORY OF FLOORING AND HUMAN

These days there are plenty of choices for covering floors and even ancient types still in use. The very first indoor floors were just made simply of the ground itself. In some cases, hay, straw, and cow dung are sometimes used on the floor and tamped down as people walk on it to soften this surface and make it slightly warmer in the winter. The rural houses were often shared with livestock, and remained trashes dropped by households would compress down into the floor by waking and resulting in a hard surface like concrete. Mint was used in many European floor surface mixes as a room deodorizer to help counteract the smell of waste and feces scent through the room. Animal skins may also have been draped over the ground surface as another option to provide some degree of padding and heating.

Settlers would sometimes pour large amounts of sand over the dirt floor in early North American indoor spaces to create a warm, soft, relatively sanitary floor covering. Other settlers in North American would spread peanut and sunflower seed shells over the floor. The oil from the shells would spread out across the ground as they walk on the ground, causing them to become stiff, free of dust, and uniform over time. In India, colored sand was used to form patterns on the surface called "rangoli" as an art that could be mixed with rice powder and colorful flower petals to color the dirt surface of the ground. These were designed at the entrance to greet visitors. Stone floors and construction were first developed in Egypt about 5,000 years ago, and stone and brick floors began to appear. As far back as 3,000 years ago, the Greeks were creating pebble mosaic floors. These were sticking hundreds of small stone pieces into a mortar frame to form an image. This method was utilized in ancient France, Spain, Italy, and Northern Europe. The ancient Greeks considered marble a unique stone and were formal and luxurious because of its translucent abilities that seemed to glow in the sunlight (Lewitin, 2019). During the Roman Empire (27 BC to AD 476), engineers created a technique to keep the stone flooring warm. They built a small room on one side of the basement and a vent at one end. With this method, after making a fire in the small room, the heat and smoke circulation would keep warm the stone floor above. Evidence also demonstrates that ceramic tiles were applied for floors thousands of years ago. The modern tile industry began in 1843 by Herbert Minton in England (Huntington, 2004). The use of wood as flooring dates back to the Middle Ages. At first, rough planks were used as the floor. Then these were sanded with stone or metal to provide a smooth surface.

Later, varnishes or stains were used to make it last longer. Stains were also applied to create patterns like a puzzle (Flooring, 2020). The oldest woven rug called the *Pazyryk* carpet was discovered in Siberia in the 1940s, dating about 400 BC. Experts agree that it was most likely not made there, rather Persia or Armenia. Some forms of the rug were used in Egypt, Mesopotamia, and the Middle East about 4,000 years ago. The Romans applied rugs on the floors or walls or even used them to pay taxes. Iran (then called Persia) significantly progressed the art of rug weaving during the Safavid Dynasty (1502 to 1736). The patterns and geometries they created are still utilized in rugs worldwide (Interiors, 2020).

Rubber floors (known as Resilient floors) first emerged around 1200. An English rubber manufacturer, Frederick Walton, invented linoleum in 1863 by mixing linseed oil with powdered wood or cork (or both), resins, pigments, ground limestone, and drying agents. Rubber, cork, and asphalt tiles appeared in the early 1900s—European inventors composed vinyl chloride gas in a mixture that resulted in a stiff material. In 1926, American researcher Dr. Waldo Semon used the vinyl chloride mixture with other chemicals to bond rubber to metal. In the long run, he made a material we call PVC (polyvinyl chloride) or vinyl. This material was first used in shock absorbers. Later, it was applied to create synthetic tires, insulate wires during World War II, and floor covering after the war (Huntington, 2004).

A fundamental change was achieved with the advancement of technology, supply, and demand in architecture and other branches of art and industry. Changes in the structure of architecture and design due to the different needs of society caused architects to use emerging materials and technology in line with their goals in the plan. In the modern world, the flooring was no longer just a clean surface. The type of flooring had to be changed regarding the kind of use in the space. It was aesthetically pleasing and functional, and this trend continues to grow and increase due to the diversity of materials and creative innovations. Natural materials such as stone and wood or industrial and synthetic materials and even recyclable materials were included in this range. In this regard, this issue was a new concern for architects to improve their designs.

2.1.1 FLOORING IN HOSPITALS AND LONG-TERM CARE RESIDENTS (LTC)

Falls in hospitals and healthcare centers are a significant problem of international concern. Approximately 60% of long-term care (LTC) residents fall at least once a year, and about 30% of falls in LTC cause injury, which is 2 to 3 times more than for community-dwelling seniors. Evidence pointed out that LTC resident's areas are ten times riskier in hip fracture than community-dwelling seniors, and 25% of LTC residents die within six months after a lengthy hospitalization, and less than 50% of them regain their preinjury ambulation status. Furthermore, about One-quarter of fall-related traumatic brain injury (TBIs) in older adults occur in LTC sites. As mentioned, architecture and design have been affected by industrial societies for decades. As a result, public buildings such as hospitals have mainly been designed to operate and look like factories. Hospitals and healthcare primarily focus on treating illness while are often unaware of a patient's psychological, social, and spiritual needs. There is an important relationship between an individual's health and the characteristics of the physical environment; therefore, a health problem is an architectural problem as well (Stevens, 2000) (Harvey, 2012) (Watson, 2011).

Some interventions with the potential for efficiency separately have been studied, and some investigations have been analyzed some interventional methods independently of a multi-component falls prevention program:

- Identification bracelets
- Physical restraints
- Bed alarms
- Special flooring
- Hip protectors

Few hospitals or other institution-based randomized controlled trials of standardized fall interventions, although the necessity for well-designed studies is apparent (Shojania, 2001)**.** Flooring is a considerable subject in hospital or healthcare center design for the architect to reduce injuries and provide a safe and comfortable area for the patients, elders, and staff. The selection of appropriate flooring materials is related to many factors, such as durability, maintainability, aesthetics, easy cleaning, sound absorption, safety, slip-resistance, warranty, life cycle, and expense. Flooring material has a considerable effect on the cost of ownership over the facility's life, especially in healthcare centers. As can be seen, most of the flooring available in hospitals is from terrazzo, ceramic, granite, marble, which are very hard, slick, and, because of the light reflection, creates a dazzling light on the surface. Hard floorings do not feel underfoot comfort, and it causes fatigue in employees, increases the risk of injury, and makes noise while walking (Harris D. D., 2015). Studies show that increasing elasticity, reducing energy absorption, and increasing rigidity caused minor discomfort and fatigue (Cham R. a., 2001). Hospitals are noisy environments. The U.S. Environmental Protection Agency (EPA) has explained that noise causes more worry, stress, distraction, and mental fatigue. Noises decrease the performance, concentration, especially in the work areas (Belojevic, 2003). It also should be mentioned that flooring materials in the health care centers should be resistant and durable because repairing and maintenance are probably causing disorders to patient services and hospital administrations (White, 2007). The functionality of an area is an essential factor in choosing an appropriate flooring material. For instance, polyvinyl chloride (PVC) tiles are preferred to be used in a dining space, while terrazzo or ceramic are recommended to be used in an area connected with outdoor space. Besides, cleaning the floors in health centers is one of the priorities. The uses of disinfectants, anti-microbial, anti-bacterial, anti-allergies are among the materials that the floor is expected to be resistant to and easy to clean (Kim I.-J. , 2020).

Flooring materials used as soft floors include carpets, linoleum, rubber, PVC, or vinyl. Dark and damp spaces underneath the soft floorings are excellent for collecting unwanted microorganisms, such as the underside or between the lint of carpets. Although the potential risks of distributing microbial contamination in the carpet are higher than solid floors, White (White, 2007) mentioned that carpets are not directly related to nosocomial infection as the source of hospital-acquired infections (HAIs). In any case, carpeting is not suggested in spaces where there is a possibility of frequent spillage of liquids, the areas where odor control is needed, operation rooms, obstetrics, intensive care units, chemotherapeutic units, or laboratories (Bartley, 2010). Carpets can be as dangerous as a space with a potential source of fungal infection (Ferguson, 2009) (Khan A. H., 2011). Reports indicate that the carpet creates mechanical friction due to the lint and disrupts the movement of the large wheel-based carts or trollies. (Ulrich, 2008) (Harris D. D., 2013).

The ownership more welcomes hard floors due to their longer life and easier maintenance. Examples of Hard floorings include resilient floors, marble, brick, ceramic, cement/concrete, terrazzo, and wood (parquet) found in abundance in the market. They are much easier to wash than soft floors, do not need to polish, and are fully compatible with the ecology and environment. It must be considered that hard floors need to make arrangements to control the risks of water failures with daily washing to prevent mold growth which can be designed to cover the surface (Bartley, 2010). The Health Revision Committee (HGRC, USA) suggests approbate flooring types with high endurance in the face with frequent cleanings and high traffics and authorization of cleaning products that do not damage the flooring (Carling, 2006).

In addition to all factors mentioned above for proper floorings in healthcare settings, flooring in such areas should be considered as a possible intervention for reducing injuries from falls as well. Few studies have been conducted on this subject, but still, these areas suffer from a lack of suitable products as shock-absorbing floorings. A study conducted in a hospital (Healey, 1994) compared the amount of injury to patients who fell on the carpet with vinyl. They stated among 225 patients who accidentally fell, those patients fell on the carpet, only 17% suffered injuries, but in those groups of patients who fell on vinyl, 46% suffered injuries. Due to Harris's study (Harris D. D., 2015) and a proposed tool for projecting costs of ownership for flooring, soft flooring (carpet) is more cost-effective for the primary step of purchase and installation, equipment, and maintenance compare with hard (terrazzo) and resilience (rubber) floors. Carpet tiles are perfect for noise absorption and anti-fatigue (Harris D. D., 2015).

Improves in biomedical engineering could lead to the potentially considerable redesign of the physical environment in hospitals and nursing facilities. The first goal of specialized flooring could be to reduce the risk of falling or reduce the risk of injury in the event of a fall. The studies analyzed show that carpeted floors may increase falls but diminish fall injuries; other materials as flooring surfaces may yield better results. Further investigation of this area is warranted. (Shojania, 2001).

2.1.2 COMFORT IN FLOORINGS

Ergonomics is the recognized discipline to prevent injuries by reducing or eliminating employee's exposure to occupational risks. Contributing to the frequency of these injuries include: falling, lifting patients and heavy tools, moving furniture, pushing or pulling heavy carts, and wearing inappropriate footwear. The National Institute for Occupational Safety and Health (NIOSH) (Department of Health and Human Services, 2010) has recommended protecting the safety and health of healthcare staff is to use non-slip floorings and clean up spills immediately. Mostly the risk of injury is because of pushing or pulling carts. The friction between the floor's surface and the healthcare staff's footwear or the object's weight being pushed or pulled. Not many studies focus on the coefficient of friction (COF) and interaction between man, device, and flooring. Investigations of the influence of flooring characteristics on comfort suggest that three factors of elasticity, stiffness, and thickness may contribute to staff fatigue and need further research. However, it is essential to mention that part of studies examining the effect of flooring on constant standing comfort and fatigue with low activity (and do not account for the group of nurses stand in one place for a long term in a day, suffering foot fatigue). They are in continuous movement between patient rooms or other sections, including the nurses' station, supplies, and other support areas. (Harris D. D., 2013).

Redfern (Redfern M. S., 1995) studied the influences of surface material properties on workers' perceptions of tiredness and comfort. He noted that the more rigid surfaces, the lower the feeling of comfort. Because the rigid surface does not attenuate impact or pressure on the foot and reduce blood circulation in the foot and leg, the rigid surface may also focus on a few small muscle areas, accelerating fatigue. He added the thicker materials lead to lower perceptions of tiredness and swelling of the feet and legs. It should be noted an incredibly soft surface increases perceived exhaustion as the body works unconsciously to maintain balance, which means neither too hard nor too soft will provide the best performance. He offered O.69 MPa as hardness (elastic modulus in the range 0.5-0.9 MPa) of an anti-fatigue mat. Also, Redfern's data propose that materials with a bottoming out depth of more than 5 mm with a thickness of more than 10 mm give the best results unless they are too soft. Before entering the category of features of safe floorings, firstly, it is necessary to address many concepts.

2.2 FALL AND DYNAMIC OF IMPACT

2.2.1 KINEMATIC OF FALL

FALL: According to the definition presented by WHO, a Fall is the consequence of any event that the patient precipitates on the ground against his will. In older people, it is a widespread event with a high prominence on their state of health and increased morbidity and mortality, both for trauma and for the sequelae that it produces. Fracture strength depends on various parameters, including the subject's loading conditions, age, body size, weight, height, and bone mineral density.

Fall detection and the reason for falls is a significant public healthcare problem. Timely diagnosis can be a great help in providing immediate medical services to the injured. One of the common methods in fall detection is based on videos captured via the ambient camera, which usually need extensive data affected by the image quality. However, it is hard to collect fall data through the video method. Therefore, fall simulation in a laboratory with protective measures is another strategy to record the dataset, which is restricted to a limited quantity (Okan J.-S. S., 2015). Due to the investigations executed by Robinovitch et al., the most common falls happened were walking, sitting down, and standing.

Regarding the video-recorded data over three years in long-term care, the reasons cause the fall mainly was in the order of probability of occurrence included incorrect weight shifting, Trip or stumble, hit or bump, Loss of support with an external object, or loss of consciousness (Robinovitch S. N.-G., 2013). A hip fracture is the most common event in the elderly (Nordin, April 2001) that often needs an operation, including fractures to the femoral head, neck (Tortora, 2011). In a study executed by Parkkari et al. (Parkkari J. P., 1999) The model and direction of hip fracture patients' fall have been investigated. They came to an overall assessment so that 76% of the patients landed directly to the sideway. However, 12% of the patients fell obliquely backward, and 8% fell straight or obliquely forward. This study concluded, about 81% of the hip fracture individuals received the essential impact on the greater trochanter. The mentioned study results are almost identical to the personal interviews done by the author with the elderly and the statistics received from the nursing home as a case study. Sabick et al. (Sabick, 1999) noted that impact applies primarily at the hip and then at the shoulder.

The peak lateral loads inducing fractures in senior individuals range from 1000 to 6000N. Younger peoples have enormous femoral strength (United States, Washington, DC Patent No. US7575795B2, 2009). The ranges of hip impact velocities during sideways fall from standing height, the ranges of body shapes at impact and muscle activation, or using hand affection are the issues of Fall dynamics or kinematics of fall (Van den Kroonenberg A. J., Hip impact velocities and body configurations for voluntary falls from standing height, 1996). The failure load in a hip fracture is the force that can be applied to the greater trochanter until a fracture in the proximal femur happens. This load is different regarding age and bone density. The results reported in Robinovitch's investigation stated that an individual experiences peak impact forces on the hip in the muscle-relaxed state and the muscle-active state of approximately 5,600 N, and 8600 N falling, respectively. (Robinovitch S. N., 1991).

Courtney et al. (Courtney, 1995) surveyed the difference in failure load between ages 33 and 74. This load for the younger ones at 7200 N (SD=1090) and the older ones 3440 N (SD=1330) (Figure 2-1). Kannus et al. reached the fracture threshold (3100 ± 1200 N) of the proximal femur of older women with a mean age of 71 years (Kannus, 1999). In the study conducted by Courtney et al., the median compressive force needed to account for fracture of the cadaveric proximal femur from older adults in a sideways fall 3,770 N for specimens of mean age 74 years (SD=7 years) versus 7,550 N for specimens of mean age 33 years (SD=13 years) (Courtney AC, 1994). The average hip-fracture threshold in elderly ones is estimated at 3,472 N, range 2,110 to 4,354 N by Robinovitch et al. (Robinovitch S. E., 2009). In other reports (Michal N. Glinkaa, 2013), they used a load of 4 kN for the head, and hip impact simulations, based on peak force applied to the hip during sideways fall averages (Robinovitch SN, 1997). Ning et al. (Ning Li, 2013) used a value of 5939±81 N in their impact simulation trial, which was almost similar to the impact force of 5600 N, which was reported as sideways falls from a 70 cm height in Robinovitch (Robinovitch S. N., 1991) study in 1991. In their trial, they tested different hip protectors by simulating impact force via a pendulum device. Failure strength of the hand's bones was estimated at 10 kN (fracture of the radius, ulna, or humerus) by Melvin et al. (Melvin, 1985) besides the wrist fracture threshold in older females of 2300±800 N (Giacobetti, 1997).

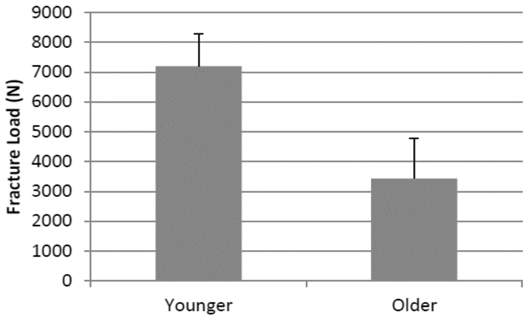


Figure 2-1. The mean fracture load of the proximal femur was tested in a fall-loading. The mean age of seniors is seventy-four, and the mean age for adults are thirty-three year old (Courtney, 1995).

The impact velocity, i.e., the velocity at which the body receives an impact during a fall, has been investigated in previous research. The average hip impact velocity based on kinematic studies of humans falling was about 2.6 m/s (Van den Kroonenberg A. J., Hip impact velocities and body configurations for voluntary falls from standing height, 1996). Due to Feldman and Robinovitch's (2007) observation, the mean hip impact velocity in unexpected falls from a standing position is 3.0 m/s (Feldman F. a., 2007). Due to a study conducted among young adults, the estimated hip impact velocity in a sideways fall from a standing position was 3.17 (SD=0.47) m/s. The angle between the body and the flooring was 68.3° (SD=13.3°). This study showed no significant differences in impact velocity between standing or walking. (Van den Kroonenberg A. J., Hip impact velocities and body configurations for voluntary falls from standing height, 1996) According to another research, the impact velocity was specified to 3.01(SD=0.83)m/s (Feldman F. a., 2007). Van den Kroonenberg et al. (1993) reported in their study that hip floor impact velocities ranging from 2.14 to 4.25 m/s' and averaging 3.19 m/s (Van den Kroonenberg H. H., 1993).

Different results may be related to the fact that there are no applied external forces in their analyzed fall or that the volunteers controlled their impact velocity by some action like stepping or impacting the hand first. A similar study was conducted with 44 volunteers sideways falls, 90 % of them impacted the pelvis, and 98 % impacted the hip region. The impact location was on the mean 8° (SD=15) to the posterior side, the mean impact velocity was 3.01 m/s (SD=0.83), and the body angle was 48° (SD=15) (Feldman F. a., 2007). These results are all conducted in the laboratory with young participants and may not apply to real-time falls on the seniors. In a study conducted by Robinovitch in 2009 (Robinovitch S. E., 2009), they simulate a pendulum to evaluate the hip protector performance. They use a falling mass of 28 kg (the (mean + 0.5*SD) measured in young women) with an acceptable, effective falling mass range of 22–33 kg), with an impact velocity of 3.4 m/s (the (mean+0.5*SD) measured in young adults). They noted impact velocities of 2 m/s and 4.5 m/s could be utilized to simulate a soft fall and a more severe fall, respectively. Peak force will scale accordingly.

2.2.2 IMPACT FORCE IN FALLING OBJECTS

The energy has all achieved from the gravitational potential energy (*PE*) that has before falling, so the equation for gravitational potential energy is (Figure 2-2):

$$PE = mgh \qquad \text{2-1}$$

PE = gravitational potential energy; *m* = mass of object;

g = the acceleration due to gravity constant (9.81 m s−2 or 9.81 meters per second squared);

h = the height the object falls from.

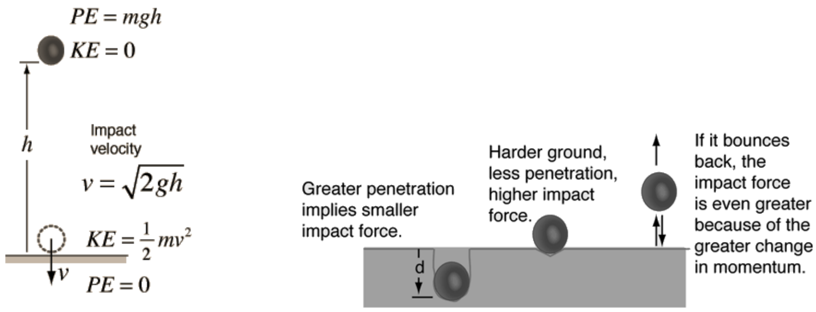


Figure 2-2 Object falling from rest[23]

The kinetic energy just before impact is equal to its gravitational potential energy at the height from which it was dropped. A body with a mass of *m* that is moving at a velocity of *v* is characterized by kinetic energy (KE) and known with:

$$KE=1/2 \times mv^2 \qquad \text{2-2}$$

v: velocity *KE*: Kinetic Energy (Energy at the moment of collision)

But this information is not enough to calculate the force of impact! And how far the object travels after impact is important to predict the impact force. If d assume as the distance traveled after impact, the impact force may be calculated using the work-energy principle to be (Johnson, 2020):

average impact force x distance traveled = change in kinetic energy

$$F \times d = KE \qquad \text{2-3}$$

average impact force = change in kinetic energy / distance traveled

$$F = KE/d \qquad \text{2-4}$$

d: distance traveled

Therefore, the equation shows that the gravitational potential energy and work (W)equal to each other:

$$W = PE = Fd = mgh \qquad \text{2-5}$$

W: work

[23]http://hyperphysics.phy-astr.gsu.edu/hbase/flobj.html

The distance traveled simply shows how far the object travels before coming to a stop. If it penetrates the surface, the average impact force will be smaller. Sometimes this is called the "deformation slow down distance," and this value can also be mentioned as such an object deforms and comes to a stop, even if it doesn't penetrate the surface. Considering that the change in kinetic energy is the same as the gravitational potential energy, the complete formula can be expressed as (Johnson, 2020):

$$F = mgh/d \tag{2-6}$$

When an impact occurs, the kinetic energy can follow two directions. The first direction is to transfer, i.e., varying the velocities of the colliding objects. Instead, the energy is transformed into work in the second path, i.e., deforming the body. The second case indicates a significant problem that leads to body injury when hitting the surface (Kleiven, 2003). Due to an unexpected fall, a vertical force is naturally applied to the body. The intensity of this collision and its impact varies according to different factors. Researchers have proposed various measures to control the value of vertical impact on the body and reduce damage. When an object falls from rest, its gravitational potential energy (PE) changes to Kinetic Energy (KE), and Kinetic Energy can be calculated by using the following formula if the weight of the object and fall height is known:

2.2.3 GROUND REACTION FORCE (GRF)

According to Newton's third law, in physics, specifically in biomechanics, when an object exerts a force on the ground, the ground will press back with equal force in the opposite direction. This reaction to the force by the ground is called 'ground reaction force (GRF).' It is the force that we can measure based on our interaction with the ground. When a person is just standing, the GRF corresponds with the person's weight. Similarly, we put force into the ground to move, and the GRF increases due to acceleration forces (Figure 2-3).

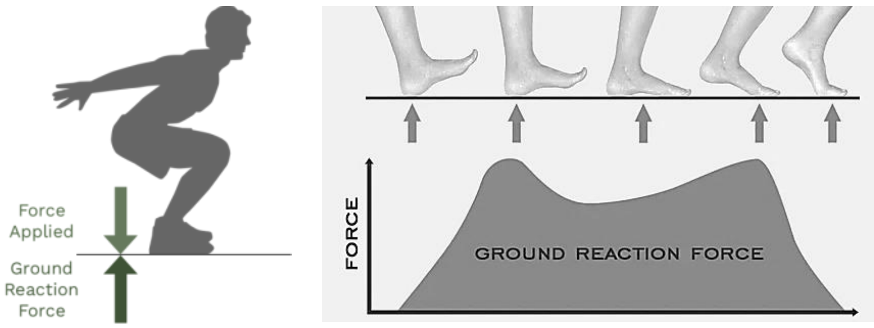


Figure 2-3. Ground Reaction Force-source[24] [25]

[24]https://mass4d.com/blogs/articles/what-is-ground-reaction-force

[25]https://success.spartascience.com/hc/en-us/articles/360045246173-What-are-Ground-Reaction-Forces-

2.3 RISK REDUCTION STRATEGIES IN THE EVENT OF A FALL

Fall Prevention, Fall Detection, and Fall Protection are three very essential categories that reduce post-fall injury.

2.3.1 FALL PREVENTION

FALL PREVENTION: Fall prevention is a series of strategies and instituting special precautions with the patient at risk for injury from falling that reduces the number of accidental falls. It refers to maintaining a safe environment for all patients. Its efficiency is before the fall.

Visiting lifestyle and the home condition is invaluable for evaluating the feasibility of risk factors to modify and determine appropriate interventions. Some devices such as the staircase with handrails, forearm crutch/cane, walker, Grab bar mounted in a bathroom are strategies to prevent falling in the seniors. Preparing a home safety checklist would guide the visit and ensure a perfect assessment (Table 2-1). It is vital to distinguish caregiver and housing arrangements, environmental risks, alcohol-medication interactions (Hsiao, 3 Nov 2016).

<u>Prevention of hazards with some edition:</u>

Table 2-1 Suggestions to avoid falling hazards (Rubenstein LZ. Yoshikawa TT, 1993)

Prevention of Environmental hazards (Rubenstein LZ. Falls. In: Yoshikawa TT, 1993)	Prevention of physical hazards (Physician, Apr 2000)
All living spaces	
• Remove throw rugs or fasten them to the floor with carpet tape	• To get regular check-ups from a doctor, and take good care:
• Secure carpet edges	• Have eyes checked every year for evaluating vision, cataracts, glaucoma, and any other problems.
• Remove low furniture and objects on the floor	• Have hearing checked every two years, or anytime you feel that you can't hear well.
• Reduce clutter	• Visit a doctor immediately if you feel dizzy, weak, or unsteady on your feet, if you feel confused, have foot pain or corns, or if you fall.
• Wear shoes with nonskid soles (not house slippers)	• Inform the doctor if medicine has any negative effect on you such as making you feel dizzy or making you lose your balance or confuse.
• Remove cords and wires on the floor	• If it is detected that you should use a cane or walker, be sure to take it seriously and then use it all the time.
• Be sure your home is well lit, Check lighting for adequate illumination at night (especially in the pathway to the bathroom, hallway, and stairway)	• Before getting up immediately from bed (during the night or in the morning), sit on the side of the bed for a while. This delay helps the blood pressure to adjust, and you will feel less dizzy.
• Secure carpet or treads on stairs	• Trust your doctor and talk without embarrassment and express all your problems
• Install handrails on both sides of staircases	• And keep your body in good shape
• Eliminate chairs that are too low to sit in and get out of easily	• Never quit regular exercise, especially walking, and strengthen the muscles for walking and lifting.
• Avoid floor wax (or use non-skid wax)	• Don't smoke and limit your alcohol intake
• Ensure that the telephone can be reached from the floor	
• Don't put electrical cords across pathways.	
Bathrooms	
• Install grab bars in the bathtub or shower and by the toilet	
• Use rubber mats in the bathtub or shower	
• Take up floor mats when the bathtub or shower is not in use	
• Install a raised toilet seat	
Outdoors	
• Repair cracked sidewalks	
• Install handrails on stairs and steps	
• Trim shrubbery along the pathway to the home	
• Install adequate lighting by the doorway and along walkways leading to doors	
• Have sidewalks and walkways repaired so that surfaces are smooth and even	

Balance and Gait tests:

The “Up & Go”, “Get-up and Go,” “Postural control,” or many other different tests evaluate the balance, gait, and weakness of muscles. For instance, in the “Up & Go” test, the patient with regular footwear gets up out of a standard chair (seat height of approximately 46 cm), walks a distance of about 3 m, then turns, walks back, and sits down again. This test has been displayed to be as valid and reliable as sophisticated gait testing. Postural control, like balance and gait testing, evaluates balance, ambulation capability, endurance, range of motion, sensation, and strength. The patient stands without a side aid on one leg for five seconds to test the One-leg balance. Stands on one leg (based on personal comfort), bends the other knee to check the balances on one leg for as long as possible. To assess overall physical function, the patient's ADLs and instrumental activities of daily living (IADLs) are evaluated. Physical Performance Test (PPT) (Van Swearingen JM, 1998) includes seven normal daily activities such as writing a sentence, lifting normal stuff, putting on and taking off a jacket, walking, and turning back.

The physician assesses the performance of these activities to decide whether the patient is at risk for frequent falls. If any problem is detected, the physician must take the necessary actions to prevent falls, such as making some medication changes (when possible), improving environmental security, and encouraging exercise that improves balance. When the reason for a fall is not distinguished, or a patient stay at high risk for falls, referral to a fall prevention schedule may be warranted. Recent studies have demonstrated that such plans can decrease the rate of falls in the elderly (George F. Fuller, 2000).

2.3.2 FALL DETECTION

FALL DETECTION: Refers to a system that diagnoses and announces the occurrence of a fall. Its efficiency is after the fall.

Prevent falling, is an approach of treating a fall as an abnormal activity that occurs rarely can reduce the risk of danger, and increase safety in almost 90% of the studies related to “Fall detection.” Fall detection is a general term for a series of methods with the same concept and performance. Fall detection systems can be determined as an assistive method whose main objective is to alert when a fall occurs. In fact, the systems are able to mitigate some of the adverse consequences of a fall. In particular, fall detectors can have a direct influence on the decrease in the fear of falling and the quick assistance after a fall. In fact, falls and fear of falling depend on each other. Psychologically, falls persuade fear of falls and other physical activities; This is a factor in the possibility of falling in the elderly. The other important aspect that the system may help to reduce is the time the elderly remains to lie on the floor after falling (long lie). Many older are unable to get up after falling without assistance. This is exclusively critical if the older lives alone or loses consciousness after falling. It can cause severely irreversible physical and psychological effects and many of them pass away before they receive assistance. Elderly individuals, especially those with dementia, need special care to retain their independent living conditions. It is estimated that about thirteen percent of the population over 60 in the world have dependent living conditions (ADI, 2013). There are close to 7 million dementia patients in Europe, and this rate is expected to increase significantly over the next twenty years (Wortmann, 2012).

The application of fall detection is highly regarded both at the academic and industrial levels due to its importance, especially among the elderly. However, they are not readily accepted and liked by the elderly. Fall detection devices can make alarms immediately after a fall and are aware and relevant for assistance. Unfortunately, fall wearable detectors devices based on sensors, are not popular in elderly and they, especially those with dementia, often forget or avoid wearing them.

Moreover, fall detectors based on artificial vision are not yet commonly available on the market. (De Miguel K. A., 2017)

The detection method can be classified into two primary wearable and non-wearable systems. Wearable systems generally include a sensitive accelerometer embedded on the wearable subject, distinguishing changes in acceleration, patterns of motion, or impact on detecting collapse. (Bourke AK, 2007) (Kangas M, 2009) The wearable system as the **first group** is like a cloth, shoes, a wristwatch, belt or vest, which is equipped with accelerometers and by analyzing the defined pattern of gait, controls by electronic sensors (Chung, 2014) (Dinh, 2009). In the **second group,** the non-wearable method uses to detect falls. The technologies embedded in the environment due to the program and the sensitivities defined therein, such as cameras (Belshaw M, 2011) (Sixsmith, 2004) , microphones, acoustic (Li Y. Z., 2010) (Popescu, 2008) or barometer sensors (pressure sensors) (Alwan, 2006) installed underneath the flooring, mat, or environment apply, diverse measurements to specify if the subject has fallen. The researcher tries to propose a system by sending an alarm when a person falls or is about fall with minimum error (N. Noury, 2007) (Gustavsson, Bonander, Andersson, & Nilson, Oct 2015) (Sankar Rangarajan, 2008). The **third group** of approaches, which is mainly used in smart houses, use data, often via evaluating ambient monitoring systems, to find changes in activity levels that may increase the risk of falling or any risky events. The third-group strategies are more preventive rather than reactive methods (Martin, Sep 2006). Lifestyle-monitoring technology is used to monitor behavior patterns and detects where a reduction in activity could be an increased risk of falling (Doughty, 1998). These devices can distinguish the difference between normal activities of daily living (ADL) and emergencies. For example, accurate calculations can distinguish a normal lying down or a sudden change in direction as an outcome of a fall. Typically to measure the changes in direction, detectors use accelerometers and gyroscopes. Another feature of this method is movement-monitoring, which observes one's movement up to 30 seconds after a sudden change in direction. If, after 30 seconds, the device does not receive any movement, it will alert help. Without this 30 sec monitoring, the device may make a mistake and alert help at any time (Preece, 2017).

Basically, the main structure of all fall detection systems is similar. This is not an easy task as certain daily living ADL activities, such as sitting down or changing from a standing position to lying down, have close similarities to falls. Thus, it is essential to collect data from fall events and ADL activities, which can be real and practical or simulated by volunteers in order to test a fall detector and find the rules to classify using a fall detection method able of identifying falls and ADL. These data are recognized and recorded by sensors and can be in form of acceleration signals, images, pressure signals, etc. (Igual, (2013)

This section will better evaluate the types of falls before considering different fall detection methods. It helps towards a perception of the existing approaches and also contributes to the design of new algorithms. Types of falls: falls from walking or standing state, falls from the different level or standing on supports, falling out of bed while lying down, and falls from sitting position on a chair (N. Noury, 2007)

Fall detection methods can be categorized into three main classes (Ramachandran, 2020) (Figure 2-8):

- Wearable device-based,
- Ambiance sensor-based, and
- Camera (vision) based.

Wearable systems are classified into posture-based and motion-based devices.

The factors monitored by wearable sensor-based systems include the following: "heart rate variability (HRV), electrocardiogram (ECG), pulse oximetry (SPO2), and kinematic attributes measured by accelerometers, gyroscope, and magnetometer." The information recorded by such systems is fed as input data to a threshold-based system or as properties sets to a machine learning-based system to categorized and detect falls. Wearable systems are less expensive with lower power consumption which decreases the overheard on charging the system, and are normally in the form of a band that can be fixed and fastened around the wrist or thigh, which rarely happened to be separated from the subjects (Ramachandran, 2020). Wearable device-based methods rely on clothing with placed sensors to distinguish the motion and location of the individual's body. Wearable fall detection devices, in general, can be categorized into two main groups of user-manipulated and automatic systems (Custodio, 2012) (Patel S. H., 2012). User-manipulated approaches (Figure 2-4) have a panic button pressed after falling by the subject to create a fall alarm. Some wearable accessories include necklaces, bracelets, and belts that a person can alert to a fall by pressing a button. User manipulated systems are easy to use and inexpensive. However, this is applicable in which the person is alert after the fall and can press the button, but these systems are non-functional during the loss of consciousness when first aid is needed the most by the user. A reliable fall detection system should be automatic (Özdemir, 2016).

- Wearable and hand-held solutions

This method, based on the technology of accelerometers and gyroscopes, has been developed for coping with fall detection and fall prevention. The accelerometer detects the value and direction of acceleration along a certain axis (Tomkun, 2010). Therefore, any motion that exceeds the defined threshold magnitude of acceleration will be considered a fall. The orientation of a falling person often changes from a vertically standing position to a horizontally lying position on the floor. Hence, analyzing post-fall orientation is an important issue to be considered (Chao, 2009). Researchers commonly accept that the waist is the optimal fall sensor placement on the body (Bourke, 2008). Figure 2-5 (b) shows the TEMPO (Technology-Enabled Medical Precision Observation) three sensor nodes for the tri-axial accelerometer and shows the placement of two TEMPO nodes (Li Q. J., 2009).

Alarm Necklace | Alarm Bracelet | Alarm Mat

Figure 2-4. User-manipulated approaches

The automatic systems (Figure 2-5 a) have many different methods (Figure 2-8). This approach is based on measuring physical activities to monitor activity patterns using accelerometers. Accelerometry is embedded in a part of cloth or vests. The acceleration and air pressure data are recorded by a wearable device connected to the individual and analyzed offline. Mathie et al. (Mathie, 2004) used an integrated approach of waist-mounted accelerometry. Physiological reactions such as changing heart bits or blood pressure may result from physical activity or body position.

Evaluating motion and posture becomes an essential factor in an ambulatory monitoring environment.

Figure 2-5 Wearable automatic safety system (a), Tri-axial accelerometer TEMPO 3.0 sensor node (Li Q. J., 2009) and placement

A wearable airbag is another method that has been developed using both acceleration and angular velocity signals to shot airbag inflation, Figure 2-10 (Tamura T. T., 2009). The system detection algorithm could find signals 300 ms before the fall. Although the proposed method can support to prevention of fall-related injuries.

- Movement-sensing solutions

On the other hand, another classification is to sort products into movement-sensing monitoring solutions and anti-wandering solutions like weight-sensitive reverse pressure pads use for bed, chair, and toilet fall monitoring, there are weight-sensitive pressure pads. When pressure sensors detect connection the pressure pad will be active. The fall mats/pads placed next to the patient's bed (Figure 2-4), in a wheelchair, on the bed, in front of the exit door, and so on. If the older adult wants to get out of bed or wheelchair or leave the house (Figure 2-6), the sensors detect a change in the patient's or older adult's condition and sound the alarm for the nurse (El-Bendary N. Q., 2013).

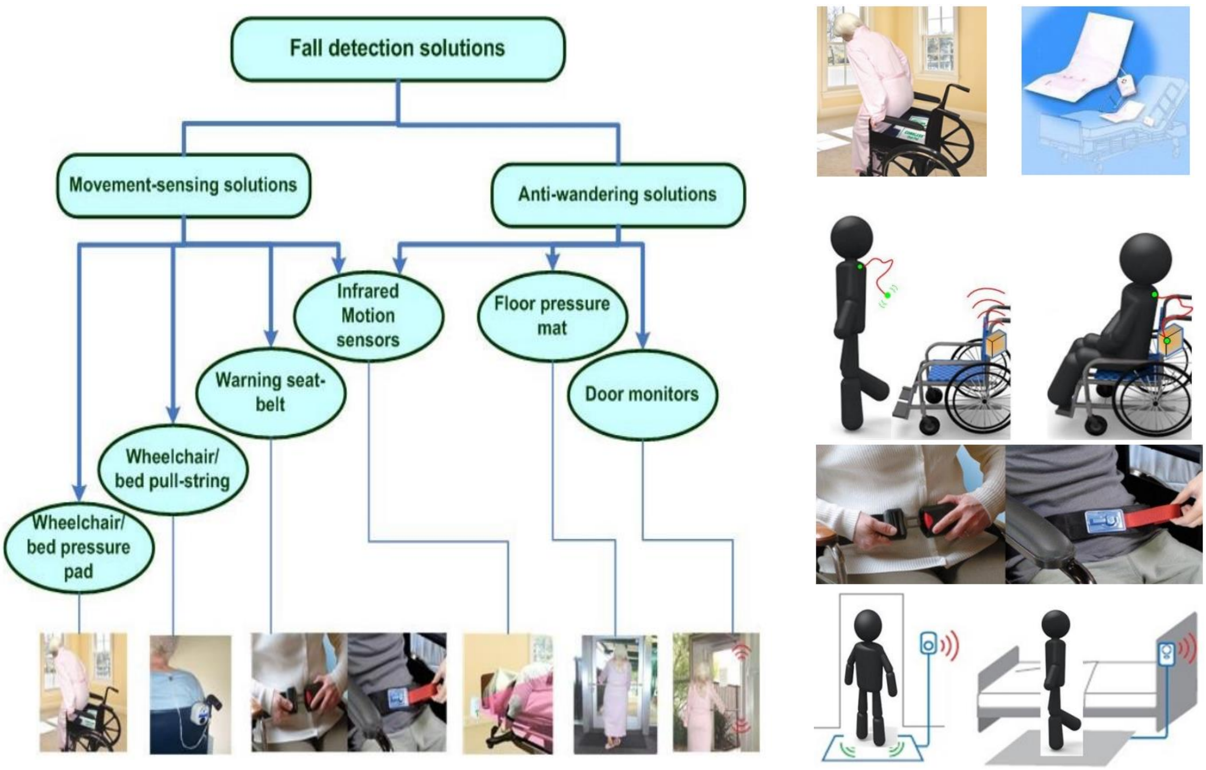


Figure 2-6 Categories of commercialized fall monitoring and prevention products (El-Bendary N. Q., 2013)

In othe point of view there are two approaches to fall detection using wearable sensors:

- Threshold-based systems
- Machine learning based systems (Wu, 2015)

Due to the specialization of the subject and the type of structural analysis in these two methods, it was decided not to enter this category.

<u>Ambiance/Environmental systems are classified into presence and posture-based sensors.</u>

Ambiance-based devices try to combine visual and auditory data and event sensing via vibrating data. Using intelligent systems in elderly' homes (smart homes) (Figure 2-7) increases independence, comfort, and safety feeling (González, 2017)and prevents depression (Cotten, 2014). Also, it frees Relatives and nurses from specific daily care tasks to monitor their elders. Consequently, the cost of healthcare is dramatically reduced. Ambient devices measure the environment of a subject under protection. Environmental sensing-based systems perform on data received from sensors placed in the environment. The infrared sensor and acoustic and passive infrared (PIR) motion detector-based systems are examples of these approaches. Infrared sensor-based systems sense definite characteristics of an area to detect a fall. Microphone-based FDSs focus on acoustic signals to detect sound in an area, distinguish the source, and classify it as a fall or a non-fall status. Motion detector-based methods recognize falls based on motion detection within an area (Ramachandran, 2020). Infrared sensing is the common sample for measuring, but supplementary technologies relied on sound and vibration sense is an innovation that can be expanded. One of the disadvantages of these approaches is that they have to be installed in different rooms to cover the whole space of actuation. Most ambient device-based systems apply pressure sensors for object detection and tracking. The pressure sensor relies on the high pressure of the object's weight for detection and monitoring.

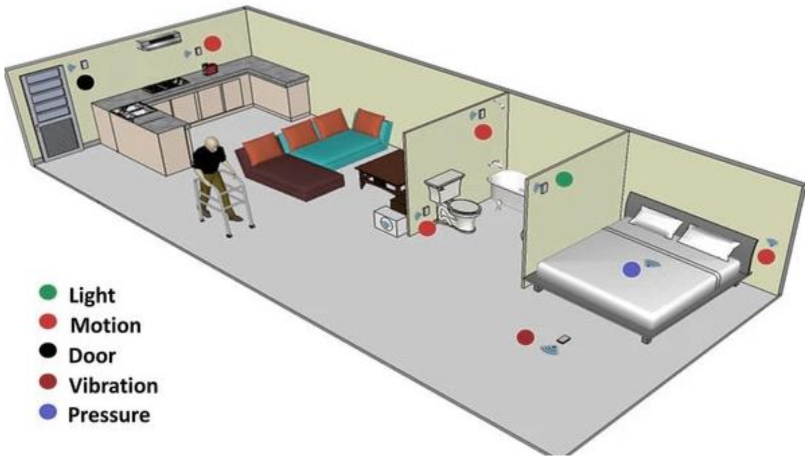


Figure 2-7. Ambient Sensing (Patel S. H., 2012) (De Miguel K. A., 2017)

Many various systems with different techniques are presented, for instance, by researchers. Zhuang et al. (Zhuang, 2009) provide a system based on audio and acoustic sampling. Khan et al. (Khan M. S., 2015) sample environment offer a method to better noise discern made by a subject. Another interesting approach was presented by Alwan et al. (Alwan, 2006)with the ability to distinguish activities through vibrations sensors embedded into flooring. Rimminen et al. (Rimminen, 2010) provide a method using electromagnetic sensors in floor plates to create an image of objects touching the floor. The system reported by Cheng (Cheng, 2016)is based on a laser to detect that a person has fallen. Another method proposed by Tao et al. (Tao, 2012) using an infrared ceiling sensor network system that detects falls if the person remains too long in the same position.

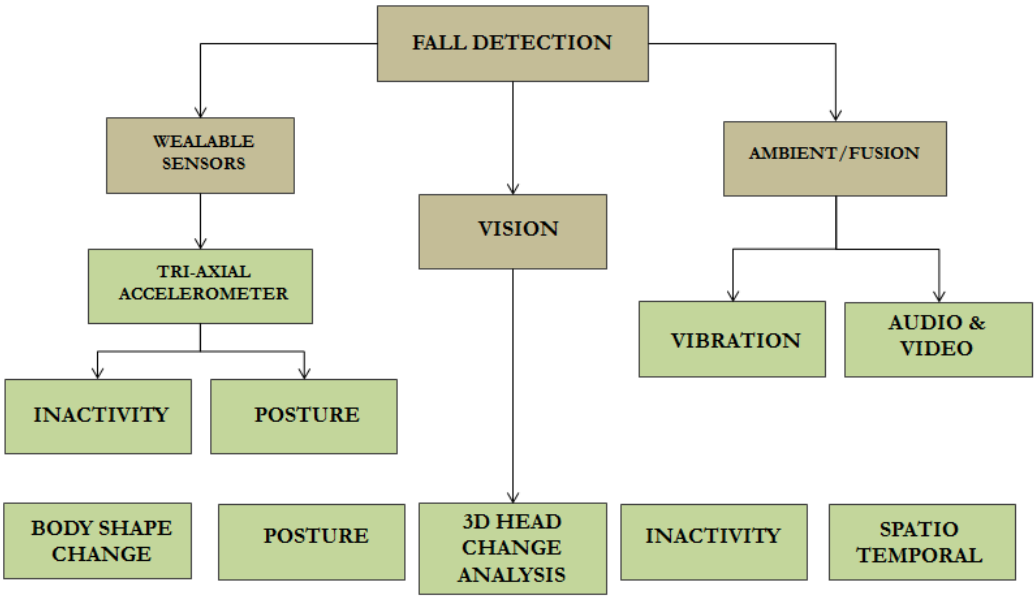


Figure 2-8. Classification of fall detection methods (Mubashir, 2013)

To terminate this sector, an exciting approach system is described by Tamura et al. (Tamura, 2009) that activates an airbag when a fall is detected. This wearable airbag involves both acceleration and angular velocity signals to active inflation of the airbag. Most ambient device-based systems apply pressure sensors for object detection and tracking. The pressure sensor relies on the high pressure of the object's weight for detection and tracking.

Camera (vision) based methods

The use of cameras to control and monitor older adults in in-home assisted/care systems is prevalent these days. Cameras can detect multiple events simultaneously with less direct intervention. Vision-based systems are not based on any parameter monitoring of the subjects; instead, they perform image processing techniques on the video frames or image slides captured by cameras around the area. Vision-based approaches provide precise details of unusual situations to a remote caregiver through images or video data. The system is more expensive and computationally intensive and needs more processing time (Ramachandran, 2020). There are several methods applied to capture semantic information through video analysis. In a study conducted by Mubashir et al. (Mubashir, 2013) they classified the data analysis into five groups of body and shape change, posture detection, inactivity, spatiotemporal, and 3D head change. In this system, cameras are one of the essential components. Following the discussion presented in (Mubashir, 2013), the vision-based methods rely on the real-time execution of the algorithm using standard computing platforms and low-cost cameras. Moreover, two types of cameras are utilized in fall detection include 2D cameras (Hsu, 2015), or 3D time of flight (ToF) cameras (Diraco, Leone, & Siciliano, 2010) (Kepski & Kwolek, 2014) with a lower lateral resolution. Much more expensive compared to standard 2D video cameras (Figure 2-9). In addition the system to being soft interference to the privacy of the subjects.

Vision-based devices have a similar disadvantage as ambient devices. They have to be installed in different rooms to cover and monitor the whole zone of actuation. Intrusion into a person's privacy is another disadvantage of this system. For these reasons, some systems are designed to send photos only when a fall has been detected. These images can be faded to prevent recognition from third parties. Some systems also incorporate cameras and accelerometers, like a method used by Kwolek (Kwolek & Kepski, 2016,).

Figure 2-9. Vision-based devices (De Miguel K. A., 2017)

The tracking of a subject's process from one frame is the typical phase in fall detection algorithms. This issue necessitates either recognizable identifying specifications of the subject that can be followed or applying previous data to evaluate the new position of the individual. De Miguel (De Miguel K. A., 2017) propose a specific recognition method using a color-based algorithm to filter that the color of a person's head, body, and legs are easily differentiable. If all the environmental and physical safety conditions are done to prevent the fall or the place and cause of the fall is determined. However, the fall is still inevitable in the elderly, and the elderly should be protected from the fall to reduce the injuries.

2.3.3 FALL PROTECTION

FALL PROTECTION: Fall protection is a system designed to control and protect a person from falling or fall to reduce severe injury in the event they do fall. Its efficiency is after the fall.

A hip protector is a wearable device that is used to impact reduction and protect the pelvis in the event of a fall for the elderly. This type of device is provided in different forms. Skirt, airbag (Figure 2-10), belt, and even airbag helmet[26] are samples of such devices that protect the elderly during the day from a fracture in the event of a fall. Some older adults are unwilling to cooperate, and they think this tool is disturbing their daily activities and is not comfortable enough during the night for sleeping. The automobile airbag systems in Shi (Shi, 2009) proposed device is based on the support vector machine (SVM) filter, an embedded digital signal processing (DSP) system is developed for real-time fall detection. The compressed airbag is embedded inside a belt. When a senior loses his/her balance, the embedded microsensors in the belt detect disorientation. The integrated response system has enough time to activate the system in a few milliseconds (0.133 s) before the person falls.

Hip protectors are presented in two hard[27] and soft[28] shell types. Some of these protectors have been proven to have a force attenuation ability of as high as 95% (Kannus, 1999). 'Fifteen of fifty books' published by the European Design Institute[29] (IED) in Barcelona by presenting many different designs Airbag skirt protection (Figure 2-10) forecasts future designs by 2033. Fashion collection Inde provides airbags triggered when the dressing item notes that the person falls to prevent bone breaks (Laura Sangra, 2018).

[26] https://www.chicagotribune.com/lifestyles/health/ct-experts-developing-safer-helmets-20170913-story.html
[27] Made from different materials such as polyurethane resin
[28] Made from different materials such as polystyrene elastomer
[29] Instituto Europeo de Diseño

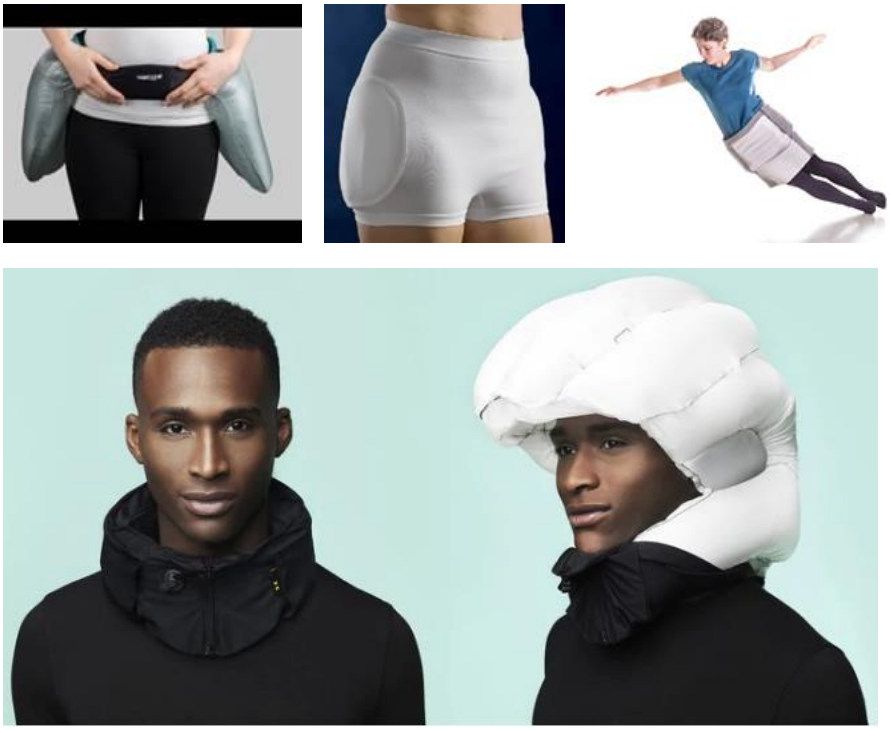


Figure 2-10. Conceptual illustration of the “intelligent” human airbag system (Shi, 2009) (Laura Sangra, 2018)

Mat or flooring is another approach to fall protection. There are various types of fall safety fall mats generally made of Polyurethane foam available in the market. It is usually placed next to the bed or chair of the elderly so that if the elderly fall, it will fall on a soft surface and be less damaged. Some of the products absorb 65% of the impact. *SATECH*[30]. The company provides a product called *SmartCells* made of rubber that is used as flooring tiles that can be covered with PVC or carpet. This flooring with about 2.5 cm thickness consists of a series of cylindrical hollow columns that reduce the impact on the body through the cushion system.

2.4 SAFETY FLOORING

There are numerous methods to reduce the severity of fall injuries, and one of them is to have a shock-absorbing floor. Reducing and absorbing the impact applied to the body caused by the fall is the main idea of shock-absorbing flooring resulting in a less severe injury. Studies have shown that the safety floorings can reduce the forces applied to the hip during a fall impact by up to 47% (Laing A. C., 2009). Other investigations have also demonstrated that safety floorings can also reduce the Head Injury Criteria (HIC) and hence could be an impressive strategy for the healthcare organization to reduce injuries from fall accidents (Wright, 2012). Before entering into this topic, a series of directly related subjects to the main issue should be examined and studied.

2.4.1 HUMAN BODY AND FLOORING

As a result of gravity, the weight of the object applies vertical force downward on the ground. Concerning Newton’s third law, a force equal to the force used must exert upward to the object from the floor in the opposite direction. This reaction is known as the ground reaction force (GRF) (Meadows, 2008). When the body is moving (normal walking), the GRF increases because of

[30] https://www.smartcellsusa.com/

acceleration forces. For instance, while running, the GRF gains up to two or three times the body weight.

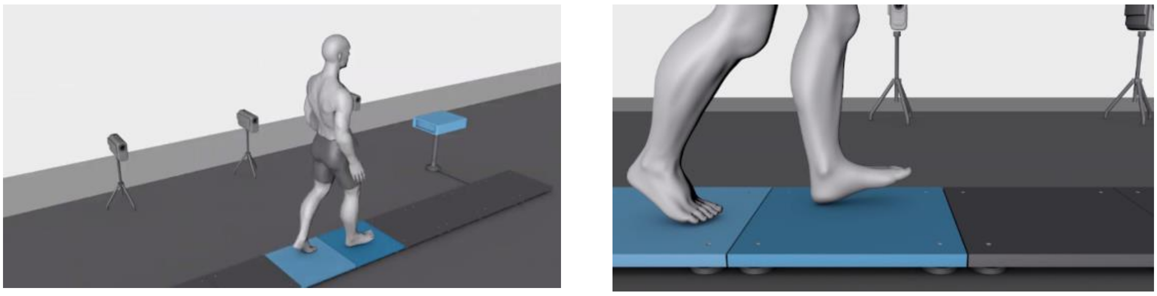


Figure 2-11. Gait analysis and measurement with a force plate[31]

The most effective method to measure ground reaction forces (GRF) uses a force plate (Figure 2-11). The Figure 2-11 shows the platform with sensitive sensors that records the force applied by weight (GRF) and the pressure points or areas of sole of the foot in each gait. GRFs are one of the most often approaches to analyze biomechanical measurements and help characterize human motions. Measuring GRFs is mainly used in the areas of sports performance analysis, rehabilitation, product ergonomics, and clinical research.

GRF is different depending on flooring materials. Surfaces covered by sand, stone, rubber, straw, or wood will show different GRF after jumping or falling on them. The total energy dissipation is greater for the soft surface. Drop jumping tests (DJT)on hard and soft surfaces showed the height of jumping on the soft surface was higher, and the energy rates of the participants during the contact phase were more than on the hard one. The participant's adaptation to different surfaces is associated with the stiffness of the surface and the intensity of the motion. (Arampatzis A. S.-K.-P., 2004). Infrequent daily activities or during sport, there is an interaction between the human body system and the type of flooring surfaces that depend on the elastic or viscoelastic of the surface (Arampatzis A. D., 2001) (Derrick, 2000). However, human-shoe affected this interaction. This means the energy exchange is very few to show a direct impact on energy consumption (Shorten M. R., 1993). It must be considered that the interaction between the flooring surface and the human body has a considerable effect on performance (Arampatzis A. a.-P., 2001) (Kerdok, 2002).

In the literature, it is mentioned that the human body system often adapts its behavior to changing the stiffness of the surface; by reducing the surface stiffness, the leg and joint stiffness of the human body system increase (Farley, 1998). As a result, the mechanical activity accomplished by the subject is decreased, whereas the mechanical activity conducted by the surface is increased (Ferris, 1997). Redfern et al. (Redfern M. S., 1995) had a survey about the influences of flooring on the perception of fatigue and discomfort for workers and employees after standing for an 8-h shift on different flooring conditions. In this study, the hardness of the floors was examined, but the influence of material thickness was evaluated. Results from this survey verified the following findings. First, The discomfort ratings demonstrated that the more stiff flooring materials resulted in more significant discomfort (Redfern M. S., 2000). By increasing the distance from the floor (use of insoles), the discomfort of the lower extremities decreases (Zander, 2004) (Orlando, 2004). Second, as a result, the softer the flooring material, the lower fatigue is perceived by workers experienced. However, this is not a general and permanent principle. The material's amount of softness and thickness have the opposite effect (Zander, 2004). Besides flooring hardness, the thickness of the material shows a significant impact on workers' perceptions of tiredness, as does mat softness. Blown urethane mats with 12.4 mm thickness showed a considerable fatigue effect on workers. Third, there is a direct

[31] https://www.kistler.com/?id=17

connection between leg tiredness and general tiredness. Either type of flooring material or shoe insole affects both the legs and the entire body. Flooring material reveals the most significant influence on discomfort in the lower legs and lower back but not the upper legs and hips (Orlando, 2004).

In general, it can be said that the dynamic features of the floor material and structure are essential in mitigating fatigue and discomfort. These features demonstrate the floor's capability to absorb and transmit forces to the body during walking or running. In conclusion, flooring characteristics such as elasticity, stiffness and, thickness play essential roles in discomfort perception in the leg and body (Redfern M. S., 2000).

Table 2-2 Biomechanical characteristics of initiation of gait in 43 control subjects (Welter, 2007)

	Natural gait	Fast gait
Step length, L (m)	0.55 ± 0.07 (0.38–0.74)	$0.71 \pm 0.11^*$ (0.43–0.89)
Maximal velocity, V_m (m/s)	1.06 ± 0.18 (0.73–1.54)	$1.49 \pm 0.25^*$ (1.08–2.24)
Fall of the CG, V1 (m/s)	-0.12 ± 0.04 (−0.22 to 0.07)	$-0.20 \pm 0.07^*$ (−0.36 to 0.05
CG vertical velocity at foot-contact, V2 (m/s)	-0.06 ± 0.05 (−0.08 to 0.04)	$-0.09 \pm 0.06^*$ (−0.19 to 0.00
Braking of the CG fall (%)	56.8 ± 25.8 (16.2–100)	60.7 ± 22.8 (23.1–100)

Values are mean standard deviation; values in parenthesis indicate the range for each parameter. * $p < 0.05$ when compared to the natural gait condition. Center of gravity (CG).

Many investigations study the walking parameters (Welter, 2007) (Parijat P. T., 2008) (Chong, 2009). They stated that as walking speed increases, the Vertical Excursion[32] (displacement) of the foot also increases (Gard, 2004), which accelerates the velocity of the heel impact to the ground. Therefore, the surface curvature must be considered in the event of fall and during walking as a factor that may cause footfall deflection. The heel contact velocity or vertical velocity of foot contact during walking, the step length, and the horizontal velocity of walking are calculated. (Table 2-2)

2.4.2 COMPLIANT FLOORING (CF) A NEW FLOORING SYSTEM

Compliant flooring (CF) (Lachance C. C., 2017) represents a promising passive interventional strategy that provides substantial impact force attenuation due to fall-related injuries. The CF system and relieves standing stress and fatigue in high-risk areas such as nursing homes, hospitals, gymnasiums, and senior centers (Laing A. C., 2006) without impairing balance or mobility during daily activities (Glinka MN C. K., 2013) (Wright, 2012). CF technology is based on reducing the stiffness of the ground surface and the subsequent forces applied to the body in the event of a fall (Lachance C. C., 2017).

In the literature review, the importance of the floors is to take the impact of our daily activities and is generally the first surface to reflect wear and tear. There are hundreds of flooring types to choose from, but it's essential to choose the right one from the start as the wrong floors can practically cause irreparable damage. Compliant Floorings (CF) or Shock Absorbing Flooring (SHAF) are passive intervention methods that may protect an individual from many types of fall-related injuries. The injury rates are considerably greater in elderly residence community-dwelling seniors, approximately seven times greater for females and 11 times greater for males (Rapp K, 2012). A lately published scoping review and extensive biomechanical research (Lachance C. C., 2017). stated that compliant flooring with shock-absorbing capacity might reduce the incidence and severity of fall-related injuries in older adults in residential care. Hence this claim confirms previous laboratory findings (Laing A. C., 2006) (Drahota A, 2013). CF systems will be efficient and practical when besides

[32] The peak-to-peak amplitude of the vertical body center of mass (BCOM) displacement, known as the vertical excursion, is generally estimated to be approximately 4–5 cm for adults at their freely walking speed.

force attenuation not being so soft that they impair balance and mobility. Several commercially available compliant floors have been demonstrated to considerably reduce impact forces, including vinyl (>0.2 cm), carpet (standard), carpet tile, *Sorbashock, Forbo, Tarkett Omnisports EXCEL, DAX Tatami Martial Arts, SmartCells, Landsafe, Kradal, SofTile.* (Wright, 2012) (Bhan, 2013) (Lachance C. C., 2017).

Although more investigation is needed regarding the implementation aspects in clinical settings, few sites have implemented compliant flooring due to the high risk of the real environment. Partly because of high risk, synthesized evidence about key performance aspects has not been available (Lachance C. C., 2016). In some cases, it is stated that the most significant impediments of compliant flooring were financial considerations, lack of investigation evidence, and challenges with installation (Lachance C. C., 2018). Much academic research and theory have been conducted on compliant flooring. There are many measures and flooring products with a different material which are used in sport areas (gym and fitness), industrial environments, and kid's playground. But this is even though there are no proper flooring products used in the indoor areas associated with the elderly. Broadly, the research focusing on compliant flooring is divided into several categories: Compliant flooring systems, Biomechanical efficacy, Clinical effectiveness, Cost-effectiveness, Workplace Safety, and Fall-related injury.

<u>Biomechanical efficacy:</u> results from laboratory investigation about (1) impact force attenuation or shock absorption during fall or fall simulation onto compliant flooring systems, or (2) validation of gait and mobility performance, using the assistive device and balance products.

<u>Clinical effectiveness:</u> evaluating how compliant flooring systems affect falls and fall-related injuries (How and severity of the fall).

Table 2-3 A scoping review protocol, 2016 with permission from BMJ Publishing Group Ltd. (Lachance C. C., Compliant flooring to prevent fall-related injuries: a scoping review protocol., 2016)

Concept	Definition
Compliant Flooring Systems	Broadly defined as flooring systems or floor coverings with some level of shock absorbency, for example, safety flooring, shock-absorbing flooring, dual stiffness flooring, rubber flooring, acoustic flooring, and carpet.
Fall-related injury	Broadly defined as fractures or soft tissue injuries (haematoma, dislocation, laceration/cut, sprain/strain, contusion/bruise, swelling, pain) as a direct result from a fall.
Biomechanical Efficacy	Evidence from experiments conducted in a controlled, laboratory environment about (i) impact force attenuation or energy absorption during real or simulated falls onto compliant flooring systems, or (ii) balance, gait and mobility performance, and/or assistive device use on compliant flooring systems.
Clinical Effectiveness	Evidence from research involving human participants and measurement of how compliant flooring systems affect fall-related injuries and falls.
Cost-effectiveness	Evidence related to the costs of compliant flooring systems relative to their effects on fall and fall-related injury healthcare costs.
Workplace Safety	Evidence about the effects of compliant flooring systems on musculoskeletal health and fatigue of healthcare workers as a direct result of differences in floor compliance.

<u>Cost-effectiveness:</u> provide reports related to the expense of compliant flooring (e.g., material, installation costs, and product durability) compared to their performance on fall and fall-related injury healthcare costs, which most reports indicate cost-benefit ratios and/or cost-effectiveness ratios of the compliant flooring system.

<u>Workplace safety:</u> broadly provide records about the effects of the systems on fatigue and musculoskeletal health of healthcare staff (Lachance C. C., 2016) (Table 2-3).

2.4.3 STRUCTURE AND GEOMETRY

Some of such systems use closed-cell foam or vulcanized rubber chips compressed together to create a shock-absorbing structure. Others apply an array of flexible elastomeric cells (units) under an elastomeric or stiff surface layer. Foam or some other conventional impact reduction structures practically get more rigid as the force applied to them increases, and they can bottom out with the impact of the hip, or elbow, or even just Standing for a long time. In most conventional systems, especially closed-cell foam systems, the force attenuation mechanism starts with an instant displacement at the very surface of the product, which often causes dangerous foot lock or foot entrapment or instability for those who play, walk, or stand on such a surface. Conventional systems in football fields are typically dense with time. Thus it hardens some parts of the area, which makes it challenging to absorb impact. Sports mattresses made of foam, which are covered with a thin layer, are easily torn, and because of their softness, it causes instability of the foot on them. Thinner foam mats are not suitable to protect critical body parts (head, hip, elbow, and the like) or full-body in the face of impact applied by a more rigid floor surface beneath the mat.

Generally stated, the aim of all shock cushioning or absorbing devices or products is to retard or coop a moving subject without severe damage or injury to the issue. An impact absorber is expected to absorb or dissipate the kinetic energy of a moving object. Accordingly, to be effective, a shock cushioning material must be so designed that it be deformable enough to absorb or dissipate a great magnitude of the kinetic energy of the impacting body. Dense forms of compact rubber chips used in fitness salons as a flooring surface do not provide bottoming-out protection. They are partly compressible that provide small protection from fall impacts. Many mats in the marketplace are weak and flabby. They are easily damaged by carts, wheelchairs, or any vehicles that hit the edge of the mats. In specific embodiments, the flooring structure includes (i) a top surface of the flooring fabricated from a material of selected flexural modulus, (ii) arrays of columns/cells that may or may not be fabricated from the same material of the top surface, and (iii) a matrix/binder material in contact with the columns. It typically has a similar flexural modulus that is employed in the top surface of the flooring (United States Patent No. U.S. Patent 8,539,728, 2013).

What is required for risky areas is a mat system that presents little or no surface deformation in the face of loads but which is resilient and soft at levels below the surface to decrease fatigue causing factors and protect the body by absorbing the severity of the impact in the event of a fall. In compliant floorings, when the flooring structure is exposed to a pressure force lower than a critical buckling pressure, the columns of the flooring structure remain naturally stiff to prevent deflection of the floor. When the flooring structure is exposed to a pressure force greater than the critical buckling pressure, the columns/cells are expected to buckle. According to the evidence, typically, the static load-carrying capability is greater than the dynamic force that causes buckling. Consequently, columns do not buckle when the top surface of the flooring is exposed to a static pressure up to or even significantly higher than a critical dynamic buckling pressure.

The property of cells is helpful for practical reasons, enabling the continual presence of furniture[33]on the floor without causing column buckling or load deflection to the flooring structures. Without any minimal theory, it is believed that the forces applied by a constant static situation of a subject are able to distribute more effectively throughout the surface of the flooring, matrix material (if exist), columns (if exist in the flooring structure), and the sub-floor (e.g., concrete floor). In contrast, a dynamic force created by a sudden impact, such as the fall of a person or object, cannot be distributed as effectively in space and time (United States Patent No. U.S. Patent 8,539,728, 2013).

[33] wheelchairs, beds, equipment, testing stations, carts, heavy fire extinguishers, security boxes

Regarding the literature, the function of dissipating or absorbing force in the compliant flooring is based on two main factors: material and structure.

2.4.4 MATERIAL AND PROPERTIES

Using resilient[34] material with proper mechanical properties is a good option depending on the application used for damping energy. Non-Newtonians materials, natural or synthetic shock-absorbing or viscoelastic polymer materials (thermoset, polyurethane material), rubber, neoprene, silicone foam/rubber, or even agricultural fibers are examples of such materials. Whether the problem is the impact on the human body or the impact of an electronic device – the aim is the same, and that's to protect the materials inside.

In some samples, the columns, matrix material (if present), and the top surface of flooring are generated from thermoplastics or thermoset materials, which may contain plastics, elastomers, and composites. Thermoplastics may include polyether or polyester materials. Sometimes maybe more than one elastomeric gel or viscoelastic thermoset materials utilized. In some examples, a thermoset polyurethane material with the ability to be turned into foam is applied for the top surface of the flooring, columns, and/or matrix material (United States Patent No. U.S. Patent 8,539,728, 2013). *Bayfit*® and *Sorbothane*® (Sorbothane, Inc., Kent, Ohio, US) are polymer brands utilized as matrix materials. *Bayfit*® is high-resilience polyurethane foam, and Sorbothane is a viscoelastic memory polyurethane foam that incorporates shock absorption, good memory, vibration isolation, and vibration cushioning properties. In some products, to reinforce matrix material, cork, rubber, or any other proper viscoelastic polymer with urethane binder is combined in the flooring structures (United States Patent No. U.S. Patent 8,539,728, 2013).

The flexural modulus is another critical factor of the material that shows the ratio of stress to strain in flexural deformation, or the tendency for a material to flex or bend. It is an intensive property that only associates with the material selected for the top surface of the flooring. This property is regarded as severe and significant because if it is too small, the flooring structure will tend to be soft and can cause imbalance and promote falls. Conversely, Suppose the flexural modulus is too high. In that case, they can create a surface with an insufficient transfer of forces through the top surface of the flooring to the lower part of structure, thereby reducing the effectiveness of the overall system. The flexural modulus of the top surface of the flooring is typically selected from about 5,000 psi to about 25,000 psi (United States Patent No. U.S. Patent 8,539,728, 2013).

2.4.5 COST-EFFECTIVENESS

It has been previously documented that the shock-absorbing flooring intervention will prevent hip fractures while having the potential of saving costs compared with regular rigid flooring (Ryen, 2016). However, there was an argument about the potential advantages of shock-absorbing flooring as health care savings by the government. Still, in any case, the implementation decision and cost are left to individual LTC sites (Laing A. C., 2009). But it should be mentioned that if the shock-absorbing flooring does not increase the faller rate, it is probably to express a predominant economic strategy generating cost savings and quality-adjusted life years (QALY) gains (Latimer, 2013). Shock absorption flooring may be more effective in reducing injuries upon a fall and less costly than

[34] Resilience can be defined as the maximum energy per unit volume that is capable of elastically stored. Resilience is the ability of a material to dampen or store energy when it is deformed elastically and then, upon the force is removed, to have this energy recovered. And the area under the linear portion of a stress-strain curve is the resilience of the material. It is noteworthy that the energy is stored best in the elastic region.

providing hip protectors. However, the evidence suggests that further study is needed to confirm the rate of injury when shock absorption flooring is used in residential facilities (Njogu, 2008).

2.5 SIMILAR PRODUCTS AND APPLICATION (Shock Absorption-Cushion System-Damping energy)

Controlling the impact force is a matter that must be considered in all fields of industrial to damping the energy from the vibrations of the devices. A damping system is provided in all appropriate sports shoes to prevent and avoid damage to joints and soles of the feet. Helmets, gloves, clothing for motorcycling, sports flooring, car, sports mat and flooring, packaging industry, etc., are all the systems offered to the marker considering damping or cushioning the energy. To assess the compatibility of such equipment or floorings, various norms and standard tests stand for evaluating their safety behavior. Industrial workplaces, motorcycling, or rock climbing pose concurrent hazards to the body, especially the head. Several international standard methods used to validate the performance of safety include helmets (EN 397:2012+A1:2012), Motorcyclists' protective clothing against mechanical impact (UNE-EN 1621-1:2013), sport mat-Determination of shock absorption (UNE-EN 12503-4:2017), Impact attenuating playground surfacing - Methods of test for determination of impact attenuation (UNE-EN 1177:2018+AC:2019-HIC), Surfaces for sports areas - Determination of shock absorption (UNE-EN 14808:2006), Surfaces for sports areas - Determination of vertical deformation (UNE-EN 14809:2006/AC:2008), Standard Test Method for Impact Attenuation of Athletic Shoe Cushioning Systems and Materials (ASTM F1976 - 13), Sports Parquet Floors Shock absorption and Vertical Deformation (EN 14904), etc.

According to studies, generally, two methods have been considered in this category. First, using the resilience materials with proper flexibility and elastic property, and second, using specific structures depending on the application.

2.5.1 MATERIAL AND STRUCTURE

Using resilient material with good mechanical properties is a good option depending on the application used for damping energy. Non-Newtonians materials, natural or synthetic shock-absorbing or viscoelastic polymer materials (thermoset, polyurethane material), rubber, neoprene, silicone, or even agricultural fibers are examples of such materials. In addition to the type of material used in shock-absorbing products, sometimes must also consider the product's type of structure and geometry. Types of lattice structures, honeycombs, or cellular units that make up the structure, such as egg boxes, pyramid, cylinder, hourglass, etc., are such cases.

2.5.2 HELMET

In this research, not only floor tiles but also other products with a focus on impact reduction have been investigated. For example, examining the structure of a helmet may not be relevant to the subject of this study. However, the reason for examining this example is simply to study the geometric structures provided by the designers to prevent and reduce the rate of force applied to the head. This and similar cases with the use of impact reduction can be indirectly effective in designing the structure of floor tiles. Head injuries have been recognized as being one of the most debilitating types of injuries experienced in accidents. The sufferers often involve a high cost to society, either because of early death or long-term treatment costs and loss of productivity. The use of helmets as a head protector tool is prevalent in many areas such as cycling, skiing, skating, motorsport, and other dynamic sports with high speeds and potential risks due to injuries falls (B. Chinn, 2001). A vital component of a safety helmet is energy-absorbing and minimizing the likelihood of head injuries during an accident. Using the ABS plastic layer with deformable cones on it is an idea to impact reduction that cones will be folded and collapsed aftershock (Blanco, 2010) (Figure 2-12). The outer part is usually made of thermoplastic materials (Acrylonitrile Butadiene Styrene (ABS) or Polycarbonate (PC)), or composite materials (Glass Reinforced Fibers (GRF)) and the inner part that absorbs the most significant segment of the impact force aftershock is usually made of Expanded Polystyrene (EPS) (Kostopoulos, 2002)

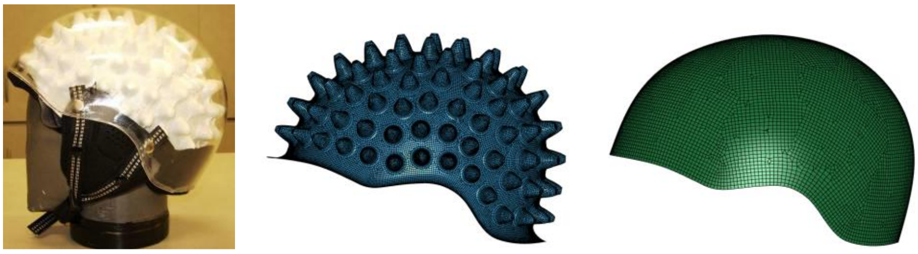


Figure 2-12. Ski helmet prototype on the head form - Discretized geometry of ABS liner and PC shell (Blanco, 2010).

Using an aluminum honeycomb structure (S. Santosa, 1998) presented as a reinforcement material is another novel idea to protect the head. They used Kevlar, carbon, and fiberglass fibers for the first upper layer (Figure 2-13 and Figure 2-12). The second layer was made of Kevlar fibers composite, and the third additional layer was fiberglass composite. The epoxy resin was used to pressure bag molding. The inner liner was made of expanded polystyrene (EPS) foam with a density of 50 kg/m3 (Gaetano D. Caserta a, 2011) (United State Patent No. US 7.254,843 B2, Aug. 14, 2007).

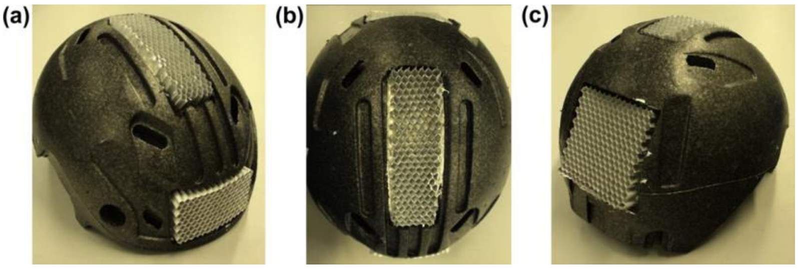


Figure 2-13. aluminum honeycomb structure in the helmet (S. Santosa, 1998)

The *Unicode* is a design studio in Barcelona (Figure 2-14), and a brand of co-designed products, digitally fabricated. This studio was founded in early 2011 with many design sections and novel ideas. They presented specific opinions for designing helmets following geometrical lattice structures. They use EPS material inside the helmet and TPU (Thermoplastic Polyurethane) material to 3d print the lattice structure and mainshock absorption part in safety helmet projects. (Cunicode, 2019)

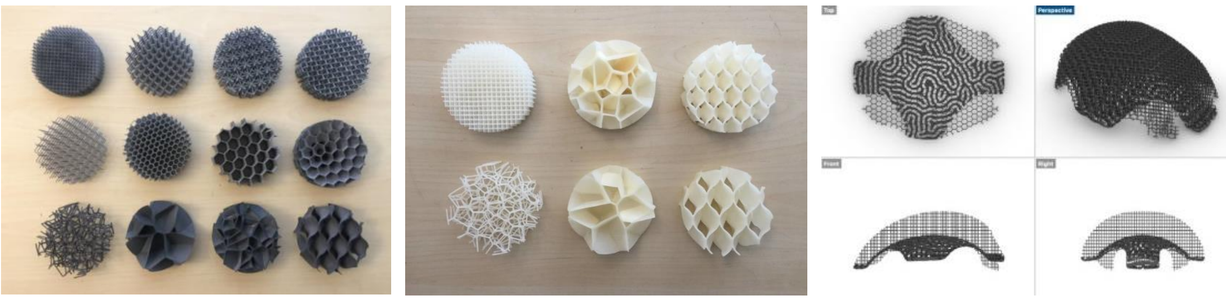


Figure 2-14. lattice structure designed by Cunicode studio use in safety helmet (Cunicode, 2019)

Depending on the direction of the honeycomb, it can behave as a very stiff or cushion and resilience tile. Using cells vertically enables sandwich panels (Zhang, 1989-1992) (Sharma, 2006) to be used in the aeronautical structure, high-speed marine craft, racing cars, and beam (Petras, 1999) (Figure 2-15) due to enough stiffness and lightweight.

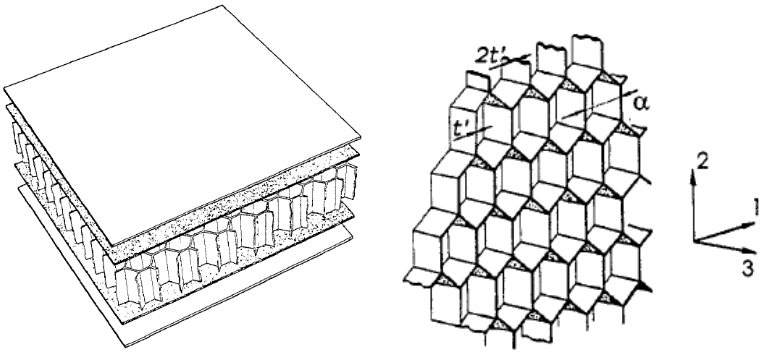


Figure 2-15. hexagonal honeycomb sandwich panels (Petras, 1999)

James Riddell Ferguson used honeycomb structure as impact-shock-absorbing material that is flexible and comfortable to be worn by kids and elderly easily which is fashionable in appearance and can be used throughout certain activities, walking and/or even sleeping hours (United State Patent No. US 8,087,101 B2, Jan. 3, 2012).

2.5.3 PACKAGING

Packaging, as an essential method of distributing, preserving, and protecting goods from external loss caused by transportation and/or storage. Packaging has made transportation more accessible and faster so that the product and the package cannot consider one without the other. Cushioning materials include sawdust, wood shavings (excelsior), drive or wheat straw (bagasse), crumpled or shredded waste paper, coco fiber, and cellular wadding are popular since ancient times to protect the goods from dealing with the outer impact. Besides traditional materials, polymers have been mainly replaced with cushioning, tailored for more accurate protection. The most popular polymer-based cushioning is in the form of rigid or flexible foams. Polystyrene in the shape of granules or molded frame or air plastic wraps in the shape of the bubble, rectangle, or column are other instances that are used widely with the same performance. Due to its lightweight, energy absorption ability, high strength, and appropriate cushioning properties, paper honeycomb sandwich panels have been commonly used in the packaging industry and other fields of energy absorption (Wang D. , 2009).

2.5.4 TATAMI

As a type of compliant flooring, *Tatami* plays an influential role in hip fracture reduction, and its performance is even better than the hip protectors. Findings by Jorge suggest that tatami could be a promising interventional approach for controlling hip fracture hazards in both the home environment and any high-risk areas (Ning Li, 2013). The tatami matting as a traditional modular flooring type has been used in Japan for a long time (Figure 2-16 and Figure 2-17).

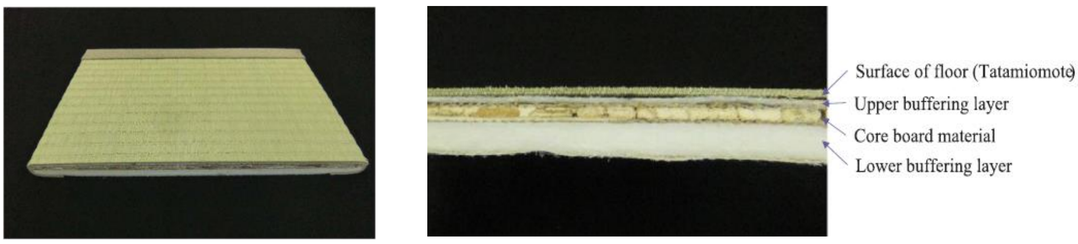


Figure 2-16. Tatami layers (Shimizu, 2019)

Usually, it can last for more than ten years, and it not only has good performance in heat and sound insulation properties and impacts force absorption, and this caused to be widely used in Judo in the sports field. Many types of compliant flooring are good in shock attenuation, but they are too soft and resilient that compromise balance while standing or walking and thus increase fall risk (Laing A. C., 2009).

The basic structure of tatami is simple and consists of three main compressed layers. Comprising *Doko* (base) made of multilayered rice straw, tightly fastened, and compressed, but there are three types of non-natural base: insulation board made of compressed wood chips; polystyrene foam sandwiched with the board, and 100% board (Figure 2-17).

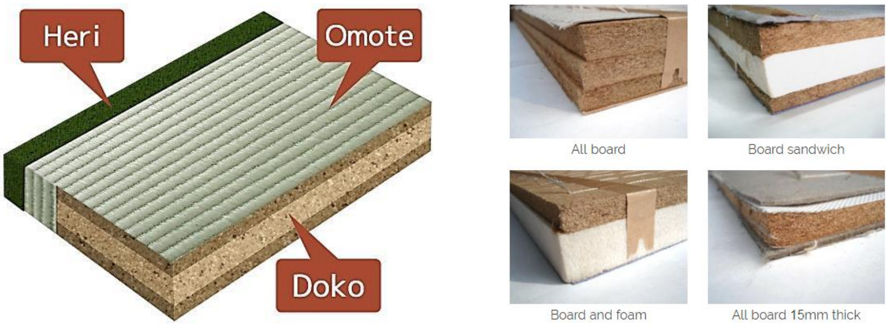


Figure 2-17. Tatami structure (Tatami, 2020)

This has the same feeling and function. It is even lighter and has better humidity resilience than the natural base. Still, it is more rigid underfoot and less durable., Omote as a cover is from natural Igusa (rush), and heri (border) is made from cotton or hemp. Still, synthetic fiber has become mainstream these days (Tatami, 2020).

2.5.5 BOAT DECK SAFETY MAT

Skydex boat decking or sea shocks helm mat (Figure 2-18) as a shock-absorption mat used in an emergency speed boat or military vehicles usually involves an anti-fatigue core for impact protection. Soft side edges are more comfortable on bare feet and ankles with a durable textured top surface. It consists of layers of hemispherical or twin-hemispherical (hourglass) made of gray thermoplastic polyurethane able to dissipate a large amount of kinetic energy during the crash/blast event with its micro-structures (Binhui Jiang, 2013). Rubber or similar materials and geometries used in the structure of the mat will cushion shocks by absorbing vibration and impact. Thus, these mats minimize the potential for injury due to wave slam in high-speed craft operations. At the same time, they are offering a minimal amount of cushioning while standing (skydex, 2020) (United State Patent No. U.S. Patent 6,029,962, Feb 2000).

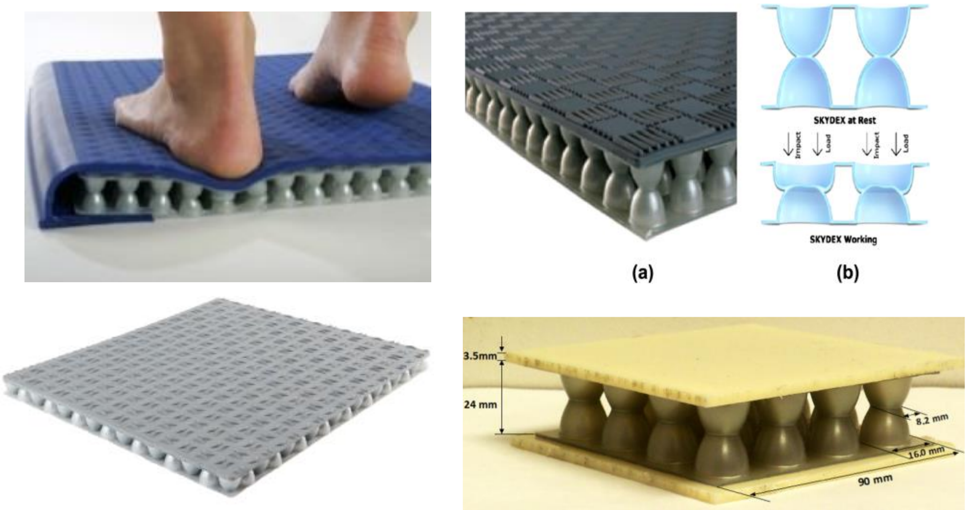


Figure 2-18. *SKYDEX*-Sea Shocks helm mat and Boat Decking (United State Patent No. U.S. Patent 6,029,962, Feb 2000) (skydex, 2020)

2.5.6 SHOE INSOLE

The footwear industry has been experiencing rapid development with a permanent request for new and comfortable models. Different structures and materials are tested and manufactured by companies to gain more comfort and cushioning system. Using the bi- and three-dimensional design of the cushioning system, using 3D scanners, 3D modeling software, and finite element analysis are some of the techniques used recently very often.

(a) (b) (c)

Figure 2-19. Oetzi from the Stone Age footwear (a), Ancient Greek and Roman sandals (b), Strategia model, and Baroque times shoes (c) (Shoes, 2018)

The first generation of footwear was discovered in 1991. Archeologists found a mummified human from the Stone Age about 3300 years ago (Figure 2-19) wearing shoes made from deerskin with a sole made from bearskin and stuffed with hay. They wrinkled the leather to reach the smaller stitches so that the legs would be dryer and warmer. Meanwhile, in the Southern regions, mostly sandals were made from palm leaves or papyrus fiber. Despite the climate, the first footwear had the role of protecting the feet from the natural outside effects. Many footwear models emerged during the 4th- 6th centuries and 11th- 13th centuries during the Crusades as the second generation of footwear. Over time, the beauty and decoration of shoes increased. In ancient Rome, clothes and shoes were a symbol of power and civilization, so depending on the level of the person's position, the shoes were classified. For instance, the more laces the sandals had and the thinner the sole worn by Roman soldiers, the higher rank the soldier was. In a different era of Gothic, Renaissance, or Baroque (Figure 2-19), different styles were expected in terms of color, heel, design, and material of shoes according to social status (Shoes, 2018).

There was a vast revolution in footwear in the second part of the 20th century with the success of American pop culture. With the increasing number of working women, high-heel tendencies began changing by wearing low-heeled shoes in the 9th decade. Sports shoes had a significant influence on footwear fashion. The first steps toward trendy sports shoes happened in 1917 with sports shoes for basketball players by "*Converse*". In 1892, "*Keds*" was invented by the "*U.S. Rubber Company*." It was a modern, comfortable, beautiful fabric-made sports shoe model with a rubber sole. From the middle of 1940, a constant revolution in sport's shoes started, and the ladies and gentlemen's era ended. The "*Sneaker*" came from the English word "*sneak*" which started its progress by flexibility, without sound during walking and comfort. At the first step, the progress of sports shoes did not go quietly, and the aim of such footwear was comfort, style, improvisation, and creativity (Shoes, 2018) regardless of one's social status. As we can see in a different Nike, Puma, or Adidas brand, the new generation of sports shoes compete for comfort and shock absorption (cushioning and damping energy).

A simple explanation is, the system structure includes several apertures and springs. (Figure 2-20) The compression springs positioned within the lower and upper spring retainers to increase the overall performance of a shoe by increasing the stability and shock absorption of the heel (The United States Patent Patent No. U.S. Patent 6,055,747, May 2, 2000) (United State Patent No. US 6,457,261 B1, Oct. 1, 2002).

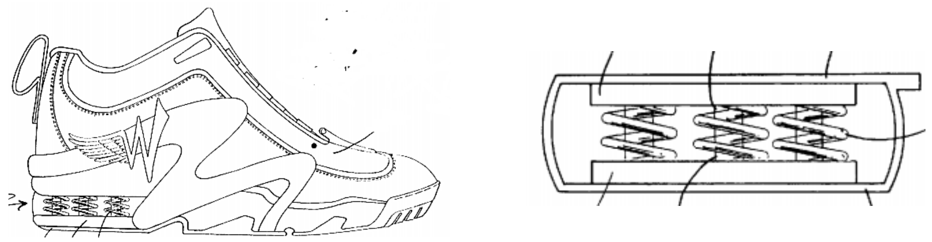


Figure 2-20. spring model to damp and rebounding energy (The United States Patent Patent No. U.S. Patent 6,055,747, May 2, 2000)

Using convex and concave elastic plates (The United States Patent Patent No. U.S. Patent 6,598,320, Jul. 29, 2003) or using flexible columns in the shape of an hourglass (Figure 2-21) are methods to damp and rebound energy after pressing while walking or running.

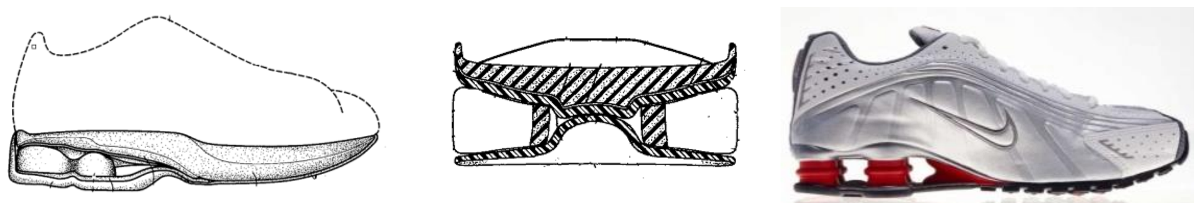


Figure 2-21. hourglass model to damp and rebounding energy (The United States Patent Patent No. U.S. Patent 6,598,320, Jul. 29, 2003)

One of the newest forms of proprietary footwear cushioning (*joyride*) is made up of thousands of TPE beads (Thermoplastic elastomer) covered by pods presented by Nike (Nike, 2019) com. The elastomer beads placed within zonally-tuned pods can move and expand in all directions (Figure 2-22).

(a) (b)

Figure 2-22. Nike Joyride with thousands of TPE (a), the lattice structure of Adidas Futurecraft 4D (b) (Adidas, 2020) (Nike, 2019)

The lattice structure of *Adidas Futurecraft 4D* (Adidas, 2020) sneakers (Figure 2-22) which is manufactured by 3D printed midsoles shoe out of a liquid resin material, is one of the boldest innovations to damping energy for runners (Cardoso, 2019).

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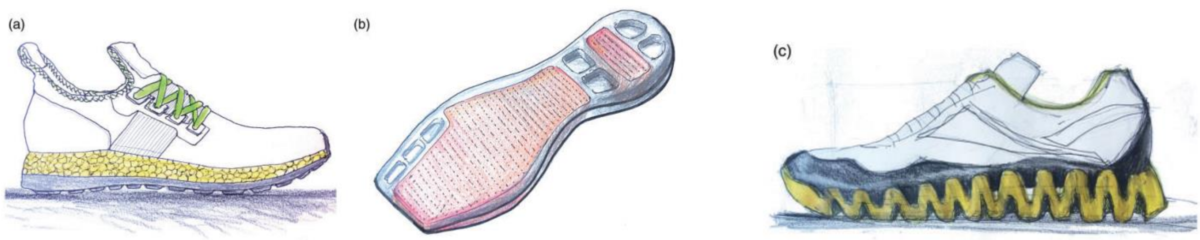


Figure 2-23. Examples of analyzed technologies: (a) Adidas BOOSTTM; (b) Nike Air; (c) Reebok Zig Tech. (Cardoso, 2019)

There is a great deal of variety in the insole structure of sneakers to reduce the impact during sports activities, and factories are still competing with each other in this field (Figure 2-23).

2.5.7 SPORT MAT

Sport foam mats with different thicknesses and designs are used in gymnastics or martial arts. Usually, Foam Floors include a layer of cross-linked polyethylene foam with high-performance EVA foam to create a sports surface rebound and shock absorption characteristics, providing safety to the athletes. Damping or shock absorption, Friction, and Deformation are the critical factors considered in sports mats depending on the thickness of the mats. According to the F.I.G (2000) different standard thicknesses have been defined for mattresses of gymnastic and mats. However, the standards allow deformation of 87.5%, 62.5%, and 55% for mattresses of 12, 15, and 20 cm, respectively, since if the maximum deformation is not limited, injuries could be caused due to the fixation of the foot (sprains and fractures) (Table 2-4).

Table 2-4 Classification of FIG mats (1994) according to their dimensions and regulatory criteria (Hans J. Gros, 1994)

Thickness	12 cm	15 cm	20 cm
Deformation (mm)	< 105	< 105	< 110
Rebound (mm)	< 150	< 100	< 120
Maximum Force (N)	< 4500	< 4000	< 3650

In the last modification, the gymnastic mats have been classified into two types of 10 and 20 cm. The European Standard uses EN 12503 for the determination as to the characteristics of absorption of impacts and deformation in gymnastic mats (Hans J. Gros, 1994).

2.5.8 SPORT FLOORING

Depending on whether the sports space is indoor or outdoor, in some factors, the design features of the flooring may have different priorities. Some properties of similar systems involve high ball rebound, extreme robustness, resistance to spikes, high anti-slip properties, the on-site glued system consisting of the highly compressed elastic layer and wear-resistant EPDM top layer, flexible underlay to protect the musculoskeletal system and the joints. The method avoids injuries from repeated impact. Natural, synthetic, and combinations of natural and synthetic materials are used widely in contemporary indoor sports floorings. Such surfaces have been designed to elastic deformation under load to increase athletic performance and reduce the risk of injury. In response to this requirement, companies have developed a wide range of flooring system types. Therefore, sports surfaces may be a complex arrangement of compounds that contribute to the complex behavior. The ultimate goal is for an athlete to apply less energy to a level and, as a result, reduce the energy returned to the athlete (Walker, 2013). The performance characteristics of a sports surface vary from sport to sport due to the particular modes of interaction of the ball, athlete, and surface.

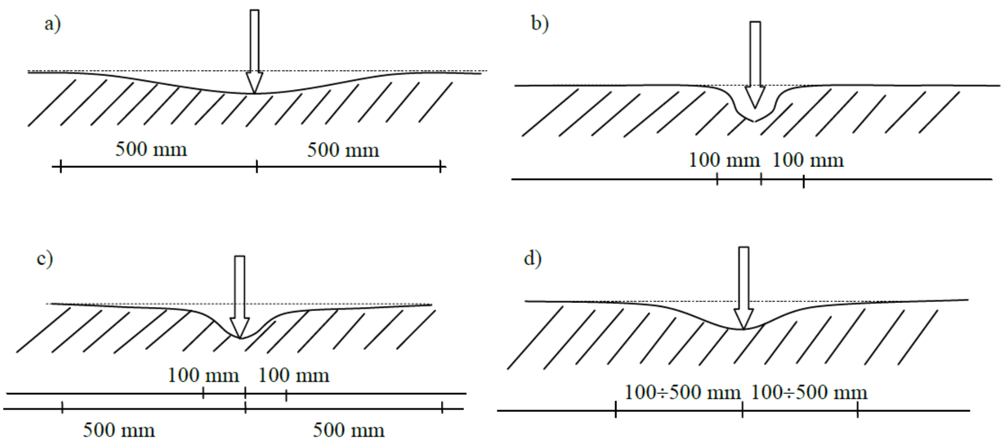


Figure 2-24 Sports floor behavior scheme under load and vertical deformation (Sudol, 2013)

Numbers of tests exist to optimize the indoor/outdoor floorings for sporting activities. Vertical deformation is as much important as shock absorption of the sports flooring. Vertical deformation value represents the capability of the surface to deform under load. High deformation of the surface can affect the security of the athlete, causing instability and imbalance of the foot. In contrast, low deformation may cause injuries on joints and ankles due to sudden impact force. Too much deformation is like running on sand and is unstable and takes a lot of energy and leads to fatigue, while too little change in vertical form like concrete surface may result in injuries on impact or falls (Dynamik, 2020). Therefore, Viscoelastic materials are used as synthetic shock absorbers to reduce the domain and increase the duration of an applied shock.

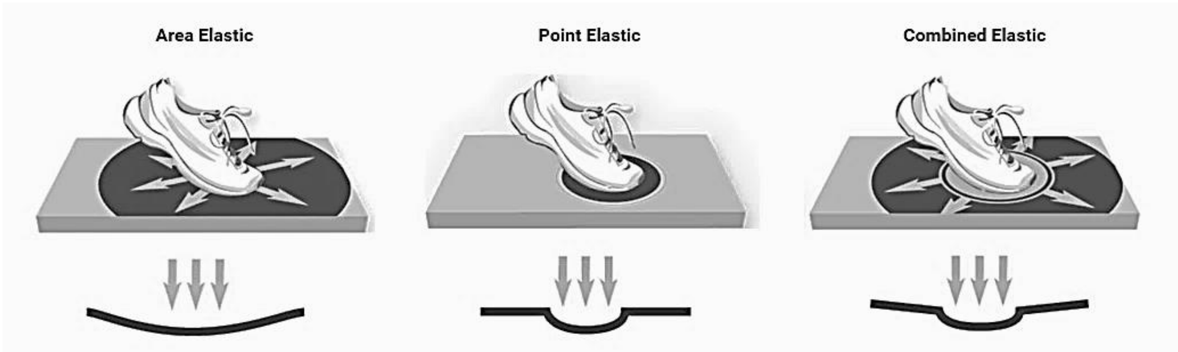


Figure 2-25 Sports floor behavior scheme under load: area-elastic floor (A), point –elastic floor (P), combined-elastic floor (C) (Dynamik, 2020)

Sports floors are classified for performance under load, shock absorption, vertical deformation, and reaction to fire. Given the behavior under load, four areas of area-elastic (A)[35], point-elastic (P)[36], combined elastic (C)[37], and mixed-elastic (Mx)[38] floor can be categorized (Figure 2-25 and Figure 2-26). A-type floors have relatively hard surfaces and are entirely inert in reaction but behave perfectly in the event of falls with multi-plane load (whole-body) and fully protect the athlete.

The P-type floors are soft and have deformable surfaces. The floors respond quickly at a low load and protect the elbow or knee when collapsed on the floor, but are not effective enough in case of a whole-body collapse. C-type floors are a combination of the advantages of the surface and point resilient floors. Mx floors are partly similar to the P-type ones. Still, they also contain synthetic ingredients for local stiffness, making them soft and resistant enough to, e.g., rolling load and similar effects (Dynamik, 2020) (Sudol, 2013). Such surfaces are typically used and installed in multi-sport or multifunctional saloons with group sports like basketball or volleyball (Figure 2-24).

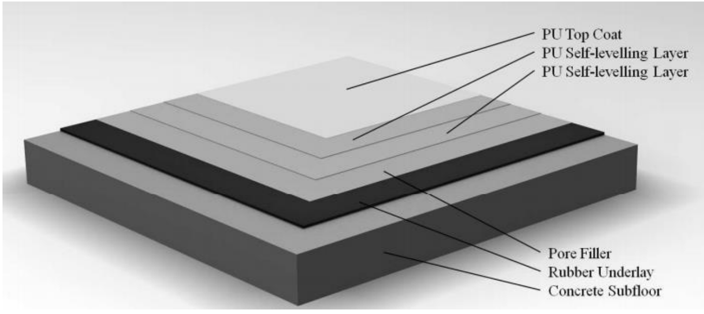
Team sports are played on a wide range of natural and synthetic materials such as timber, ceramic, concrete, bitumen, and various multilayered polymeric surfaces. Furthermore, the structure of such flooring requires a specific design on the sub-floor, into which the sports surface can be positioned to reduce ground reaction forces and, with that, the injury risk to the athlete. But the structure and method of the shock absorption in individual sports such as gymnastics, judo, martial arts, or yoga are different. There is a high degree of upper-body contact with a surface in such sports, typically using portable gymnastics mats placed on top of the sports surface.

[35]They are systems where the contact area is significantly larger than a point. Hardwood timber and wood composition sports surfaces generally fall into this category, where surface materials have a sprung undercarriage sub-structure positioned between them and the sub-floor.

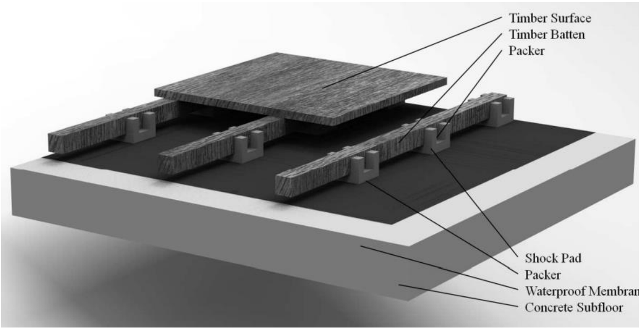
[36]It is installed directly over a concrete substrate. There is only a small contact area and deformation during an impact on the surface.

[37]These systems are synthetic sports surfaces that have been installed directly over a resilient undercarriage sub-structure positioned between a synthetic surface and the sub-floor (a combination of area elastic and point elastic flooring systems), they are likely to be hardwood timber and prefabricated sheet systems.

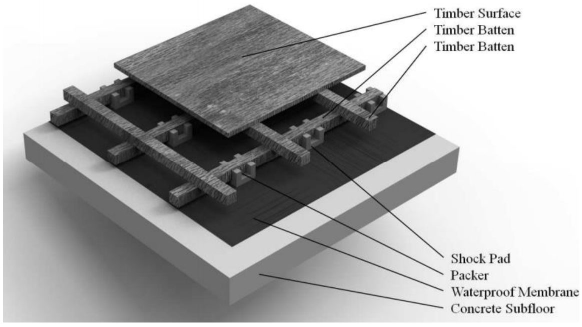
[38]They are surfaces that have mixed characteristics area elastic and point elastic sports flooring systems, with mixed elastic M3 and M4 category surfaces often constructed from multi-layered prefabricated sheet systems with thick elastomeric foam underlays.



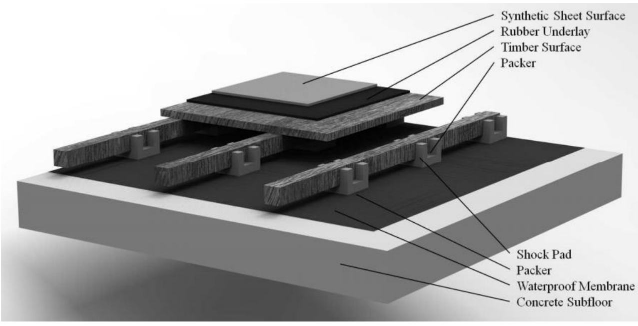
Point Elastic sports surface



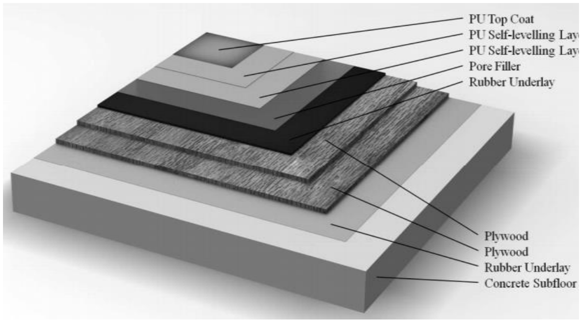
A3 Area Elastic sports surface



A4 Area Elastic sports surface



Combined Elastic indoor sports surface



Mixed Elastic indoor sports surface

Figure 2-26 Flooring System Classifications for Sports Surfaces depends on character of layers and structure faced with an athlete's foot impact (Walker, 2013)

The European standard EN14904 (CEN, 2006) has attempted to unify sport surface performance among European standards. As a result, all of the national standards organizations in the European Union are now obliged to obey the rules. The performance characteristics of floorings under the EN14904 standard are categorized into mechanical, safety, and biomechanical performance.

Mechanical Performance: includes Rolling Load Behavior, Ball Rebound (Ball Rebound = Rebound height from sport surface / Rebound height from concrete x 100), and Area Indentation due to the irrelevance of the items mentioned in Mechanical Performance, they will not be addressed at this end.

Safety and Biomechanical Performance

Safety and biomechanical performance include:

Force Reduction, which is also generally known as shock absorption property, has the most robust biomechanical foundation within the EN14904 standard. It measures the capability of sports floorings to decrease maximum impact forces compared to an impact on a non-resilient surface (hard surface) such as concrete. This property provides a level of comfort for an athlete. The force reduction can then be calculated as the percentage force reduction compared to a hard surface such as concrete. The most commonly used surface performance testing device and the current industry standard is the Berlin Artificial Athlete (BAA). The maximum impact force can then be calculated from the following equation (Demker, 2009):

$$F_{max} = mg\ (1+\sqrt{1}+\frac{2hk}{mg}) \qquad 2\text{-}7$$

F_{max} = Maximum force measured by the load cell in N m = The mass of the weight in kg

g = Acceleration due to gravity, 9.81 m/s^2 h = Drop height in m

k = Spring rate in N/m Force reduction, FR, can then be then calculated from the following equation (Demker, 2009):

$$\text{FR}=[1-\frac{F_{max}}{F_{max,ref}}]\ x\ 100 \qquad 2\text{-}8$$

F_t = Maximum peak force in N F_r = Reference force as measured on concrete

Force reduction describes how a sports surface attenuates impact energy which is expressed as a percentage. The average force reduction values recorded will generally be in the range of 25% to 75%. According to ASTM F2772 and PN–EN 14808 norms, shock absorption is tested with an average value recommended 25–75%. (Table 2-5)

Slip resistance is the friction property of sports flooring. When slip resistance on flooring is low, this property will lead to extreme sliding during sports competitions and make direction changes difficult for the athlete. Conversely, if slip resistance is high, it may increase the value of forces and moments being transferred through the joints during braking, acceleration, or changes in direction and increase the risk of injury. Slip resistance is measured using a pendulum, and the average magnitude will generally be in the range of 80 to 110.

Table 2-5 Sports floor classification for shock absorption (Sudol, 2013)

Type	Sports floor type			
	A	P	C	Mx
	Shock absorption *R*			
1	-	25% ≤ *R* < 35%	-	-
2	-	35% ≤ *R* < 45%	-	-
3	40% ≤ *R* < 55%	45% ≤ *R*	45% ≤ *R* < 55%	45% ≤ *R* < 55%
4	55% ≤ *R* < 75%	-	55% ≤ *R* < 75%	55% ≤ *R* < 75%

Vertical deformation is the capability of flooring to deflect during an impact from a biomechanics perspective. High surface vertical deflection value can cause an athlete to lose balance when a surface is impacted or affect an athlete's limbs and hurt his/her knees and ankles. The BAA can also be used to measure vertical deformation and force reduction, except the spring stiffness and the drop height are modified. The vertical deformation, D values are stated in millimeters unit and are obtained from the following equation (Demker, 2009)

$$D = (\frac{1500N}{F_{max}})\ \text{X}\ f_{max} \qquad 2\text{-}9$$

Fmax = Maximum force generated during impact (peak value) in N

fmax = Maximum deformation at the point of impact in mm

Table 2-6 EN14904 performance criteria (Walker, 2013)

Categories	EN 14904 Requirements
Force reduction (minimum)	25% < *FR* < 75% (Range plus or minus 5% of average)
Ball rebound (minimum)	90% < *BR* (Range plus or minus 3% of average)
Rolling Load	1500 N
Vertical deformation (mm)	*D* < 5 mm
Area indentation (maximum)	Not measured
Slip Resistance	80 < *SR* < 110

Because of using different springs in force reduction and vertical deformation on the BAA method, the time is taken to achieve peak rate will be different for each test method under analysis. The time to reach maximum peak impact can be defined using the following equation:

$$t_{(v=0)} = \frac{\pi}{2}\sqrt{\frac{m}{k}} \tag{2-10}$$

t(v=0) = Time to maximum peak force when velocity equals 0 *m* = Mass in kg

k = Spring rate in N/m

Table 2-7 Sports floor classification for vertical deformation (Sudol, 2013)

Type	**Sports floor type**			
	A	P	C	Mx
	Vertical Deformation *D*			
1	-	$D \leq$ 2.0 mm	-	-
2	-	$D \leq$ 3.0 mm	-	-
3	1.8 mm $\leq D <$ 3.5 mm	$D \leq$ 3.5 mm	1.8 mm $\leq D <$ 5.0 mm 0.5 mm $\leq D_p$* < 2.0 mm	$D \leq$ 3.5 mm
4	2.3 mm $\leq D <$ 5.0 mm	-	2.3 mm $\leq D <$ 5.0 mm 0.5 mm $\leq D_p$* < 2.0 mm	$D \leq$ 3.5 mm
* D_p – point resilient component flexure				

Vertical deformation is tested according to ASTM F2157 A, and PN–EN 14809 norms with a value recommended ≤ 5 mm. (Table 2-7)

The essential factors measured by ASTM F2772 or ASTM F2157, DIN 18032, and EN 14904 include force reduction, surface finish effect (also called “friction”), ball rebound, and vertical deformation (Table 2-7).

2.5.9 PLAYGROUND FLOORING

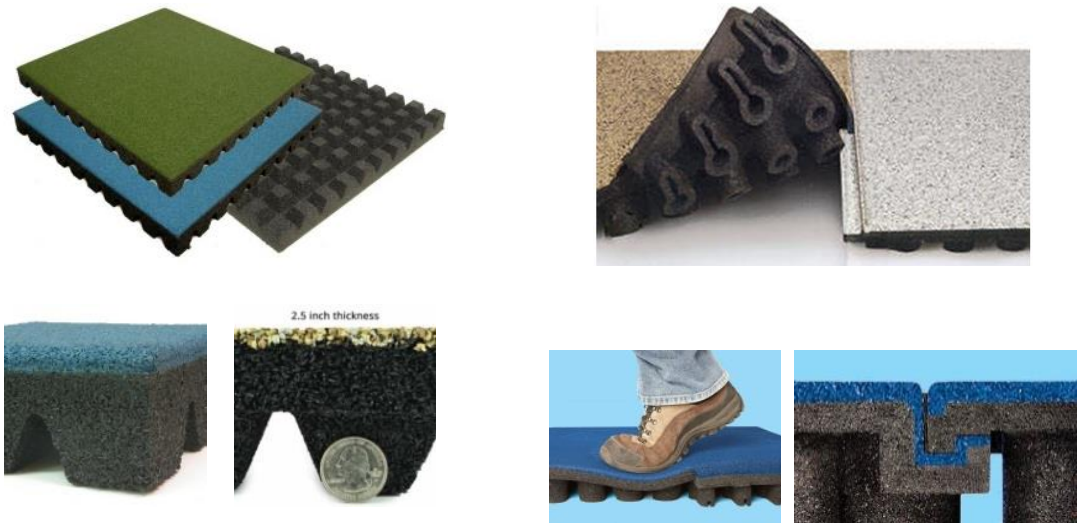
Hard flooring is not healthy for the human body. In high traffic areas, hard floors can cause various ailments on the knees, backو spine, soles of the feet. Fitness or weight rooms, physical therapy facilities, kids' playgrounds (Figure 2-27), jogging tracks, exercise rooms, factory floors, etc., are prime instances of injuries caused by contact with hard surfaces. These safe floorings can come in various models and materials. Unconsolidated loose-fill materials such as natural or artificial grass, sand, sawdust, and wood chips are widespread in risk zones. Rubber flooring is another common option to minimize the impact because of the resilient property. Examples of such flooring areas are marketed by many manufacturers such as *Bounce Back* Playground and *Smartcells* provided by *Satech* from the USA, Playground, *FX*, *Overall, Everlast*, and *ECO* tiles brand names provided by *Dodge-Regupol*, Inc from Germany. *Duratrain, Durasafe* provided by *Sofsurfaces* company in Canada. And *Energy CF*, *Sportex* provided by *Supreme floors* in Spain.

Creating an optimal balance between resilience and durability is a challenge in designing the performance of shock-absorbing surfaces. Usually, the cushioning properties of a system will decrease as the density and durability of the material are increased. For this purpose, the engineered design of the hollow-core pedestal is presented to increase the density of the wear layer without reducing the safety factor of tile face with fall. By engineering a thin hollow-core impact pedestal underneath the outer surface to absorb the impact of a fall, the cushioning properties of the system will remain firm and consistent after years of use (Sofsurfaces, 2020) (United States Patent No. US 6,623,840 B2, Sep. 23, 2003). Most similar products are manufactured exclusively with recycled materials especially tire granules (Supreme, 2016) (Sofsurfaces, 2020). A prepolymer material is provided between the rubber granules, which binds the granulated rubber together.

Figure 2-27. Playground covered by SofTILE DuraSAFE product (Sofsurfaces, 2020)

ASTM F355 or EN1177 is the safety norm that qualifies the impact absorbing properties of playground flooring. HIC (Head Injury Criterion) and G-Max (Maximum acceleration-shock) are two common methods to measure the impact attenuation performance requirements for playground surfaces in the event of falling from the top of playground equipment (UNE-EN 1177:2018+AC: 2019, ASTM F3351 - 19, ASTM F1292 – 18). The Head Injury Criteria (HIC) and G-Max are the main factors that the criteria of general protection standards were 200g for optimum acceleration and 1000 for HIC when the device showed the result of the dropped instrument from the height on the intended surface (Sofsurfaces, 2020).

BOUNCE BACK with 6.35 cm, and *SofTILE DuraSAFE* about 5.08 cm thicknesses are two examples of shockproof products to secure children's playgrounds. Both are made of recycled rubber that makes them a green product and non-slip outdoor rubber safety surfacing. They have the same ingredients with mostly different cellular structures. *BOUNCE BACK* has pyramidal structural cells with a vertical trapezoidal section (egg–box). *SofTILE DuraSAFE* has cylindrical structural cells and a horizontal circular section. The connection type of both to the subfloor is without glue, and the adjacent tiles are connected by the interlock method (Figure 2-28).



a b

Figure 2-28. BOUNCE BACK (a) and SofTILE (b) (Sofsurfaces, 2020)

Many types of research have looked into the behavior of cellular structures. For example, with the help of the FE (Finite Elements) method and experimental testing, investigators achieved valuable results in the egg–box (Deshpande, 2003) (Zupan, 2003) and the cylindrical structure's cushion performance (Wang B. X., 2019) (Tan, 2019) (Tang, 2013). Other uses for these sample products include Safety Surfaces for all areas, Deck, Diving Boards, Exercise Flooring, Patios, Play Areas, Pool Areas, Rock Climbing Walls, Skateboard Parks, Sound Reduction, Stairways.

As the evidence of academic research and products presented by various factories show, the issue of impact reduction and control is a topic that is widely considered in all fields of industry, recreation, sports, and healthcare, which is fully explored in the next chapter.

CHAPTER 3

STATE-OF-THE-ART-ACADEMIC, COMMERCIAL AND ARCHITECTURAL EFFORTS

CHAPTER 3

3 STATE-OF-THE-ART-ACADEMIC, COMMERCIAL AND ARCHITECTURAL EFFORTS

Much research has been conducted bout the causes of falls, the severity of the impact, the threshold failure, especially the pelvis and femur. Many methods are presented to reduce the number of falls and the rate of damage in academics and laboratories. Most of these experiments are aimed to optimize production and minimize damage.

Keywords: Biomechanical Test, Impact Force, Impact Simulation, Force Plate System, Vertical Ground Reaction, In-Shoe Pressure Sensors, Validation Tests, Norms, G-Max, HIC Test, CoR, SLR, PMF, CF system, SF System, FE Method.

3.1 ACADEMICAL EFFORTS AND PROGRESS

3.1.1 BIOMECHANICAL RESEARCH

Not every fall leads to a hip fracture. The magnitude of the force the femoral neck tolerates before a fracture occurs, i.e., the failure load, is individual and depends on the mechanical properties within the bone that are influenced by several parameters such as density, microstructure, and morphology. These parameters are changing throughout lifestyle and especially with aging and disease. (Riggs, 1995) Furthermore, the volume of soft tissue overlying the hip and protective reactions of the falling person, such as using hand or elbow, are other factors that affect the magnitude of load applied on the femur during a fall. Academic reviews are usually conducted to verify products such as helmets, hip protectors, or sometimes research on the impact of impact-resistant flooring named "Compliant flooring" using biomechanical methods and devices. The academic and laboratory experiments, tests are usually divided into several main groups.

- Laboratory trial: Using force plate or accelerometer to measure the fall or impact test with healthy volunteers. All particular security and safety circumstances are considered to avoid injury.
- Laboratory trials simulate the impact of a fall by applying a load on the target organs, such as the head, pelvis, legs, etc., made of synthetic materials. The impact is simulating by applying a load with a pendulum shape or drop-weight on a simulated body part (head, hand, or femur), or this process can be vice versa. Force plate or accelerometer use in such trial to measure the force and pressure.
- Field trial: Installing compliant flooring in a room (medical center or nursing home) for a specified time (few months or years) and monitor the number of people who fell and the severity of the damage to them at that time and statistically compare with the data before installing the flooring.

- Software simulation: Simulate the human body (Total human model for safety-THMS[39]) and the tile or any other tools (hip protector) by using software (Finite Element Method-FEM) to release what happened during the impact.

Over the last few decades, more attention has been paid to the flooring issue and methods to reduce injuries in the event of a fall. According to the articles collected and analyzed between the years 1981 and 2016, in the first two decades of investigations about **compliant flooring** (the 1980s and 1990s), records generally centralized on the carpet and its softness relation with preventing injury. In the following years (2000–2009), researchers studied different carpets and underlays. Research on purpose-designed **novel compliant flooring** (NCFs; i.e., flooring systems designed mainly to prevent fall-related injuries) became more outstanding in the late 2000s through the present day (Lachance C. C., 2017).

On behalf of the Center for Accessible Environments (CAE), NHS Estates[40] has developed a guide based on the design of residential places and nursing homes. It has applicable general principles, but there is no information about the materials and shock-absorbing underlayment. Royal Society has a section in its Saving Lives newsletters that include suggestions for preventing falls as well. For instance, according to the study carried out by Debra D. Harris, on three types of flooring (terrazzo, rubber, and carpet tile) in the hospital which aimed at assessing the absorption of sound, comfort, light reflectance, employee perceptions and preferences, and patient satisfaction. Finally, after 42 weeks, participants found carpet tile a perfect choice in sound absorption, providing acoustic value for walking and comfortable (Lachance C. C., 2017). While carpet is not suitable for wheelchair moving (Hacihasanoglu, 2001), it is not easy to clean, and carpet absorbs dust. Most of the flooring products and executed projects with the specifications of shock absorption are about certain functions, such as gyms & sports areas, playgrounds, or even industrial areas. According to our current research, only three flooring companies (ACMA-Kradal, SATECH-Smartcells, and Sorbashock) professionally claim to provide a shock absorber. They are very suitable for the living environment of the elderly. But many other companies generate shock-absorbing flooring with another purpose except for the elderly.

SHOCK ABSORPTION

In general, studies have shown that the shock-absorbing floorings can decrease peak force on falling by almost 65-80% compared to wood or concrete and by 20-40% compared to wood or concrete floors overlaid with a carpet, in the research executed by Michal N. Glinka et al. (2013). The force-deflection properties were measured in some flooings after applying impact via indentation tests on a Servo Hydraulic material testing system or “MTS” (Figure 3-1). Each indenter was connected to the load cell and examined through all flooring types at load values particular to the scenario. The indenter samples were made from a hardened mixture of water and *Dentstone*® a dental gypsum powder becomes. They used custom software routines (*MATLAB r2009b*) for data analysis and processing (Glinkaa, Karakolisb, Call, & Lainga, 2013).

[39] THMS is presented by Toyota Motor Corporation and Toyota Central R&D Labs. Inc., mainly to be used in car crashes injuries.
[40] https://www.property.nhs.uk/

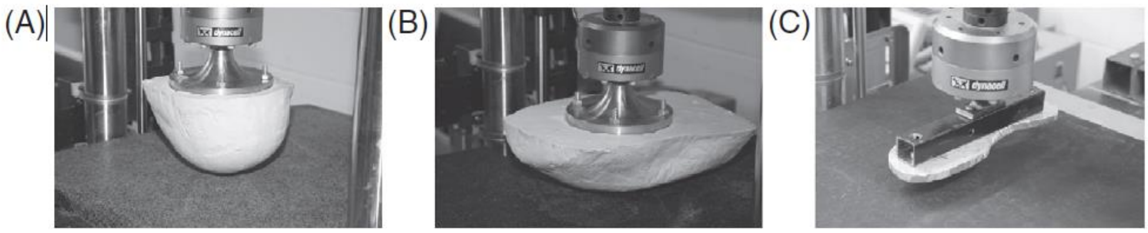
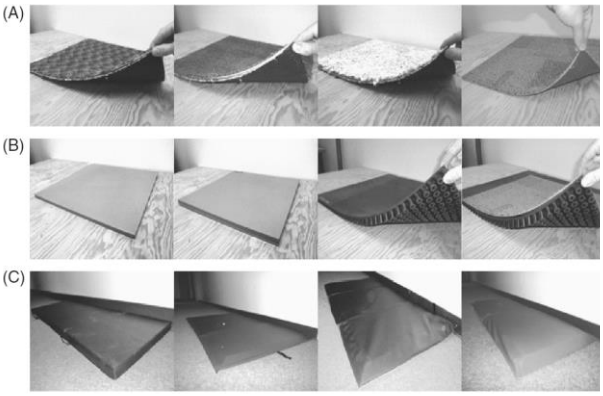


Figure 3-1 Photograph test system setup highlighting the following indenters: (A) back of the head, (B) hip, and (C) 50% female foot (Glinkaa, Karakolisb, Call, & Lainga, 2013).

According to the investigations, NCFs can reduce hip impact forces even more than carpet with underlay by 16.4% to 51.2% (Laing A. C., 2009) (Glinka MN C. K., 2013). According to the tests done by Glinka and colleagues(*Kradal, 1.27 cm; Kradal, 2.54 cm; SmartCell, 2.54 cm* with or without carpet tile overlay), NCF absorbed 3.2 to 5.4 fold more energy than commercial carpet with foam underlay (0.96 cm) (Glinkaa, Karakolisb, Call, & Lainga, 2013) (Figure 3-2). In their research, a purpose load of 4 kN used for head and hip impact simulations according to the peak force used in a report presented by Robinovitch during sideway falls on the hip approximately 4 kN (Robinovitch S. N., 2009) and for a single-foot indenter simulating they determined a load of 650 N based on the average body weight and ground reaction (66.36 kg-50th percentile female) during the stance state of natural gait (Winter, 1991) at a loading velocity of 50 mm/s (Andrew C. Laing, 2006) and a sampling rate of 2.5 kHz.



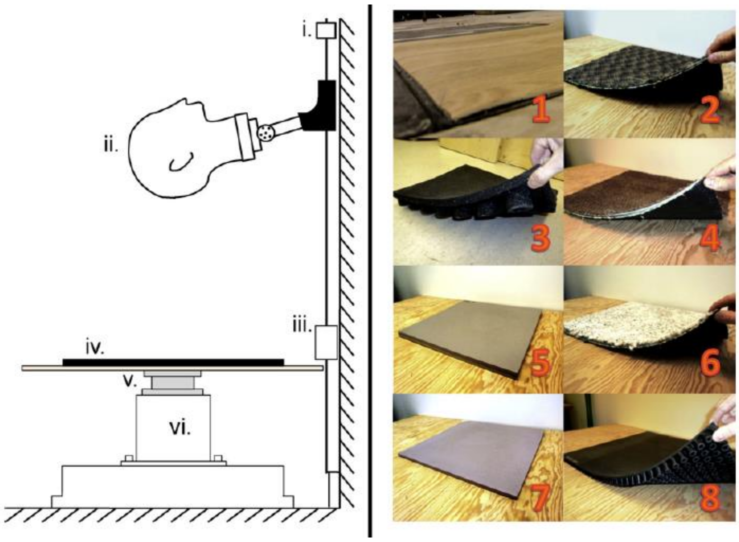
	Thickness	Material	Manufacturer	Other specs
Commercial carpet (COM)	0.35 in. (0.89 cm)	Olefin	N/A	Face wt: 26 oz/yd^2 Total wt: 59.5 oz/yd^2 Pile design: level loop
Residential carpet (RES)	0.40 in. (1.02 cm)	Polypropylene	N/A	Face wt: 32 oz/yd^2 Total wt: 70 oz/yd^2 Pile design: pile and loop
Berber carpet (BER)	0.33 in. (0.84 cm)	Polypropylene	N/A	Face wt: 36 oz/yd^2 Total wt: 755 oz/yd^2 Pile design: loop
InterFace FLOR (IF)	0.5 in. (1.27 cm)	Nylon	FLOR	Pile design: cut and loop
1/2 in. Kradal tile (1/2 in. KT)	0.5 in. (1.27 cm)	Polyurethane	Acma Industries Ltd.	N/A
1 in. Kradal tile (1 in. KT)	1 in. (2.54 cm)	Polyurethane	Acma Industries Ltd.	N/A
SmartCell (SC)	1 in. (2.54 cm)	Elastomeric rubber	SATech Inc.	Density: 1120 kg/m^3
SmartCell with InterFace (SC + IF)	See above: SmartCell and InterFace			
'Soft' bedside Posey (BSPS)	1.5 in. (3.81 cm)	Polyurethane foam with vinyl cover	Posey Com-pany	Density category: low Catalog no. 6024
'Medium' bedside Posey (BSPM)	1 in. (2.54 cm)	Ethylene vinyl acetate (EVA) with vinyl cover	Posey Company	Density category: med Catalog no. 6023
Bedside AliMed (BSAM)	1 in. (2.54 cm)	Polyurethane foam with vinyl cover	AliMed	Density category: high
Bedside Skil-Care (BSPS)	1.5 in. (3.81 cm)	Ethylene vinyl acetate (EVA) with vinyl cover	Skil-Care corp.	Density category: med

Figure 3-2 flooring conditions tested. From left to right: (A) carpets – commercial, residential, *Berber, InterFace*; (B) safety floors –1/2 in. *Kradal*, 1 in. *Kradal, SmartCell, SmartCell* with Interface; (C) bedside mats – 'soft' density Posey, 'medium' density Posey (Glinkaa, Karakolisb, Call, & Lainga, 2013)

They used a two-factor randomized group *ANOVA*[41] to determine whether impact absorption was influenced by indenter shape (hip vs. head) and floor type. Peak deflection, energy absorbed (hip, head), and the ratio of energy absorption to peak deflection (ratio) – were analyzed to determine if the results were influenced by floor condition. Effects of simulated hip impacts indicated that all floor types used in the study except the 'residential' and Interface carpets showed significantly higher energy reduction than the baseline commercial carpet (absorbed about 4.8 J). The '*Berber*' carpet showed the highest rate in carpets, about 7.9 J energy reductions. *SmartCell* covered by commercial carpet absorbed 3.5 times (16.8 J) as the most energy of the safety floors, but this rate with the same condition was more remarkable for the skil-care bedside mat with eight times (38.5 J). For the back-

[41] The ANOVA is based on the law of total variance, and ANOVA test is a method to discover if the survey or experiment results are significant. Basically, a number of testing groups are testing to see if there's a difference between them. For instance, a group of psychiatric patients is experiencing three different therapies: and the researchers want to find out if one therapy is better than the others.

of-head trials, *Smartcells* with the commercial carpet Interface gave the most incredible amount of impact absorption of the safety floors with 4.9 times (21.4 J), while the skill-care bedside mat showed over 8.0 times (almost doubled-35.4 J) more energy reduction than the control condition (Figure 3-3).



Left :
(i): mechanical release;
(ii): head form with an accelerometer mounted
at the center of mass;
(iii): light gate velocimeter;
(iv) flooring sample positioned on plywood interface surface; (v) load cell;
(vi) concrete base.
Right: floor conditions tested
1: Resilient (Resilient),
2:Commercial Carpet (Carpetcomm),
3:SofTile (SofTile);
4:Residential-Loop Carpet (Carpetres-loop),
5:24 mm Kradal (Kradal24 mm),
6:Berber Carpet (Carpetberber),
7:12 mm Kradal (Kradal12 mm),
8:SmartCell (SmartCell),

Figure 3-3 Schematic of the mechanical head impact simulator (Wright, 2012)

In some studies, electric safety jacks with complete safety have been used to simulate impact applied to hip or hand (Robinovitch S. N., 1997) (Andrew C. Laing, 2006) (Robinovitch S. N., 1998) (Figure 3-4),

Figure 3-5). Andrew C. and his colleagues have used a sling and electromagnet method to raise and suddenly release the participant from a height of 5 cm in the upright and lying landing configurations. The impact was measured with a force plate (Figure 3-4) (Andrew C. Laing, 2006). The test consisted of 15 women ranging in age from 21 to 32 years, and participants performed several consecutive trials on each of the floor conditions (presented in random order). Several floor conditions were tested on a force platform.

- The participant lay directly on the force platform one without any mat,
- Lay on linoleum,
- In the other conditions lay on a mat of closed-cell of ethylene-vinyl acetate (EVA) foam with the thicknesses of the 1.5, 4.5, 7.5, and 10.5 cm; and
- The latter conditions were stacked multiple 1.5 cm-thick mats.

Several camera movement capture systems (*Motion Analysis Corporation, Santa Rosa, USA*) were used to record the frames. A subject was supported by a chest harness attached to a ceiling-mounted safety tether; the device did not prevent natural movements or reactions (D. Wright & C. Laing, 2012). The tests included a peak force of 3000 N, similar to the mean amount predicted for a fall from standing condition (Robinovitch S. N., 1998) and a displacement rate of 50 mm/s, slightly less than that expected during a fall, and a sampling rate of 1000 Hz to dedicate the force-deflection behavior of the materials.

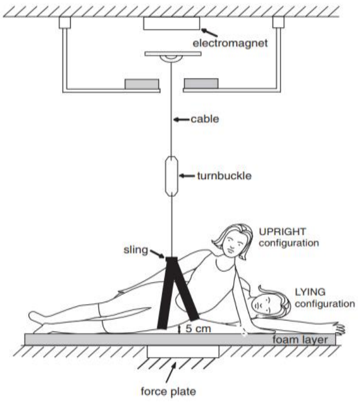


Figure 3-4 simulating the impact stage of a sideways fall on the hip (Andrew C. Laing, 2006)

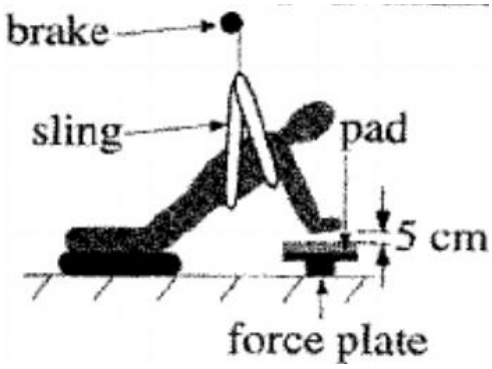
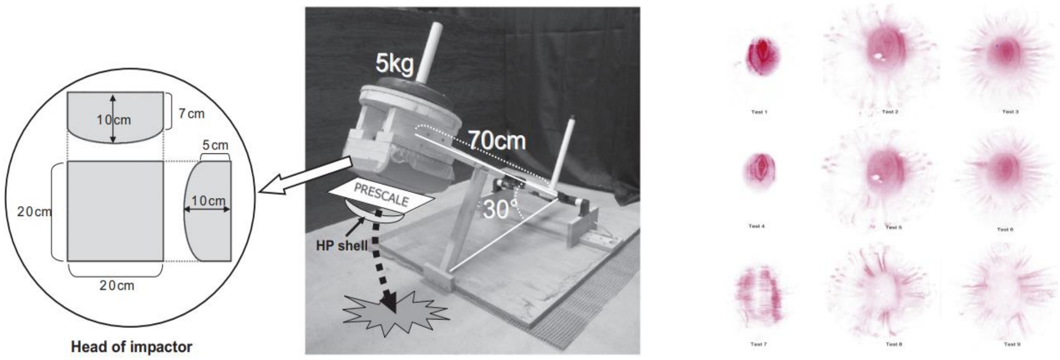


Figure 3-5 experimental falls involving a decent height (h) of 5 cm on a foam pad over the force plate. (Robinovitch S. N., 1998)

Hip protector is a technique to attenuate the impact force in a fall in seniors. However, clinical trials have contained inconsistent outcomes partly due to a lack of agreement on methods for measuring and optimizing the biomechanical test to validate the performance of hip protectors as a prerequisite to clinical trials. To present reasonable outcomes, the test technique should accurately simulate the pelvic anatomy, and the suitable impact velocity (3.4 m/s), pelvic bone stiffness (acceptable range: 39-55 kN/m), and effective mass of the body (acceptable range: 22-33 kg) during simulation of impact. Given the current methods, the first important value of biomechanical testing is to compare the protective performance of different products, to reject or accept the devices for market use (Robinovitch S. N., 2009).

Ning Li et al. (Li , Tsushima, & Tsushima, 2013) experimented on some flooring materials, namely concrete, wood, and tatami matting. In this method, the fall-impact were simulated with a pendulum-based system in which typical hip protectors (hard and soft shell) fixed on the head of the impactor to compare the impact force in each test (with or without hip protectors) and measure the value of the impact forces reduction of each floor. The device involved a 5kg falling mass with a pendulum arm to create and simulate an impact force with a velocity of 2.6 m/s and a peak impact force of 5939 ± 81 N. This peak force is close to the magnitude used in Robinovitch et al. (5600N) (Robinovitch S. H., 1991). *FUJIFILM* Co. Tokyo, Japan, provides the *PRESCALE* films with a high sensitivity to the pressure used in this study[42]. The two-sheet film is covered with microencapsulated color-forming and developing materials. Red patches appear on *Prescale* when pressure is applied. The color density changes according to pressure (MPa) level (Figure 3-6 and Figure 3-7).

[42] https://www.fujifilm.com/products/prescale/



a b

Figure 3-6 (a) Simplified fall impact-simulation device with a wooden hammer as an impactor to apply the impact. The PRESCALE film was located between the head of the impactor and the hip protector. (b) the color distribution of prescale films under different test conditions (Li , Tsushima, & Tsushima, 2013).

Two methods were proposed to distinguish the magnitude of the pressure. First, a manual guide that categorizes the color spectrum from very pale pink (meaning low pressure) to very bright pink (meaning high pressure) and the numbers in front of each spectrum can be used to estimate the pressure range of value. The second method is pressure analysis by special software (*FPD-8010E*). The final results of this study noted that the soft hip protector had a better force attenuation effect than the hard one in sideways fall from standing height. Testing performed showed that using tatami matting could be reduced in impact reduction below the average fracture threshold (3472 N) even without a hip protector and better than those. The study suggested that tatami could be a promising intervention method for reducing the force in both the home and high-risk environment.

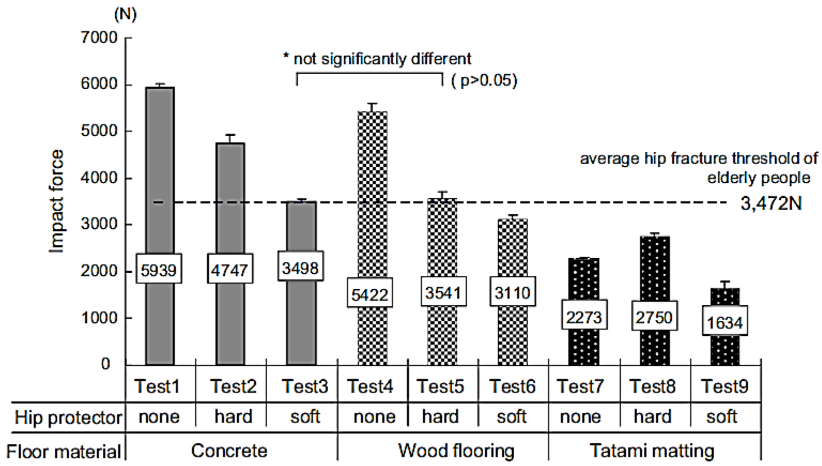


Figure 3-7 Average impact force under each test condition (Li , Tsushima, & Tsushima, 2013)

All biomechanical test systems use a falling mass to create impact energy. The falling mass can be vertically by a drop tower or in the form of the curved path by a pendulum (Laing A. C., 2009) (Glinka MN C. K., 2013) (Figure 3-8). The results of both methods are acceptable. However, care is required in both scenarios. The drop tower should avoid the connection between the falling mass and the guides during impact. In the pendulum, the effective mass and any compliance in the pendulum arm must be considered when computing the total effective mass and stiffness. Sensors are needed to accurately measure the impact velocity in both methods and accommodate this to the demanded fall velocity of 3.4 m/s. The impact velocity of the hip averages 3.01 m/s (SD=0.83 m/s), and the body's kinetic energy at the moment of impact averages 307 J (SD=90 J). But there is no agreement on the average value of the effective mass and stiffness of the body during impact. It should be pointed out that the anatomic and biomechanical characteristics that define these rates are complicated and that more study is needed on this issue (Robinovitch S. N., 2009).

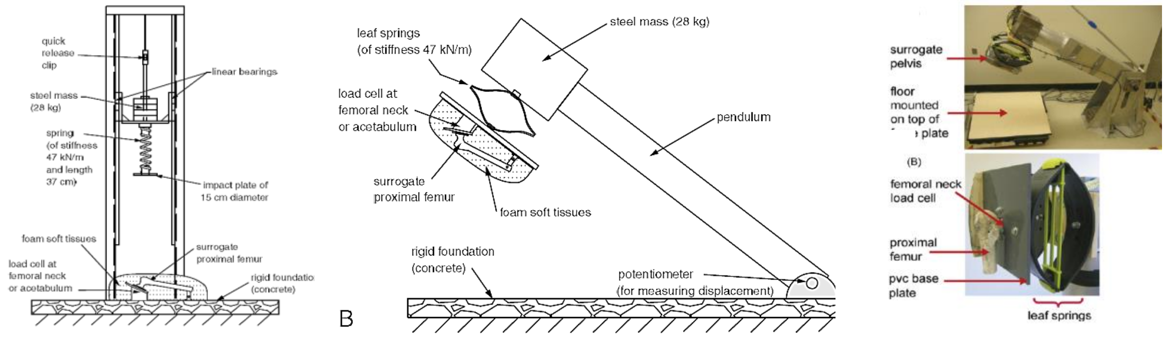


Figure 3-8 A Drop tower and B pendulum-based systems for measuring the capacity of hip protectors to attenuate the peak compressive force applied to the proximal femur during a simulated sideways fall from standing height (Robinovitch S. N., 2009) (Laing A. C., 2009)

Evidence exists that some low stiffness surfaces could impair balance in standing or during walking and increasing the risk of falls. Thus, minimizing potential impairments in balance and mobility is another challenge for companies to provide a product with an intervention approach that able to maintain static (quiet stance) and dynamic balance while attenuating impact forces. Such flooring systems are generally designed and characterized to minimize deflection during locomotion.

Photo

Floor	Rigid (Control)	SmartCell	SofTile	Firm-Foam	Soft-Foam
Thickness (mm)	2	25	100	110	100
Footfall deflection (mm)	-	0.8	4.0	85.4	92.4
Density (kg/m3)	-	1120	1057	32	22.2

Figure 3-9 Photos and properties of the floors tested. Smart-Cell and SofTile as two compliant floorings, one Firm-Foam, and one Soft-Foam as two basic foam surfaces tested in the study that was compared to a 'Rigid' floor as a control condition (D. Wright & C. Laing, 2012)

In this order, the effects of compliant flooring on balance recovery mechanisms conformity an externally induced disorder studied by Alexander (D. Wright & C. Laing, 2012) and Redfern (Redfern M. S., 1997). Alexander used a floor translation paradigm to induce a balance. Results included displacement rates and borders of safety for both the underfoot center-of-pressure (COP) and whole-body center-of-mass (COM). Thirteen healthy women participated in this study, with ages ranging from 65 to 90 years (SD = 73.7 (7.9) years), body masses SD = 70.3 (11.6) kg, heights of SD = 1.62 (0.08) m, and body mass indices of SD = 26.7 (3.0) kg/m2. (Figure 3-9). The center-of-mass and center-of-pressure borders of safety and displacement rates of two novel compliant flooring systems were almost close to the control floor. In contrast, most of the safety and displacement rate variables were highly lower for the foam floors compared to the control condition.

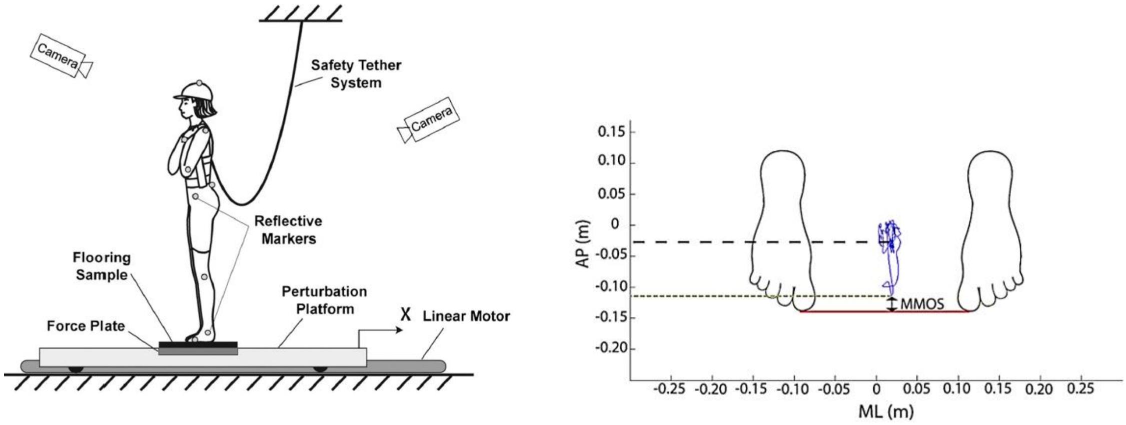


Figure 3-10 A force platform measured the time-changing position of the underfoot COP, while a motion capture system measured the status of 23 signs attached to the body. The minimum border of safety (MMOS) is derived as the minimum distance between the COP and anterior boundary of the base of support (BOS) determined by the toes. (D. Wright & C. Laing, 2012)

The participant initially stood barefoot on top of a flooring sample mounted over a force plate for each trial, fixed into a wheeled perturbation platform (Figure 3-10). The platform was connected to a linear motor, and the movement profile was controlled using a custom routine. First, the participants were required to maintain the location and balance of the COP within a 1 cm frame using real-time visual feedback while standing barefoot with their feet shoulder-width apart, arms across their chests. In the second stage, the platform was speeded up posteriorly at 5 m/s^2 until a velocity of 0.2 m/s. in the third stage, the accelerative phase ended. At the same time, the perturbation continued at a velocity of 0.2 m/s for 2 sec. The participant was needed to maintain her balance during test responses without movement, but hip flexion and arm movements, and raising of the heels were allowed. Eight-camera motion captures the movements in the system. This test simulated the type of balance disturbance that occurs following a trip or standing on a bus.

3.1.2 STRATEGIES AND DEVICES USED IN RESEARCHES

FORCE PLATE

Newton's second law explains that any change in acceleration or velocity of an object is proportional to the forces exerted on it (equation: F = m x a), and the third law states that when a force is applied to an object, the object applies a concurrent same magnitude force opposite to the direction of original force. These rules can be seen in the practice in the ground reaction to the force exerted by athletes.

Force plates have been around for over 40-years. Force plate and other force measurement systems (e.g., S-type load cells, pressure sensors) are used to distinguish external forces generated by individuals and gait analysis. It is also instrumental in clinical research by aiding specialists and researchers focused on biomechanical analysis. It can help a coach or sport scientist evaluate the kinetic characteristics of an athlete's performance of the skill or his/her physical development. Gait analysis for both human and animal patients, Pediatrics, Footwear analysis, and Physical therapy evaluations[43] can be noted in cases such as fall risk evaluations.

[43] https://www.tekscan.com/

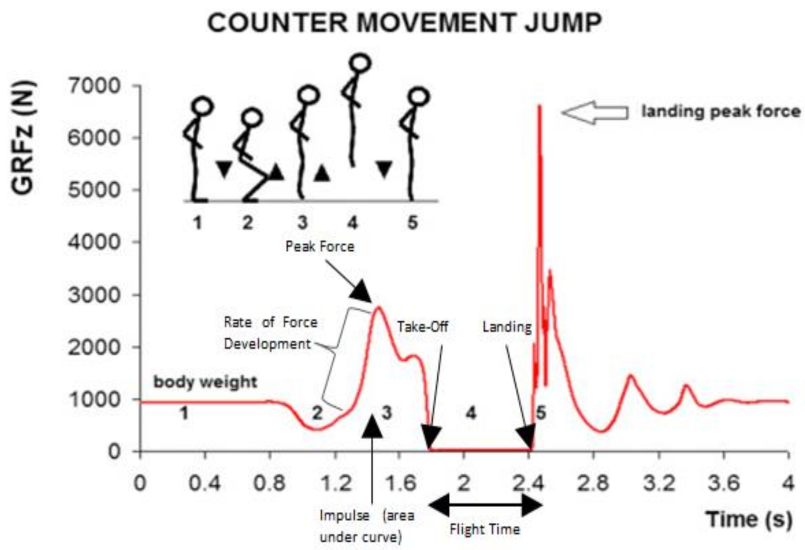


Figure 3-11 Vertical ground reaction force can attain six times body weight during standardized vertical jumps (Yunus Ziya Arslan, 2019.).– (With a few corrections in the figure by the author)

A force platform/plate is used to measure the ground reaction force (GRF) exerted by the ground on a body in contact with it (Figure 3-11). The system can measure external GRF components in three planes - vertical, anterior-posterior, and medial-lateral and present an accurate picture of the interaction between an individual and the ground surface. To achieve accurate results with the most negligible error in gait analysis, the entire sole of the subject's foot must be located on the force platform during walking. By evaluating the GRF and kinematic information with the inverse dynamic analysis, the resultant joint forces and moments can be estimated (Yunus Ziya Arslan, 2019.).

The force plates measure only the vertical component of the force, but advanced models can measure the 3D components of the single equivalent force applied to the plate and the center of pressure (CoP), as well as the vertical moment of force (Robertson, 2013.) (Harris D. D., 2010). Important information that is obtained by modern, full-featured force plate includes:

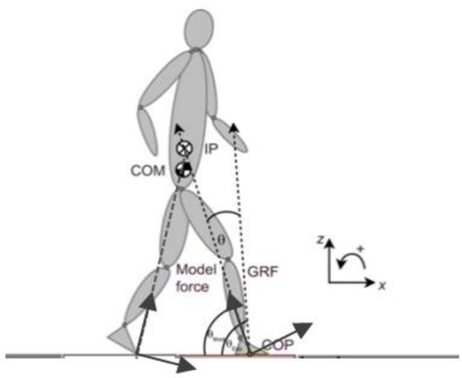


Figure 3-12 Side view of the walkway. The model force goes through the center of pressure (COP) and the assessed intersection point (IP). The angle θ is between the force vector direction and the ground reaction force (GRF) vector. COM is the center of mass of the body (Vielemeyer, 2019) - with some editions by the author.

- force in three vectors of X, Y, and Z,
- the center of pressure (CoP),
- the center of force (CoF),
- the moment (torque) around each of the axes.

In summary, it can be stated that the force applied to the plate is measured through a force transducer and converted into a measurable, electrical voltage/signal by what is known as load cells (piezoelectric transducers, strain gauges, and beam load cells). Load cell receives an excitation voltage input, which produces a different electrical current proportional depending on the transducer's force or load. Load cells have an excitation voltage that is flowing through them, with the defined initial input voltage. Monitoring the changes in voltage with exerted load allows for calculating load exerted on the system (Beckham, 2014).

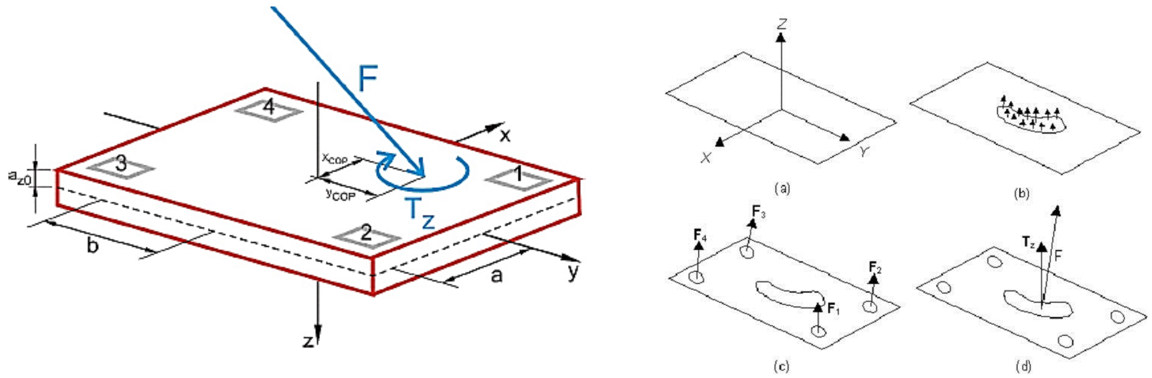
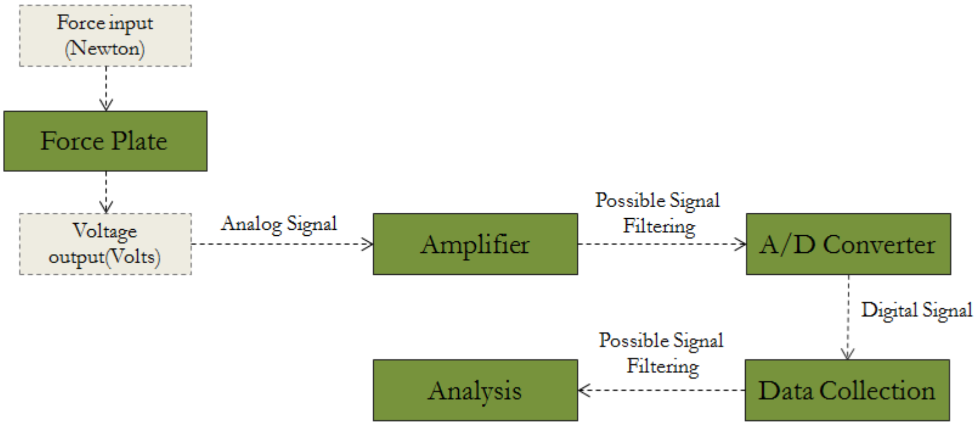


Figure 3-13 Schematic of coordinate and force plate calculation of vertical force. a) Kistler coordinate system, b) pressure distribution of foot, c) forces received from force plate sensors, and d) ultimate force and torques received from the force plate. (Scorza, 2018) (Jamshidi, 2010).

A typical force plate contains four three-component load cells that measure the force in the X, Y, and Z orientation. The four cells are located in four corners of the rectangular force plate that measuring the moments about the axes, COP, and COF from the individual cells and their places on the force plate (Figure 3-12and Figure 3-13). To obtain the total vertical force, the loads measured by each of the sensors are summed. Likewise, the sum of calculated forces in all the anterior-posterior cells gives the total force in the anterior-posterior direction in a force plate with load cells oriented. The data obtained from the output of the primary analog signal (DC voltage) from the load cells is transmitted to the final digital input signal to be finalized by computer software. The modified charge is then sent to an amplifier for scaling. The amplified signal flow is routed to a data acquisition source. It enters an analog-to-digital (A/D) converter to transform a continuous analog signal into a series of discrete digital signals at equal distances. The recorded digital signal can then be evaluated in a software program (Table 3-1) (Beckham, 2014).

Sampling frequencies must be high enough to ensure the accuracy of measurement and decrease of signal and is essential for processing adequate resolution due to force-time curves. The low frequency will not provide enough resolution to test the changing forces in this short period. STREET et al. (Street, 2001) stated that sampling values of less than 1080 Hz could cause an underestimation of jump height (estimated through the impulse method) by up to 4.4%. Some other researchers suggest a sampling frequency of 500 Hz or 1000 Hz would be accurate, mainly when an impact is involved (Barlett, 2007).

Table 3-1 Signal flow diagram-By Author



But in the study executed by Hori, the validity of usually used performance measurements deduced from ground reaction force (GRF)-time data during a countermovement jump (CMJ) in different sampling frequencies (500, 400, 250, 200, 100, 50, and 25 Hz), were examined by jumping on the force plate. The researchers and practitioners may consider sampling frequency as low as 200 Hz due to evaluation because the percentage difference is not significantly enlarged until the frequency is 100 Hz or lower (Hori, 2009) (Gudavalli, 2013). *BTS Bioengineering s.p.A* [44] is one of the most famous companies that provide the most advanced research devices, including force plates, used in the experiments of this doctoral research from model *P-6000 /INFINITI-T*.

INSOLE PRESSURE MAPPING / MEASUREMENT SYSTEM

Insole systems known as Insole Pressure Sensor are beneficial and handy compared to the more traditional platform-tools because they allow the most tangible interface to be monitored between the foot and shoe. In addition, they permit enhanced diversity of measurement for the calculation of statistical assessments. Both discrete converters and matrix techniques have been fostered; each method has its strengths and weaknesses, but, in general, matrix approaches are preferable. However, some limitations in devices and processing systems must be overcome (Cavanagh, 1992).

One of the impressive properties of the recently developed instrumented insoles as an in-shoe pressure tool is that it potentially transfers gait analyses out of laboratory settings. They record data wirelessly and with external modules are attached to the shoe, legs, or waist (S. Crea, 2014). This technology enables the measurement of balance and temporal gait parameters. Clinical screening and monitoring employing in-shoe pressure tools are helpful in various chronic conditions affecting gaits such as diabetic neuropathies, rheumatoid arthritis, or knee and hip osteoarthritis. For example, ones with hip osteoarthritis display altered stance times and rhythm (M. Constantinou, 2014) There is the various in-shoe pressure mapping system in the market.

[44] https://www.btsbioengineering.com/

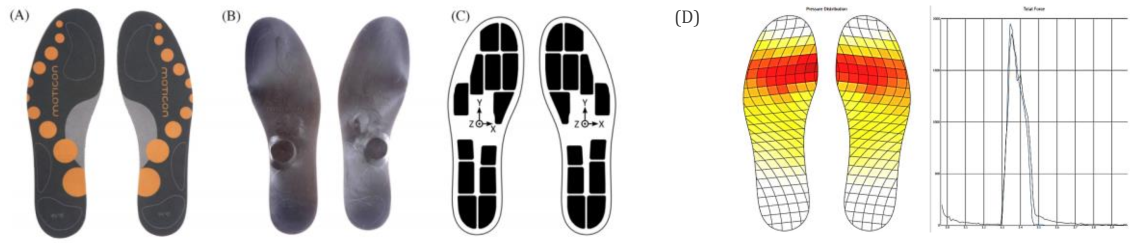
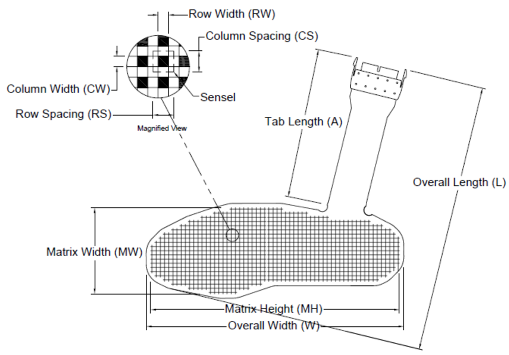


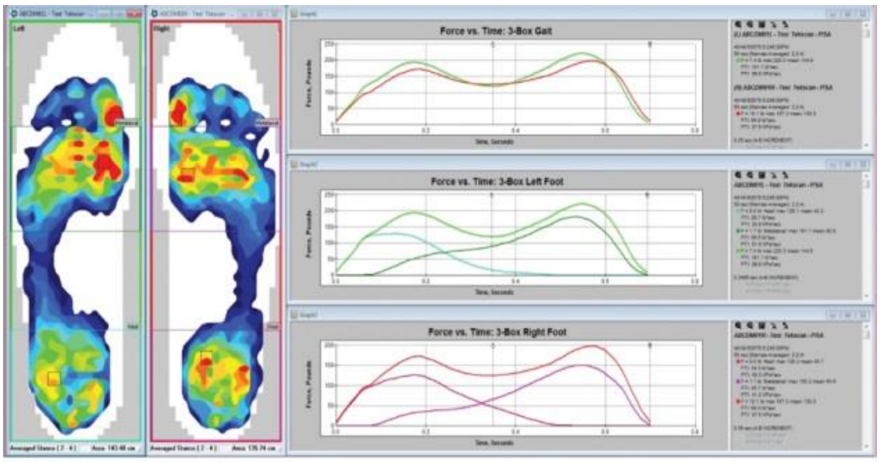
Figure 3-14 OpenGo instrumented insole front (A), the back with battery compartment (B), and the sensor layout (C). Jump Report-Pressure distribution (D)

The *Moticon OpenGo* is wireless without modules containing two thin and light fixed layers of insole regulated by pressure sensors, temperature sensors, and analyses in-clinic research (Oerbekke, 2017). The *Moticon SCIENCE* is specific software to analyze all data from *OpenGo* insoles' sensor (Science, 2020)(Figure 3-14).



(A)

(B)

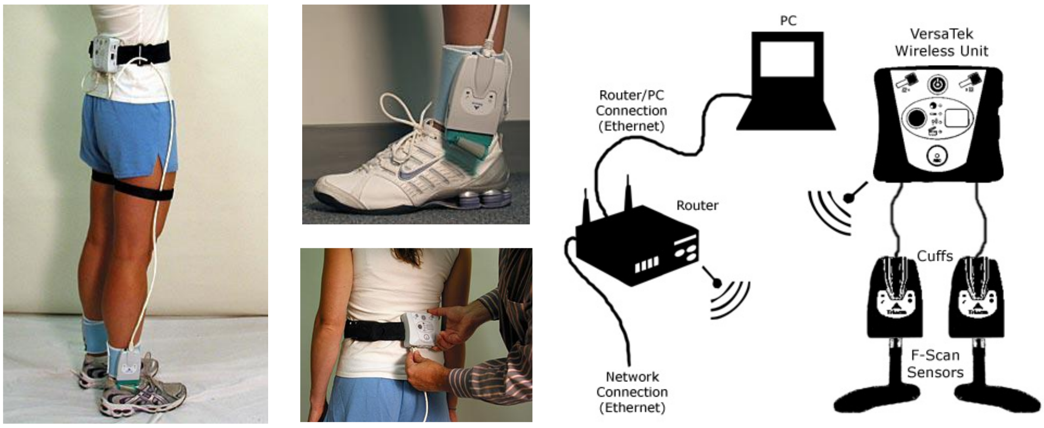


(C)

Figure 3-15 The geometry of the sensor (A). Model #3000E (VersaTek) (B). Screenshot of the software used for visualization in F-Scan system(C) (Tescan, 2020).

F-Scan tool provided by *Tekscan* company is another insole product with a different system with ultra-thin, in-shoe sensors capture timing & pressure information for foot function and gait analysis. Sensors data is transmitted through the interface wires between the insole (connected to *VersaTek Cuff*) and the internal memory (*VersaTek VWD-1 Wireless/Datalogger*) fixed on the back of the person with the band and stores in the memory for upload to software via USB at a later time (Figure 3-16).

The software (*F-Scan Research TAM*) uses a map to convert the pressure detected by the hardware into the pressure data displayed in the Real-time window. *F-Scan* contains 960 individual pressure sensing/cell locations (before trimming). F-Scan is trimmable, with scissors, from men's size 14 (US) to infant sizes. Virtually undetectable in the shoe, due to the *F-Scan* thinness, and does not interfere with the subject's normal gait (.007", 0.18mm flexible printed circuit). The top and bottom substrate of F-Scan sensors are 0.001" (0.02 mm) thick polyester sheet (Tekscan, F-Scan® User Manual, 2013). The following figure shows different parts of F-Scan and the computer system (Figure 3-15).



(A) (B) (C)

Figure 3-16 The use of self-adhesive stretchable tape wrapped around both the Cuff and Ankle Bands after they are secured to the subject (A). Sensor connectors into the Cuffs. Connection of the Cables to the Hub's[45] CH1 (Channel 1) and CH2 (channel 2)[46] cable ports (B). The diagram illustrates the Access Point Network-The connections of the cable into the Router, and then the Router's Ethernet cable to the PC's Ethernet card (C) (Tekscan, F-Scan® User Manual, 2013).

This tool is usually used for gait analysis in patients or athletes, and in some cases, it is used to design footwear and insoles. But in our case, the tool used to measure the ground reaction force (GRF) in the force plate beneath the tiles and in-shoe pressure mapping system over the tiles at the real and same time.

3.2 COMMERCIAL AND INDUSTRIAL EFFORTS AND PROGRESS

In the literature review, the importance of the floors is to take the impact of our daily activities and is generally the first surface to reflect wear and tear. There are hundreds of flooring types to choose from, but it's essential to choose the right one from the start as the wrong floors can practically cause irreparable damage. In any country, specialized laboratories are used to check compliance with standards and product validation. The standard and suitable flooring for sports and leisure should offer an optimal combination of functionality, efficiency, and safety. Also, in sports and fitness, factors like elasticity, fall attenuating, and insulating properties of the flooring (in case of the gym, dumbbell sport, cross fit, martial arts) are of the uttermost importance. Many studies have been conducted to reduce the risk of falling, reducing the rate of damage in the event of a fall, and different standard test methods used to validate floor performances. Slip resistance, fire and acoustic ratings, hardness, the effect of a caster chair, the impact of a furniture leg, and colorfastness are just some of the items that flooring factories put on their test list. Still, shock absorption is a specific property that does not have any defined test and standard range for the floors with consumption of interior space

[45] The VersaTek 2-port Hub is a gateway between the VersaTek Cuffs (and attached sensors) and the PC or laptop.
[46] A green LED indicates the Cuff is powered and connected to the Hub.

and places with a high risk of falling. Industrial and sport environments and kid's playgrounds have a better condition of standard tests and valid norms.

3.2.1 VALIDATION TESTS AND NORMS ON SPORT AND PLAYGROUNG FIELDS

INTERNATIONAL AND LOCAL EUROPEAN REGULATORY ORGANIZATIONS

Playgrounds are an essential common area in any community. They provide the kids and parents a place to get some much-needed fresh air and entertainment. But it is notable to mention that there are no national requirements for playground safety, and most states don't have any laws or standards of their own to offer a safe place. Falls are, by far, is a risk that causes the kids subjected to injury in the playground. Broken bones, concussions, and paralysis are feasible outcomes when a child falls. The two significant factors of the fall height and the resistance of the landing surface are the reason for the severity of the injury. The severity of the injury is much lower falling on the sand, wood chips, pea gravel, or rubber mats compare to packed dirt, grass, or, even worse, concrete or asphalt but depends on the height of fall or thickness of the floor, these surfaces still may be unsafe for the kids.

To measure product performance, the company will need to perform a series of standard tests (international and/or local tests) on its products. Depending on the type of test, they are assigned specific and unique numbers. And the products can be mass-produced after being accepted in testing. Some examples of these tests are listed below:

1. ISO (International Organization for Standardization)

ISO 9073-3-1989: Determination of the breaking and extension force.

2. ASTM (American Society for Testing and Materials)

ASTM F355-01-A: Test Method for Shock Absorption Properties

ASTM F1292: Test Method for Impact Attenuation of Playgrounds

3. AS / NZS (Australian Standards)

AS / NZS 2111.2: Determination of thickness loss under the dynamic load of textile floor coverings.

4. MRSA (Methicillin-Resistant Staphylococcus aureus)

MRSA A129 (Staphylococcus Aureus): A wide range of microorganisms, including bacteria, molds, yeasts, and algae.

5. EN (European standards)

UNE-EN 12633: 2003 - Method for determining the value of slip/slip resistance of polished and unpolished floors.

UNE-EN 1177: 2018 + AC: 2019 Shock-absorbing surface coatings for play areas

6. DIN (German Institute for Standardization E. V.)

DIN 18032-2: shock absorption. Sports halls. Rooms for gymnastics, games, and multiple uses. Part 2: Flooring for sports activities. Requirements, tests (Pre-standard).

A list of related international and European norms is provided in appendix A.

SHOCK ABSORPTION SURFACE COATINGS FOR PLAY AREAS- UNE-EN 1177: 2018 + AC: 2019

Test methods for determining impact attenuation

This European Standard specifies a method to determine the impact attenuation[47] of the playing surface. Define a "critical fall height-HIC[48]" for the surface, representing the upper limit of its effectiveness in reducing head injuries when using playground equipment according to EN 1176. The test methods described in the European Standard are applicable for tests performed in a laboratory and for tests on site.

Generalities

The equipment consists of: a test head equipped with one or more accelerometers, optionally a signal conditioner, a test head release system, a device to measure the real height of free fall, a signal transmission system, and equipment for measuring the impact. A uniaxial accelerometer is used; an ahead guidance system must be prepared.

G-MAX & HIC & CFH

G-max test (BODY IMPACTS) is a method used to measure shock attenuation characteristics and performance of a sports surface. It refers to an outcome in gravities which is the proportion of the maximum acceleration or deceleration that is experienced by the body during an impact (Figure 3-17). It applies both to natural and artificial playing surface systems, and a good and high result shows that a playing surface has low shock attenuation properties. G-max does not correlate with heading injury. G-Max is a good evaluation system used in conjunction with the HIC tests, but a stand-alone test does not show enough safety of a sport or playing ground. The endurance for outcomes is determined in ASTM Standards F355 and ASTM 1936 or ASTM F1292 that need G-max rates to be less than or equal to 200 (That's the number is determined to be critical for a head concussion.), and HIC rates to be less than or equal to 1000.

The Head Injury Criterion (HIC) is an international scale of the probability and severity of a head injury arising from an impact. The HIC test can be utilized to determine safety related to vehicles, personal protective accessories, and sports or playground equipment. The variable is deduced from the measurements of an accelerometer settled at the center of the dummy's head of a crash test when the dummy is subjected to impact forces. The protocol was established by the American Standard for Testing Materials- ASTM[49]. F355-E and measurement of the severity of a head injury liable to occur with an impact, determined as described in chapter 5 of the DIN EN[50] 1177: 2018 standard. The HIC Impact Test drops a 9.9 lb. hemisphere projectile and allows measuring the force of a human head when it hits a playing surface. Signals emitted by the head accelerometers during each impact are processed to determine the severity derived from the measured impact measure, defined as head injury criterion (HIC). The device can work with wire or wireless. According to the standard domain, the head impact must not exceed from Head Injury Criterion (HIC) of 1000 (Figure 3-17) units and the process defined by the following equation:

[47] Impact attenuation: Properties of a surface to dissipate the kinetic energy of an impact through a deformation or a localized displacement that allows acceleration to be reduced.
[48] Critical Fall Height (CFH): Maximum free fall height for a surface to provide an adequate level of impact attenuation determined by test method in EN 1177: 2018.
[49] https://www.astm.org/
[50] https://www.aenor.com/normas

$$HIC = [(t_2 - t_1)[\frac{1}{(t_2 - t_1)}\int_{t_1}^{t_2} a(t)dt]^{2.5}]max \quad 3.1$$

t_1 : Initial integration time; t_2: final integration time; a(t): time history of the total acceleration for the head strike; (t): is in second, and (a) is in units of gravity (g).

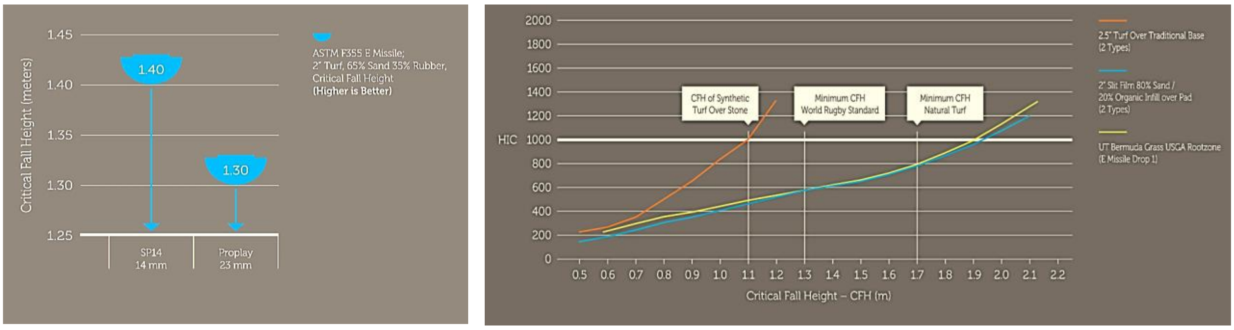


Figure 3-17 Schematic of CFH and HIC diagrams [51]

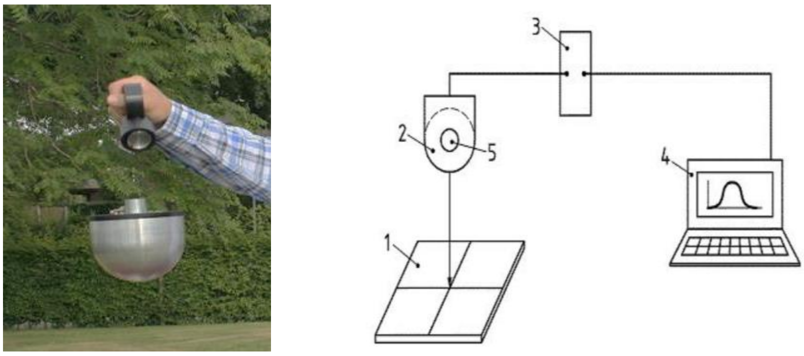
HIC and **G-max** was a method used in this research as a standard approach to validate the performances of the tiles.

CFH (Critical Fall Height) is defined as the distance of the highest point of the playground equipment, such as the slide, the monkey bars, swing, etc., to the surfaces installed on the playground (the maximum height that one can fall to the ground). Manufacturer of rubber flooring is seriously and strictly tested their product to meet safety standards (Figure 3-17 and Figure 3-18). The method consists of a specific object containing an accelerometer that drops from a defined height. How much of the impact is absorbed by the surface is the consideration. Generally, the easiest method to increase the magnitude of the safety surfaces is to increase the thickness of the layer. The greater the CFH, the thicker the rubber surfacing will be required to install. It is estimated that quality natural-grass turf has a critical fall height between 1.7-2.2 meters.

<u>On-site testing</u>

The tests can only be carried out when the surface temperature is between 5°C and 55°C. Temperature and all relevant weather conditions shall be measured and recorded throughout the test, e.g., humidity, dew, etc. The test head is dropped from at least four progressively higher fall heights, each in a previously untested position, uncompact, checking that the material is at the same layer depth at each test position, and the results are recorded.

[51] https://www.deltecequipment.com/



1-Test specimen
2-Test head
3-Signal conditioner (as appropriate)
4- Computer
5-Accelerometer

Figure 3-18 Test bench for determining the critical drop (UNE-EN, 2019)

SLIP-RESISTANCE (SLR)

Floor slip resistance (SLR) testing (or resistance to slip accidents or floor friction testing) is a strategy to measure the coefficient of friction of flooring surfaces. The surface can be tested in a laboratory (to be validated before or after installation) or on floors in situ. The SLR test is usually desired by the owners when they received a report of a slip near an accident or after a fall accident. Flooring using a tribometer[52] (floor slip resistance tester) to discover the rate of a propensity for slip and fall accidents on the surface either dry and/or (most often) when wet. There have been various standard floor SLR testing tribometers and lab devices to evaluate the static (stationary) and dynamic (in motion) coefficient of friction, but there are only a few that official has been proven for gaining safety results. Each different slip test device will have its safety criterion.

The test procedure required from the *SUA DB* (Technical Building Code (CTE) basic document), because according to statistics and evidence, one of the main reasons for the fall in the elderly is slippery surfaces. This test method makes us more accurate in identifying high-risk areas to solve the problem. An alternative method is also established based on the risk in dry areas. The Administration considers that it complies with the basic SUA1 requirement regarding the risk of a slip in those areas.

This document is complemented by a list of safe floors that comply with the SUA1[53] requirement to the extent. They significantly limit the risk of falls due to slipping. These floors can be used in any area of the building without the need to perform the test (as long as its surface is not modified with a subsequent treatment such as brilliant, polishing, etc.).

Flooring performance against slipperiness

The risk scenarios are contemplated within the requirement of safety of use and accessibility. It must be taken into account when disposing of a floor are the following:

- In dry interior areas: the risk considered in dry interior areas is that of dry slip, considering that when a floor accessible by the public and located in a dry interior area is occasionally wet, for example, during cleaning, it is appropriately signaled.
- In humid areas (both indoor and outdoor): the risk considering in humid regions is that of slipping with contaminant water, so, taking into account the exclusion of risks related to working activities established in the Introduction section, section II, when in an activity other pollutants

[52] A tribometer is a measurement that measures the coefficient of friction between the substrate (between two surfaces in contact).
[53] https://www.codigotecnico.org/DocumentosCTE/SeguridadUtilizacionAccesibilidad.html DB SUA Sección SUA 1 Seguridad frente al riesgo de caídas. 1. Resbaladicidad

are used, or even the presence of them on the floor is foreseeable during the development of the activity, the corresponding specific labor safety conditions must be taken into account.

- Areas where users are generally barefoot: the risk considered in areas such as showers, swimming pool surroundings, and glass bottoms where the depth does not exceed 1.50 m, etc., that of slipping barefoot users.

Four test methods have been presented to assess the coefficient of friction of floor surfaces and include the following slip resistance test methods:

1. Tortus digital tribometer

The Tortus digital test method is based on dedicated or patented devices, which makes it ineligible and unqualified to be included in the ASTM standard list and has been accepted and used as a secondary standard by Ceramic Tile Institute of America[54] (CTIOA) since 2001. The test method devices are known as "drag-sled meters", which means that it slides across flooring with constant speed. It drags a piece of standardized rubber on the flooring under its power (Di Pilla, June 10–13, 2001). The value of friction created by the rubber (dry or wet flooring) is measured and calculated by the machine since it travels a predetermined path length (Table 3-2). An average number of dynamic coefficients of friction (DCOF) is calculated after completed several runs. the results are expressed as Coefficient of Friction (CoF). The Tortus method can perform many slip tests in a short period, dry and wet, using both hard and soft rubbers, and that is the advantage of Tortus compared to the pendulum method. In 2013, the Tortus III became an official part of the Australian floor slip test standard AS4586-2013 (Pilla & Vidal, 2002) (Safety Direct America, 2020).

Table 3-2 The dry floor friction slip resistance slip test (AS/NZS 4586)- Tortus floor slip resistance tester machine (SafeEnvironments, 2015)

Floor friction tester mean value	AS/NZS 4586 Classification	AS/NZS 4663 Notional* contribution of the floor surface to the risk of slipping when dry
≥ 0.40	F	Moderate to very low
< 0.40	G	High to very high

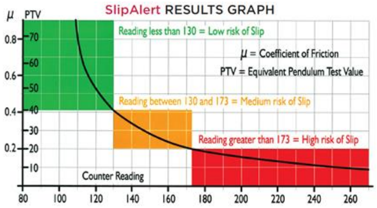
2. SlipAlert slip tester

SlipAlert[55] is a roller-coaster type tribometer that is designed to imitate the readings of the pendulum (called the TRRL pendulum tester in the UK or British Pendulum). It now has an official British standard– BS 8204-6:2008 that has been used for field testing. The method needs a long path length of flooring to conduct tests, so that make it of limited use in a laboratory setting. It does not have an official American standard test method. It can also be used in wet and dry areas (as can the pendulum, which is used in the UK for wet and dry measurements). The system has a rubber slider beneath the car, which travels across the surface after running down a fixed ramp (SlipAlert, 2019). If the SlipAlert stops after sliding a short distance, then the flooring is slip-resistant, but if it slides a long distance then the floor is considered as a slippery flooring (Table 3-3). There is a digital monitor on the device that calculates the maximum distance the car has slid across the surface and a safety criterion graph that translates the results (Kim I.-J. , 2017) (Government Agencies, 2019) .

[54] https://ctioa.org/
[55] https://www.slipalert.com/

Table 3-3 SlipAlert Slip Resistance Test -Classification of floors according to their slipperiness- BS 8204-6:2008 (Authority-HSA, 2021)

Slip Potential	Pendulum Test Value (PTV)	SlipAlert Test Value (STV)
High Slip Potential	0-24	159+
Moderate Slip Potential	25-35	136-158
Low Slip Potential	36+	105-135



3. BOT-3000E slip tester

The BOT-3000E digital tribometer system is a drag-sled meter and can be run wet or dry. America's ANSI A137.1[56] and A326.3[57] are essentially for use of this method and are not patented. The 2012 International Building Code, does not certainly adopt ANSI A137.1 with respect to floor surface testing. Notable, the 2015 issue of the International Building Code no longer comprises any reference to this test. However, municipalities are free to create modifications and may choose to adopt the standard. The BOT-3000E has passed the ASTM F2508-13 standard published in 2013. It is presently made in the USA by a single manufacturer. Although this ASTM test method was constructed with positive intentions, the test is often run and calculated by people who have a vested interest in their tribometer having passed the test. The BOT-3000E runs a test without any manual input except for setup and the pressing of a dedicated button (Frantz, 2016, Jun 9-10). The device includes many properties that help in validating a test as to time, date of the last manufacturer calibration, the last verification by the user, the location number of test run, as well as test foot (slider), used, etc. These properties help create courtroom credibility. Leather and other test foot materials are also available for this instrument. The device travels along the floor under its own power without any primary force at a constant speed recording the resistance to slip of a standard sample of rubber fixed into the beneath of the device. It calculates dynamic friction at a lower speed than the pendulum method (Safety Direct America, 2020) (Leffler, 2015). It must be noted that to date, the pendulum slip resistance tester and the BOT-3000E machine both methods have passed the ASTM F2508-13 so we assumed these methods appropriate to this criterion and standard.

4. Pendulum Slip Resistance Test

The wet pendulum slip resistance test (UNE-ENV 12633: 2003 or AS/NZS 4586 Appendix A) is generally operated using a Wessex (the one used in this study) or Munro – Stanley London Pendulum Friction Tester. Based on the research conducted on the validity and the availability of the methods approved by international standards, we decided to use pendulum slip resistance system in this study.

The *Rd* (slip resistance) value of the sample, required from the SUA DB, is obtained using the friction pendulum as test equipment. The standard matching method used in this research described in

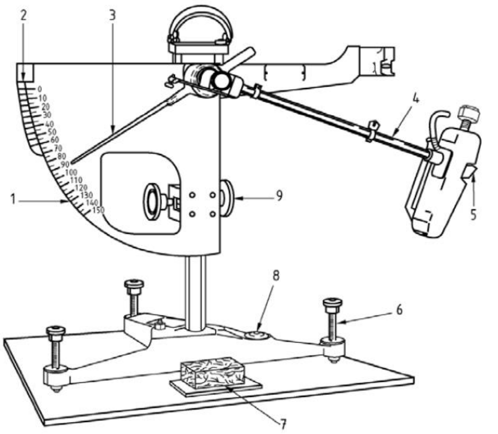
[56] A137.1 is a pass/fail test method using the BOT-3000E device for all level indoor flooring expected to get wet in use must have a DCOF of 0.42 or greater when wet to be acceptable for use. Barefoot floors, steep floors, or outdoor surfaces are not included in this test method. The 0.42 number is assumed a minimum, and many other parameters must be checked, according to the test method.

[57] ANSI A326.3 is nearly identical to A137.1 with adding more detail. A326.3 should not be used to estimate real-world slip risk but can be a useful technique to estimate changes in slip resistance due to wear, maintenance practices, and other parameters.

Appendix A of the UNE-ENV 12633: 2003 standard[58], to evaluate the friction properties of the test tube (Table 3-4). The device is portable and contains a weighted foot (sliding skate) that connects to a test slider. The pendulum slides across the surface when the surface is wetted with water. The friction pendulum (Figure 3-19) incorporates a sliding skate made of standard rubber fixed to the end of the pendulum. During the pendulum swing, the frictional force between the skate and the surface of the specimen is measured. The method measures the reduction of the length of the oscillation using a calibrated scale. The test is carried out with the test tube moistened under certain conditions of temperature and humidity. The C scale's calibrated scale represents the slip resistance for people, and the reading accuracy must be one unit.

<u>Determination of the value of slip/slip resistance of polished and unpolished floors</u>

Polished slip resistance value: The pendulum value of each specimen after polishing is calculated as the average of the two recorded values measured in opposite directions, adjusting to the integer closest to the scale. In the four specimens, if the difference between the highest and the smallest value is greater than eight units, another four specimens must be tested, and the average of the eight specimens must be calculated. The PSRV[59] value of the sample is the mean value of the pendulum obtained on the 4 (or 8) specimens after polishing.



1- Scale C (126 mm sliding length)
2- Scale F (76 mm slip length)
3-Marked needle
4- Pendulum arm
5- Rubber skate
6- Leveling screw
7- Test specimen
8- Bubble level indicator
9- Vertical adjustment screw

Figure 3-19 Slip Resistance - Friction pendulum[60]

<u>An alternative method in dry interior areas</u>

As an alternative solution, it is admitted that the risk of slipping in dry areas is adequately limited if the floor tested following the dry procedure described below has an Rd value greater than 40 for surfaces with a slope less than 6% and greater than 65 for surfaces with slope equal to or greater than 6% and stairs. To carry out the test in dry conditions, points 2 and 7 of section A.4.2 of Annex A of the UNE ENV 12633 standard must be modified in the indications in which water is added:

[58] UNE ENV 12633:2003: Method for determining the value of slip / slip resistance of polished and unpolished floors.
[59] Polished Slip/Skid Resistance Value
[60] Método para la determinación del valor de la resistencia al deslizamiento/resbalamiento de los pavimentos pulidos y sin pulir.

Table 3-4 Pendulum Slip Resistance Test -Classification of floors according to their slipperiness- Technical Building Code (CTE), Section SUA-1[61]

Slip Resistance Test-Pendulum Test -28.06.2019

According to the Technical Building Code (CTE), Section SUA-1 SECURITY AGAINST RISK OF FALLS, carrying out the test of resistance to slip / slip of pavements (USRV) with the wet surface with abundant water as indicated by the UNE ENV 12633: 2003 , the following classification is available:

Class required for the floors according to their location	
Location and characteristics of the floor	Class
Dry interior areas	-
- surfaces with slope less than 6%	1
- surfaces with slope equal to or greater than 6% and stairs	2
Wet interior areas, such as entrances to buildings from outer space *, covered terraces, changing rooms, bathrooms, toilets, kitchens, etc.	
- surfaces with slope less than 6%	2
- surfaces with slope equal to or greater than 6% and stairs	3
External areas. Swimming pools**. Showers	3

*Except in the case of direct access to areas of restricted use.
**In areas provided for barefoot users and at the bottom of the vessels, in areas where the depth does not exceed 1.50 m.

Classification of floors according to their slipperiness	
Slip resistance Rd	**Class**
$R_d \leq 15$	0
$15 < R_d \leq 35$	1
$35 < R_d \leq 45$	2
$R_d > 45$	3

- Point 2) indicates that "Immediately before performing the test with the friction pendulum, the sample is immersed in water at (20 ± 2) ºC for at least 30 min." For the dry test, it is only necessary to condition the sample at that temperature during that time but without immersing it in water. (CTE, 2020)
- Point 7) indicates that "The height is adjusted. The surface of the specimen and the rubber shoe is moistened with a large amount of water, taking care not to move the shoe from its previously fixed position. This operation is carried out a total of five times, re-wetting the specimen each time." (CTE, 2020)

For the dry test, it is not necessary to wet the surface of the specimen or the surface of the rubber pad when performing the test. The rules and standards of the restrictions defined for verifying floors are given in the (Table 3-4). The test was conducted with a specific device with a pendulum piece that works based on the coefficient of friction (CoF). The test was conducted in two main wet and dry areas, and the results were verified in four main classes (Table 3-4). A list of related norms and the standard test has been attached to Appendix D -Slip Resistance pendulum test.

The slip-resistance method was used in this research as a standard approach to validate the current flooring of the center (case study) and find the risky areas with more possibility of fall.

[61] https://www.codigotecnico.org/Documentos CTE/SeguridadUtilizacionAccesibilidad.html DB SUA Sección SUA 1 Seguridad frente al riesgo de caídas. 1. Resbaladicidad

3.2.2 THEORETICAL EXPLANATION OF IN SITE FLOORING EVALUATION METHODS

COEFFICIENT OF RESTITUTION MEASUREMENT (CoR)

The main aim of the test is related to the impact resistance and the coefficient of restitution. It is defined in turn as a ratio between the starting speed (rebound) after the impact and the metal ball's speed at the time of impact. The ISO 10545-5: 1998 standard establishes a method for determining the impact resistance of ceramic tiles by measuring the coefficient of restitution; we use the evaluation process found in the standard as a guide. The metal ball was used because it was the material used in the standard and being a rigid material and heavy enough to deform and show the flexibility and elasticity of the floors. Neglecting friction and the deformation of the sphere itself and applying the Kinematics equation expresses the conversion of potential energy into kinetics at the moment of impact. (Figure 3-20) We deduce the definition of the coefficient of restitution as a square root of the height reached by the metal ball in the rebound, which is as measured in the trial (or measuring the time between two consecutive rebounds).

The coefficient of restitution (C_R) is a measure of the degree of conservation of kinetic energy in a clash between classical particles that gives us information about the amount of energy lost in the elastic collision between a metal ball and a horizontal surface. This was discounting the energy lost in friction with air, and the deformation of the metal ball must be attributed to the deformation of the pavement surface. Being approximately constant the energies lost due to friction with the air, and due to the slight deformation of the metal ball, it comes to this result that the energy has lost in the first rebound metal ball after hitting the surface. It shows the force and energy transferred to the surface. Physics is used to deduce that this transferred energy. In this particular case that the collision is carried out against a horizontal static body, the velocity of the second body is zero before and after the collision because it is at rest, which allows simplifying the expression of the C_R quotient is:

$$e = C_R = -\frac{v}{V} \qquad 3.2$$

v is the speed of the object after impact

V is the speed of the object before impact

In the event of an object bouncing off a static target, the variation in gravitational potential energy (***PE***), during the impact is fundamentally zero; afterward, $\boldsymbol{C_R}$ is a measurement between the kinetic energy (***KE***) of the object instantly before impact with that after impact:

$$C_R = \sqrt{\frac{KE_{(after\ impact)}}{KE_{(before\ impact)}}} = \sqrt{\frac{\frac{1}{2}mv^2}{\frac{1}{2}mV^2}} = -\sqrt{\frac{v^2}{V^2}} = -\frac{v}{V} \qquad 3.3$$

In the case if the frictional assume zero and the object is dropped from rest and stationary situation onto a horizontal surface, the variation in ***KE*** is zero thus:

$$C_R = \sqrt{\frac{PE_{(at\ bounce\ height)}}{PE_{(at\ drop\ height)}}} = \sqrt{\frac{mgh}{mgH}} = \sqrt{\frac{h}{H}} \qquad 3.4$$

h is the bounce height

H is the drop height

For the test, a metallic ball is dropped from a height of ***H***. After hitting a frictionless pavement, the $\boldsymbol{C_R}$ value can be estimated knowing the maximum height ***h*** after the first bounce. It is assumed that ***H*** must be greater than h due to the loss of energy during the rebound process. H>h

$$V = \sqrt{2gH} \tag{3.5}$$

Where ***g*** (gravity) is the constant ground acceleration, on the other hand, the velocity after the rebound can be deduced from the maximum height reached ***h*** (considering the friction of the air is negligible), in such a way that:

$$v = -\sqrt{2gh} \tag{3.6}$$

That allows grouping both expressions of velocity in the previous definition in such a way that it will enable expressing the quotient $\boldsymbol{C_R}$ as a function of heights between two successive bounces:

$$e = C_R = \sqrt{\frac{h}{H}} \tag{3.7}$$

This formula has been used in the experimental determination of the coefficient of restitution.

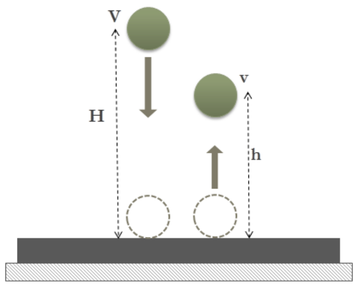


Figure 3-20 A ball rebound Ignoring air resistance-By Author

<u>Procedures</u>

To calculate this coefficient, the steel ball must be released from a height of 1 m above the exposed face of the test unit and allowed to bounce. The height of the rebound ball with an accuracy of +/- 1mm measure with the help of a suitable detector. The difference shows the coefficient of restitution (***e***). Any appropriate method can be used to measure the height of the bounce. The procedure repeat for all other floors.

If ***e = 0*** perfectly inelastic collision. If ***0 <e <1*** semi-elastic collision. If ***e = 1*** perfectly elastic collision.

The coefficient e presents values in the interval of real numbers that go from 0 to 1; that is, it satisfies the inequality. If its value is zero, a perfectly inelastic shock is assumed, while if ***e = 1,*** it is considered an elastic shock.

PRESSURE MEASUREMENT FILMS - PMF (FUJIFILM)[62]

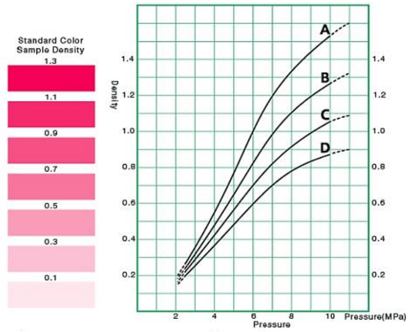
"*Prescale*" is the only type of film that could measure the pressure visually by the color density. It could easily calculate the distribution and the amount of pressure. It was created by using *Fujifilm's* advanced technology of coating a thin film. It visualizes the pressure distribution of the whole

[62] https://www.fujifilm.eu/eu/products/industrial-products/pressure-heat-measurement-film/

surface by changing its color to red according to the applied pressure. There are nine types of rolls to cover the wide range of pressure. "*Presheet*" is a sheet type of *Prescale* that is cut into A4 size beforehand. These sheets are very simple to use. It needs to insert the film to the surface you need to measure. Insert Presale between the surfaces you need to measure and apply the pressure[63]. Take off and check the color density visually (Fujifilm, 2021). There are nine types of Prescale and six types of Presheet (Table 3-5) (Figure 3-22)according to the pressure (MPa) range which is suitable for pressure measurements with different applications (Fujifilm, 2021).

Table 3-5 Prescale Sheet Types with standard color sample density[64]

Product (Code)	Pressure range [MPa] 1MPa≒10.2kgf/cm² (0.006, 0.05, 0.2, 0.5, 0.6, 2.5, 10, 50, 130, 300) / Pressure range [psi] 1psi≒6895pa (0.87~7.3, 7.25, 29, 73, 87, 363, 1,450, 7,250, 18,850, 43,500)	Roll Type Product size W(mm)xL(m)	Sheet Type Product size W(mm)xL(mm)	Typ
Super high pressure (HHS)		270 x 10	270 x 200 (5 sheets)	Mono-sl
High pressure (HS)		270 x 10	270 x 200 (5 sheets)	Mono-sl
Medium pressure (MS)		270 x 10	270 x 200 (5 sheets)	Mono-sl
Medium pressure (MW)		270 x 10	–	Two-sh
Low pressure (LW)		270 x 10	270 x 200 (5 sheets)	Two-sh
Super low pressure (LLW)		270 x 6	270 x 200 (5 sheets)	Two-sh
Ultra super low pressure (LLLW)		270 x 5	270 x 200 (5 sheets)	Two-sh
Extreme low pressure (4LW)		310 x 3	–	Two-sh
Ultra extreme low(5LW)		310 x 2	–	Two-sh

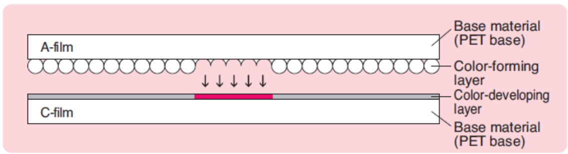


Two-sheet type (5LW~MW)

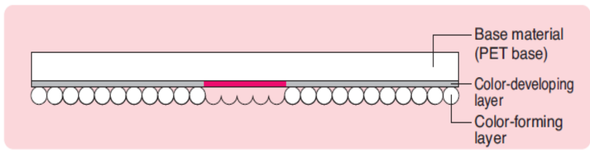
- Composed of two kinds of films: A-film and C-film

A-film: Base material (PET base) coated with a color-forming material (microcapsules)

C-film: Base material (PET base) coated with a color-developing material



(A)



(B)

Figure 3-21 Two-sheet type (5LW~MW) (A), Mono-sheet type (MS~HHS) (B)[65]

The coated sides of each film (color-forming and color-developing) must face each other. These are the sides with the matt finish. When pressure is applied, the microcapsules are broken, and the color-forming material transfers to the color-developing material and reacts, thereby generating a red color (Figure 3-21).

Mono-sheet type (MS~HHS)

- A color-developing material and color-forming material (microcapsules) are coated, one above the other, on a single base material (PET base) (Figure 3-21). When pressure is applied, the microcapsules are broken, and the color-developing material absorbs the color-forming material and reacts, thereby generating a red color (Fujifilm, 2021). Figure 3-22 is a representation of the process of scanning a sheet formed by impact.

[63] When using two-sheet type, be sure the matt-side of the two films will be put together.
[64] Notes: W in the product codes indicates two-sheet type; S indicates mono-sheet type.
[65] https://www.fujifilm.com/

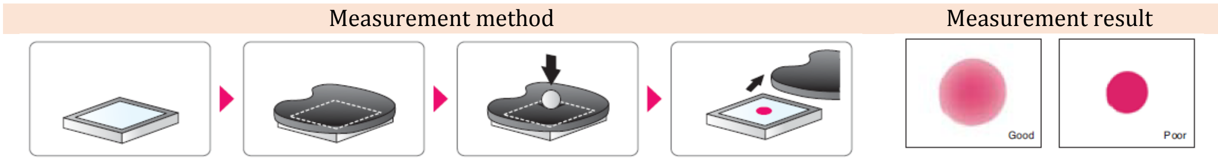


Figure 3-22 Wide range of application and measurements techniques[66]

There are two methods to evaluate the films after applying pressure. One using the manual sheet (Table 3-5) with the range of color and defined pressure (MPa), and the second method using a specific scanner (Figure 3-23) (Figure 3-24) to scan the sheets and import them to the *FPD-8010E* program on the computer (Corporation, 2009).

The FPD-8010E is a pressure imaging system that scans pressurization and converts it to pressure values. The types of *prescale* film manufactured by *FUJIFILM* that the *FPD-8010E* can measure are diverse. The impact will appear in the software in three color spectrums of red, yellow, and green. Each color shows:

- Pre-scale film sufficient speed (%): This is the ratio within the pressure sensing range of the pre-scale film. The red section (within the detection range) of the total surface area is reproduced in red, yellow, and green on the pressure bar. (Yellow is the part above the upper limit, and green is the part below the lower limit.)
- Pressured area (mm^2): The surface area where color is generated, including yellow and green
- Mean Pressure (MPa): Mean pressure of the area where the color is generated, including yellow and green.
- Maximum Pressure (MPa): Maximum pressure of the area in which the color is generated, including yellow and green.
- Charge (N): This is the charge value of the area where the color is generated, and implying that the product of the pressurizing surface area and the average pressure.
- Measured Area (mm^2): Displays the surface area of the area subject to processing by the FPD-8010E, the area specified and scanned with the scanner (Figure 3-23).

Figure 3-23 Prepare the colored prescale→ Scan Prescale samples→ Preform analysis utilizing *FPD-8010E* software[67]

All the techniques mentioned above are methods used in academic research and articles to force and pressure measurement applied to the surface or the human body. Some of the methods explained have been used in this research to validate the compliant flooring performances.

[66] https://www.fujifilm.com/
[67] https://www.fujifilm.com/

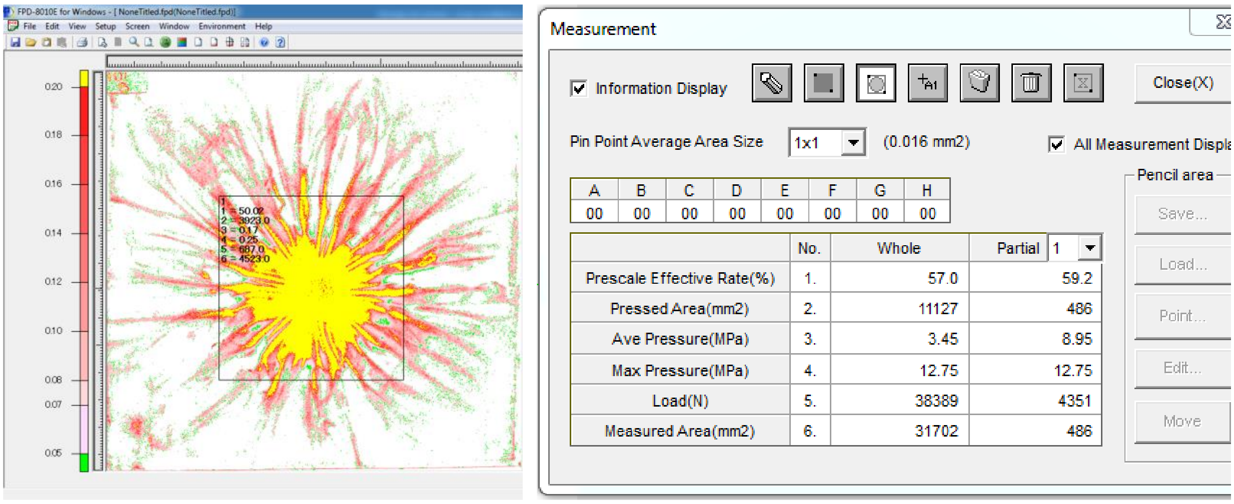


Figure 3-24 Sample Preview and Software results table -Source: FPD-8010E Software Screenshot-By Author

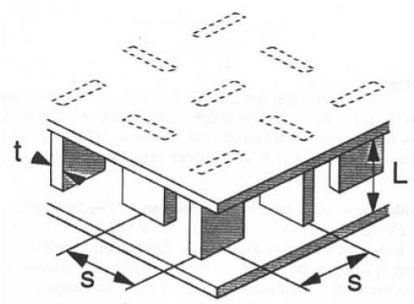
We used this particular method in our research with a premise and a hypothesis. After several trials and errors with different approaches but with the same hypothesis, we found these films to be referable. We proceeded with the assumption that tiles with the ability to absorb more force should usually show more color distribution on these sheets.

3.2.3 COMPLIANT FLOORING (CF) SYSTEM

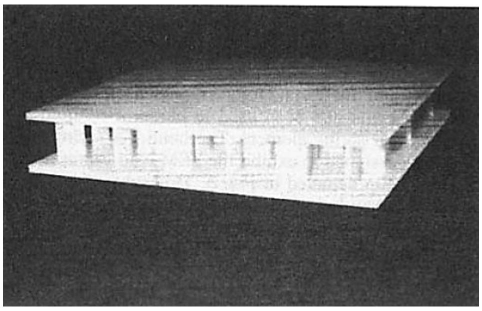
Along with features such as high durability, quick and easy cleaning, sound and heat insulation, etc., Anti-slip, anti-fatigue, and shock absorption are three salient features of safety floorings. Many flooring factories and companies provide a combination of different materials in the form of flooring to increase the security and aesthetic of the interior environment. As mentioned before, the shock absorption (Compliant Flooring-CF) property is a feature that is further explored in this research. Studies on compliant flooring or low stiffness floors (soft materials-rubber foam) as a type of safety flooring have been conducted by Laing and Robinovitch (Laing A. C., 2009) IT showed that these types of flooring could reduce the impact of energy applied to the hip when falling by up to 47 %. They also concluded that compliant floorings do not significantly affect balance and thereby not made the risk of falling higher. Wright and Laing (Wright, 2012) mentioned that compliant floorings decrease the peak acceleration, peak force, anHead Injury Criteria (HIC). Thereupon, safety floors can be an impressive interventional strategy to reduce fall-related injuries. The desired flooring material is soft when you fall onto it but firm when you stand and walk on it. The *Penn State Safety Floor, Kradal™, SmartCells™, and SorbaSHOCK™* are specifically designed to cushion the body at critical points and potentially reduce injury with entirely different materials, and structure have a good performance in a force reduction.

PENN STATE SAFETY FLOOR (PSSF)

The *Penn State Safety Floor* presents a new flooring system that can reduce peak impact to the hips when humans fall. The new idea is designed to keep the rigidity under normal walking conditions with just 2 mm of floor deflection during normal walking and deform elastically when impacted during a fall (Casalena J. A., 1998). The system is designed to minimize the peak force experienced by the hip during a fall. The idea of details and geometries of the PSSF flooring model (Figure 3-25) and the parameters in effects on flooring properties have already been made by Casalena (Casalena J. A., 1992).



(A)



(B)

Figure 3-25 (A) Rectangular cross-sectional column safety floor schematic, (B) Photograph of a complete rectangular column safety floor hand-fabricated prototype (Casalena J. A., 1998)

The structure of the design consisted of vertical rectangular cube columns between two flexible surfaces. The columns have the property to remain straight and unbuckled when a person walked on the surface. It showed the minimal flooring deflection occurs. The upright structure of adjacent columns supported lateral and torsional stability of the top surface during normal mobility. Still, upon impact, the design provided a reaction system for column buckling and upper surface deflection. In order to test the FEM of a buckling column, two groups of columns were evaluated. In terms of transverse sections, they have the same geometry in length and width of (1.65 mm) and (8.59 mm), respectively, but with two different heights of 17.4 and 14.2 mm. Polyether urethanes have been chosen in this study because of their excellent compression modulus, excellent impact characters, fatigue resistance, cut resistance, chemical resistance, hydrolytic stability, and finally castability. A 95 Shore A hardness yielded an appropriate equilibrium between stiffness and fracture hardness (Casalena J. A., 1992).

KRADAL™

The *KRADAL*™[68] Flooring was formed in New Zealand as part of *Acma's* replication to look into new formulations for absorbing force impact in fall prevention and floor product materials. The *Kradal*™[69] is 12 mm thick with the core of closed-cell, molded flexible polyurethane/polyurea composite tile (500 x 500 mm) an exterior layer of polyurethane/polyurea elastomers 1.5 mm thick. Tiles use *Dr. Schutz's*[70] surface coatings to color the floor and also "extra non-slip" into the floor (Figure 3-26). It has a stiff top surface over a layer of closed celled foam with thousands of micro-spheres that optimize cushioning impact[71] [72] and are durable and suitable for commercial and residential installation. This thin layer is made up of tiny cells of air, formed into a unique blend of cushioning yet stiff and capable of being covered by carpet or vinyl to provide beauty in a variety of final coatings. *Kradal* is based on a firm surface and soft underlay property for the international marketplaces of medical, seating, consumer, and transportation components. A rest home facility in the Swedish city of Karlstad is one of the implemented projects by polyurethane foam tile. The tile is designed with a hard surface and a rubbery foam base to cushion falls.

[68] http://www.kradal.co.nz/-2018
[69] The company is not currently active- http://www.kradal.co.nz/
[70] www.dr-schutz.com
[71] Kradal Flooring, "About us". [Online] Available: http://www.kradal.co.nz/about-us/kradal-flooring [Accessed 25.10.2016]
[72] Kradal Flooring, "Product specification CE brochure (CE-107)" [Online] Available: http://www.kradal.co.nz/product/brochures-reports/brochures- 1 [Accessed 25.10.2016]

Table 3-6 Kradal™ Floor tiles impact force reduction against various alternative surfaces in accordance with ASTM F344-01-A[73]

Comparison Material	Percentage* Reduction in peak force
Bare Concrete	About 65% to 80%
Bare Wood	About 65% to 80%
Carpet and Underlay over Concrete	About 20% to 40%
Carpet and Underlay over Wood	About 20% to 40%

Kradal provides a resilient surface for high traffic areas. *HealthGuard* antimicrobial treatment protects the floor surfaces against the expansion of yeasts, molds, algae, and bacteria. In the event of a fall, the force is outspread on the hardtop surface and then dissipated through the closed celled foam base layer. Researchers at *Otago University* tested tiles according to Standard ASTM (Table 3-6) *F355-01-A*[74] (Table 3-7).

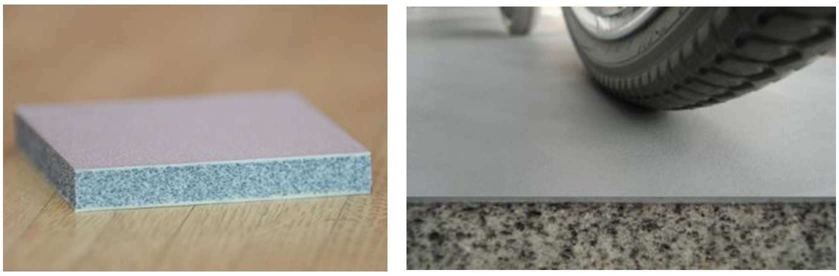


Figure 3-26. Kradal composit tile[75]

They noted *KRADAL* tiles reduced the peak impact by 65-80% compared to a hard surface such as bare wood/concrete and 20-40% compared to the carpet with underlay on concrete or wood. Fully recyclable, heat insulation and, Cost-effectiveness are some other benefits of Kradal tiles. The average results from the ASTM F344-01-A[76] testing are shown as follows (Table 3-6).

The study executed in a Swedish nursing home mentioned above contains 60 apartments with approximately 60 individuals. The residential care facilities had 24 h observation and medical care. Shock-absorbing flooring was installed in bedrooms, communal areas, living rooms, and corridors, but the flooring was not approved for wet areas such as bathrooms. The installed shock-absorbing flooring was marketed under the trademark Kradal, with 12 mm thick made of closed-cell flexible polyurethane/polyurea composite tile laid onto the subfloor (concrete). According to the product testing report, the Kradal product reduced the force by 65%–80% and showed no difference in gait stability compared to vinyl and carpet (Gustavsson J. C., 2015).

[73]https://www.architectureanddesign.com.au/getattachment/45dc01a8-70bc-4843-8aeb-6ad0fda82cee/attachment.aspx
[74] https://www.astm.org/DATABASE.CART/HISTORICAL/F355-16.htm
[75] https://doi.org/10.1371/journal.pone.0201290.g001
[76] https://www.astm.org

Table 3-7 Kradal Impact Absorbing Floor Tiles Testing Summary[77]

TEST STANDARD	TEST METHOD	KRADAL FLOOR TILES
Slip Resistance		
AS/NZS 4586	Wet Pendulum	Kradal Tiles X - Kradal Tiles Slip Resistant W
AS/NZS 4586	Wet Ramp	Kradal Tiles Slip Resistant A
Fire Ratings		
ASISO 9239 .1. 2003	CHF Critical Radiant Flux	Mean 4.8 KW/m2
ASISO 9239 .1. 2003	Smoke Value	Mean 239 %.min
Acoustic Ratings		
ISO 140-8	Reduction of impact sound pressure levels	Rating according to ISO 717-2: ΔL_w = 22 dB
Shock Absorbing Properties	**Comparison to Material**	**Percentage reduction in peak force**
ASTM F355-01-A	Bare Concrete	About 65% to 80%
	Bare Wood	About 65% to 80%
	Carpet & Underlay over Concrete	About 20% to 40%
	Carpet & Underlay over Wood	About 20% to 40%
Hardness	**Penetration of specific type of indenter when forced into material**	
ASTM D2240-05	(Shore) hardness Type A	70 - 80
Dimensional Stability	**Stability after exposure to heat %change**	
EN 434-2011	Average change = 0.04%	Pass Maximum change = 0.06%
Colour Fastness		
EN ISO 105-B02	Xenon arc fading lamp test	Pass
Wear Resistance		
EN 660-2	Part 2 Frick Taber Test Volume Loss mm3	Pass 1.5mm Group T
Effect of Caster Chair		
EN 425-2-2002	Determination of effect of Caster Chair	31 Commercial Moderate
Effect of a Furniture Leg		
EN 424-2020	Determination of effect of movement	No Damage 31 Commercial Moderate
Residual Indentation		
EN 433-1994	Residual indentation after static loading	0.03 31 Commercial Moderate

SMARTCELLS™

The *SmartCells*™ [78] (United States, Washington, DC Patent No. US7575795B2, 2009) Floor Tiles come from a US company, and their flooring system consists of synthetic rubber with a continuous top surface attached to cylindrical cells base layer. The cells are compressed during the application of force. Investigations results showed that the safety floors reduced the fracture rate from 2.4 % to 0 % (Figure 3-27). *Smartcells* with a preferably continuous array of elastomeric subsurface structures can use beneath a surface layer such as artificial turf, poured urethanes, vinyl, carpet, or other synthetic Surfaces. *Smartcells* can be installed on a hard surface with a high risk of fall, such as on athletic fields for football, soccer, baseball, school playgrounds, daycare centers, and playgrounds and the like to minimize injuries that are likely to occur in such environments. The elastomeric subsurface structures are composed of continuous array units.

[77] https://doi.org/10.1371/journal.pone.0201290.g001
[78] https://www.smartcellsusa.com/

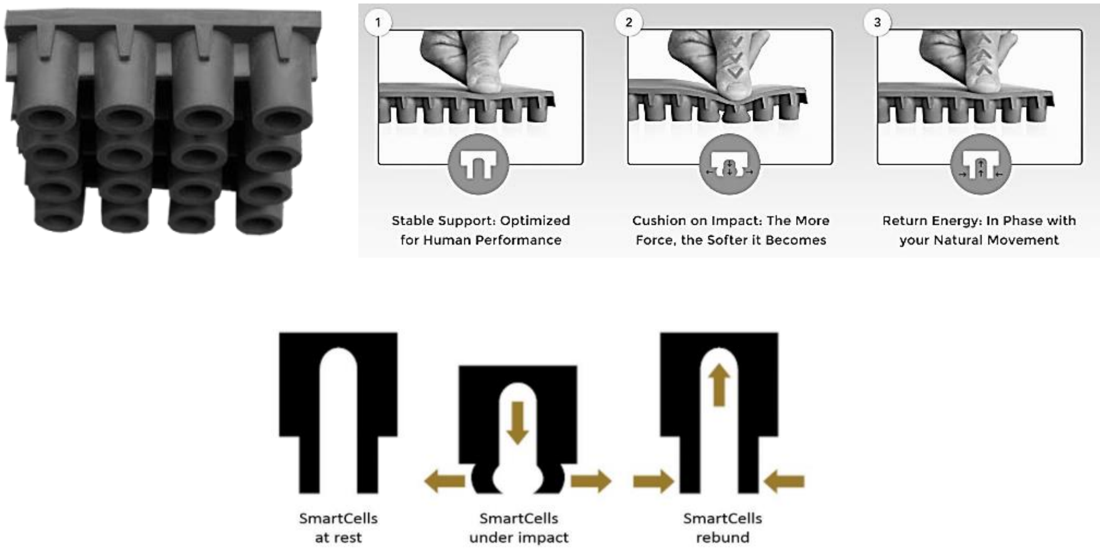


Figure 3-27. SmartCells-Loading and unloading function[79]

The geometry used in this product is cylindrical that surrounding avoid. The void is optionally surmounted or topped by a dome. The array of defined structures is a relatively more stable, less deformed surface layer that does not cause foot entrapment and provides practical impact and bottoming-out support.

The substructure is composed of series of resilient cylindrical columns with the wall surrounding a central void in the column. A dome covers the top part of each column, and the hole opens at the bottom of the column. The column has two connected sections. The wall in the bottom region of the teaches column is more compressible with more flexibility, relatively collapsible zone. And in an upper area of the column wall has a less compressible, relatively un-collapsible Zone. The flex more at the lower part of the sub-structure than at the top system leads to decreasing foot entrapment influences and provides higher support against bottoming out and a more stable work surface. The horizontal cross-section of each unit can be shaped in any geometry such as hexagon or octagon, etc.

Smartcells system with an elastomeric substructure flexes under force or impact. It provides a surface condition that attenuates overall foot and leg fatigue, standing workers, and impact force and severity of the hip fracture from a falling hip. The surface treats like a stiff spring, depending on the contact area and the curvature of a body contacting it. The surface system gives a feeling of softness underfoot when standing or walking as the load (the person's weight) is applied to the surface, but that naturally instantly returns to its resting position after the worker moves to another location on the surface (Figure 3-27). In the ASTM F-355 standard test methodology, there are two essential approaches to measure the shock attenuating characteristics of a surfacing system. The G-max of 200 and the Severity Index of 1,000 are internationally accredited as the risk threshold for a concussion in the event of a fall.

[79] https://www.smartcellsusa.com/

SORBASHOCK™

The *SorbaSHOCK Dual-Stiffness*[80]™, with a one-inch thickness (2.5cm), is a technology that maintains its rigidity and remains stable during everyday activities and walking forces. The force transfer through a network of specially-designed columnar construction, which then buckle, deform and dissipate energy in a controlled manner when impact (and the larger associated forces) occurs. Foam core provides additional energy dissipation after the columns buckle, further reducing the forces associated with a fall (Figure 3-28). This passive energy absorption device is installed underneath standard commercial carpet or vinyl flooring, retaining the durable and aesthetic finishing layer appearance of standard floor surfaces. Other features can be noted for its acoustics, wheelchair occupied with ~ 200 lb individual, minimal load deflection, and minimal induced rolling resistance (Sorbashock, n.d.).

Another critical factor of the flooring structure is the flexural modulus related to the flooring plate. The flooring plate (plate: a top layer or plurality of layers that may or may not be integrally formed with the columns) is generally the top and a cover layer of the flooring structure, located above the columns' arrays appropriate for physical contact with a user.

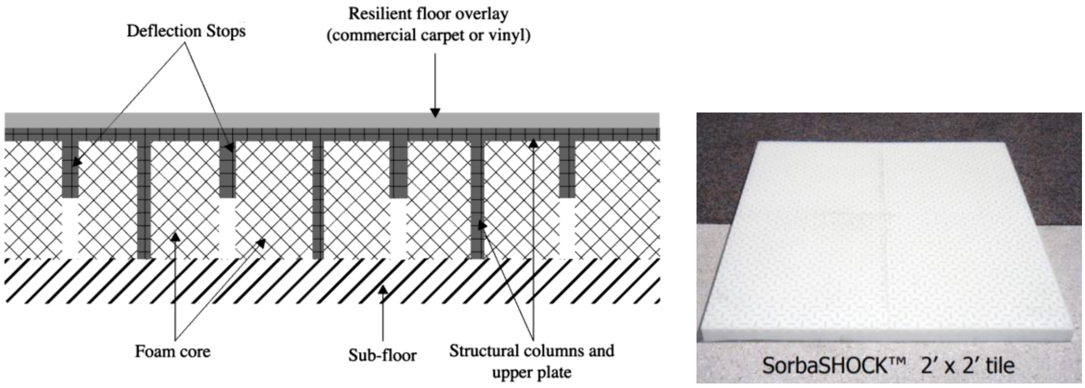


Figure 3-28. SorbaSHOCK flooring structure[81]

KTH FLOOR

A similar and very promising flooring solution has been developed at *KTH* (Figure 3-29) at the Neuronics Department[82] (2013-2018) by Prof. Svein Kleiven and Prof.Hans von Holst[83], aimed to reduce injuries in the advent of a fall. The flooring structure consists of rubber studs aligned on multiple lines in the middle layer between the top surface and the underlay. The tile supports the walking surface. It is made out of flexible rubber polymer and has a smooth layer with pins attached. The thin pins are designed to bend when high loads are applied, i.e., during a fall, making the floor flexible and softer than allowing relative movement in different directions between the layers to make a higher impact shock absorption possible. After the removing load, the floor configuration goes back to its initial shape and remains straight (Sweden Patent No. WO2011141562, 2011).

[80] http://www.sorbashock.com/
[81] http://www.sorbashock.com/
[82] https://www.kth.se/mth/neuronik/
[83] Two professors at the department of Neuronics at the Royal Institute of Technology runs a project for two years with help from the foundation Flemingsberg Science and support from the innovation agency Vinnova in order to make it a commercially available product.

Figure 3-29. A prototype of the shock-absorbing floor was developed at KTH (Hilmarsson, 2018)

The structure enables the pins to remain straight when unloaded and compressed during force, making it force absorbing. The drop tests recorded by the *Technical Research Institute of Sweden* have shown comparing with wooden flooring, the reduction of applied force was between 60-75 % and reduced the acceleration between 39-66% (Okan J.-S. S., 2015). The floor has been set up in a care facility in Stureby in Sweden for months. The problems raised were that the floor makes it harder to move a wheelchair or trolley around, and the wheels or furniture can cause a permanent indentation in the floor if they remain at the same place for a while. Studies have indicated a correlation between the rolling resistance of a wheels' cylindrical shape and the wheels' width (Zhu., 2012). In equations (3.8)-(3.9), a formula for rolling resistance is given regarding the normal force applying on a wheel (Dorian A.H. Hanaor, 2015).

$$W=\frac{\pi}{4}Eb\delta \qquad 3.8$$

$$F=C_{rr}W \qquad 3.9$$

$$C_{rr} = \sqrt{\frac{\delta}{2r}} \qquad 3.10$$

W = normal force acting on a wheel, E = E-modulus of the floor, b = width of the wheel, δ = dept the wheel sinks into the floor (indentation), *Crr* = rolling resistance coefficient, r = radius of the wheel

By synthesizing these formulas, the following formula can be derived:

$$F=\sqrt{\frac{2W^3}{\pi Erd}} \qquad 3.11$$

F = rolling resistance, W = normal force, E = Young's modulus of the floor,

r = radius of the wheel and, d = width or thickness of the wheel.

In theory, by increasing the width or the radius of the wheels, the rolling resistance should reduce. And consequently, by increasing the surface area of the wheels, they create a lower indentation in the floor (Hilmarsson, 2018).

In this study, it was assumed that there would be no change in the design of the floors, and they focused on changing the design of the wheels. Therefore the formulas show that by increasing the width and/or the radius of the wheels, the rolling resistance should be decreased. And by raising the surface area of the wheels, they will not sink as much into the floor, thus, creating a smaller indentation in the floor.

In addition to CF system, there are methods by which useful information can be extracted from them by installing them on the floor surface. The basis of these smart layers is based on sensitive sensors that record movement and pressure. And they can be monitored according to the given settings. These floors do not have impact absorption properties and are not in the category of CF systems, but they are accommodating for observing the elderly and diagnosing falls. Two examples of this technology are given in the next section.

3.2.4 SMART FLOORING SYSTEM - SF SYSTEM

FLOOR IN MOTION - TARKETT

Floor-in-motion provided by *Tarkett* flooring[84] company is not compliant flooring, but it is a thin, sensitive sheet to determine the position and location of the fall. These roll of sheets contain sensors installed with acrylic glue on top of the clean, flat, sound, dry and solid subfloor in any area, even bath, and kitchen. Then they will be covered by the floor covering of vinyl, laminate, linoleum, PVC tiles, parquet, carpets, etc. Sensors are connected to an LED strip at the corner of the walls with cables. These cables are connected to the electronic box and emergency call system, showing the accident's location in a monitor in the nursing station (Figure 3-30).

Floor-in-motion Care dramatically improves the performance of elderly care centers through behavioral and safety research. *Floor-In-Motion* is a unique "smart" floor covering capable of recognizing and tracking patient movements and transmitting an alarm in abnormal or unusual situations. Benefits for patients and their families:

- Patients value this invisible system, which allows them to preserve their dignity and personal space, in contrast to more intrusive technologies such as video cameras and bracelets.
- Communication with an alarm facilitates a quick reaction of specialists in the event of a fall or other unhealthy situation. Such a system gives confidence to both patients and their families. It can be installed in bathrooms and high-risk areas for the elderly.

(A) (B) (C)

Figure 3-30 (A)Smart flooring (B) Monitoring the areas (C) The room lights up as soon as the connection is felt by the floor in the dark of night by LED lights.[85]

- The system is linked to automated equipment that provides comfort and safety. For example, if the patient rises at night, the flooring detects his movement by transmitting a signal to the LED

[84] https://www.tarkett.com/
[85] https://www.tarkett.com/

baseboard, which in turn lights up and signals an alarm. Moreover, when the lights come on in the event of a fall, the patient will know that the safety system are activated.

SENSFLOOR- FUTURE SHAPE

German firm *Future-Shape*[86] has developed a sensor floor system (*SensFloor*) that records the movement patterns of persons (Figure 3-31). The method is used to detect falls. The technologies are integrated into the environment due to the program and its sensitivities, such as cameras, microphones, or barometer sensors installed under the pavement, carpet, or even at a certain height from the wall. The researcher tries to propose a system by sending an alarm when a person falls or is about to fall with minimal error. The system record and evaluate customer paths, speed, and duration of stay in real-time concerning privacy, and only movement paths are recorded.

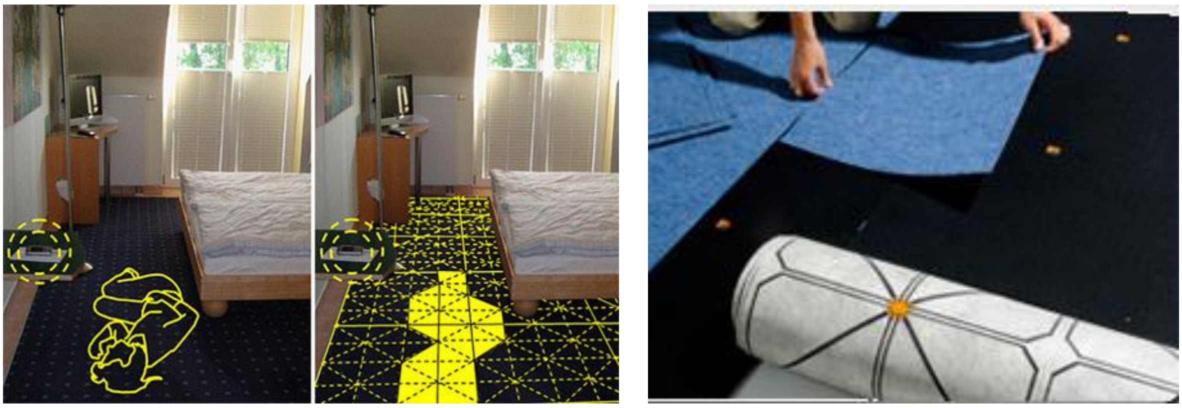


Figure 3-31 Floor with sensors - *Sensfloor* (Matt, 2014)

The nursing home staff can monitor the activities in the entire ward via the *SensFloor.* On the station terminal, the staff recognizes when a resident gets up to help if needed. If a senior falls, an alarm system is triggered immediately. *SensFloor* is invisibly able to be installed beneath all types of flooring (PVC, Laminate, parquet, and Carpet) (Matt, 2014).

SensFloor is a good way of monitoring people living alone or the elderly based on the area of disturbance to the electric field. The sensors can distinguish the condition of a person if standing or lying on the floor. It can even determine the difference between a liquid spill and a person. Each square meter of the system (fabric) includes four radio modules and proximity sensors that can track the speed and direction of a person's movement. It can track the activity of several people at the same time, even those in wheelchairs or carrying a trolley. The information is then transferred to a separate control unit.

3.3 ARCHITECTURAL EFFORTS AND PROGRESS

Indoor environmental quality (IEQ) of treatment and care spaces and the effects on safety, satisfaction, and quality of care is always one of the concerns of architects. Many investigations have been done by medical engineering departments and geriatrics focusing on biomechanical effects, Cost-effectiveness, and clinical effectiveness. The majority of research records were from the United States, Canada, and the United Kingdom, and few numbers belong to Sweden, New Zealand, Japan, and Australia (Svensson & Ryen, 2015).

[86] https://future-shape.com/

Research particular to the influence of flooring material on patient environments has previously focused on: aesthetic, durability, healthcare-associated infections (HAI), falls and fall-related injuries, staff injuries, noise, fatigue, air quality related to volatile organic compounds (VOC), semi-volatile organic compounds (SVOC), and cleaning (Harris D. , 2017).

Unfortunately, in the field of architecture, no architectural researcher has researched safe flooring. Architects only use products on the market in their designs. The choice of architects is based on the function of the designed spaces and materials that can meet the environment's needs and the employer. According to interviews conducted by the author with many architects, when it comes to safety flooring, most of their focus was on anti-slip, and the surface was smooth with no bumps or dents that caused it to fall. In the design department of hospitals and clinics, they also mention durability (due to high traffic and constant washing with detergents, antimicrobials, and bacteria) and measures to make them anti-slippery. Everyone is aware of the dangers and injuries of falls, whether in medical centers or nursing homes. Still, they do not have a specific opinion about the existence of products with the ability to absorb impact during the fall because there are no products on the market except rubber products for children and this. In contrast, a study on a medical center with the criterion of entering theoretical and experimental studies from 1982 to 2012 has shown that 79.5% of falls occurred in the patient’s rooms, 11% of falls in patients ’bathrooms, and 9.5% in hallways, exam or treatment rooms, or by the nursing stations (Krauss, 2007).

Regardless of the aesthetic aspect, the function of an area is the first important point for an architect. The purpose of the floor is to provide a clean horizontal surface that is strong enough to withstand the loads mounted. The strength of the floor depends on the type of flooring in the environment. Hard flooring includes materials such as marble, ceramic tiles, and cement/concrete. Soft flooring contains materials such as false flooring, PVC flooring, or vinyl. Vinyl flooring or hospital antibacterial flooring is the most commonly used product. Healthcare design is about creating a safe and clean environment, and a stimulating environment builds confidence and a sense of well-being among patients, staff, and visitors. When it comes to room space, most of its functionality is categorized, whether dry, wet, or specialized. Critical considerations such as infection control, stability, ease of cleaning, slip resistance, and acoustics are considered. Health is important in a health center, and to prevent entering dirt, all joints can be welded and sealed to provide a seamless finish. Unwanted noise control is also important in creating a quiet environment, and using the acoustic floor covering is one way to reduce noise levels.

Floors must be resistant to cleaning and disinfecting chemicals. Choosing a color, many people mistakenly believe that floors in hospitals should be white. This is somewhat true because bright colors enable site cleaners to detect stains and dirt quickly. However, this need is not always possible with white. Beige, pink, blue, and other colors can successfully replace white because it calms patients and staff. Beige and honey hospital antibacterial flooring is convenient and also gives the patient a feeling of warmth. Hospital roll flooring may cause adhesion problems, cracking, discoloration, and dimensionality. And the most common positive characteristics of hospital antibacterial flooring include comfort underfoot, acoustics, durability, and easy cleaning. Vinyl Composition Tile (VCT) is commonly considered to be the most affordable for the primary expenses and durable. Still, it requires steady maintenance, and the long-time expenses are of concern (Harris D. F., 2015). Sheet vinyl has a lower stability than VCT and, therefore lower durable but provides a closed seam and gaps between connections, decreasing the hazard of subfloor contamination. The positive points of Linoleum are that it is natural and has renewable resources. It is antistatic and antimicrobial but is vulnerable to water and typically needs a sealant, negating the antimicrobial properties (Harris D. D., 2015). Rubber is perfect water-resistant, burn resistant, and it can be prepared and presented in various colors, but it imposes the initial expenses and is easily stained. A more recent study that focused on initial costs, annual repair, and maintenance fees, noted that hard and resilient floors cost more than twice the carpet tile cost. (Harris D. F., 2015)

Table 3-8 Summary of Research Studies about Healthcare-Associated -By Author

Summary of Research Studies, Their Interventions, and Outcomes, about Healthcare-Associated Infections (HAIs) (About Slips, Trips, Noise, Falls and Flooring, and Fatigue and the Role of Ergonomics in Patient and Healthcare Worker Safety)	**Citation**
• Staff preferred vinyl because of perception of ease of maintenance. • Patients preferred carpet in their rooms citing comfort, slip-resistance, and less noise. • Staff perceived rooms with vinyl to be cleaner, have better odor, ventilation and fresher air; conceded that carpet may be more comfortable, have less noise and glare, and fewer shifts in temperature. • Patients in rooms with vinyl perceived their rooms to be cleaner, have better ventilation and fresher air, but those with carpet tiles perceived their rooms to have better temperatures (comfort). • Visitors spent a significantly longer amount of time in rooms with carpet tiles compared to rooms with vinyl ($p < .05$) • Bacteria samples suggest that the vinyl flooring is cleaner than the carpet tile. • Rooms with vinyl had higher levels of airborne bacteria colony forming units than rooms with carpet tile. • No significant differences were found in levels of noise, temperature, carbon dioxide, and total volatile organic compounds between rooms with vinyl and carpet tiles. • 56% of the patients met the criteria for risk of falling. • According to the medical chart data, nurses were twice as likely to assign a patient at a risk for falling in rooms with vinyl, compared to the patients assigned to rooms with carpet tiles. The increased number of patients designated at risk for falling in rooms with vinyl suggests that the nursing staff perceived the floor as a factor in determining the level of risk for their patients.	(Harris D. D., 2000)
• DNA sequencing conducted on swab samples successfully identified bacteria harbored in the carpet tile, non-tile carpet, resilient flooring and other surfaces present in the hospital corridor. • While the profile of the carpet tile contained the highest number of identified different species and total species, the backing contained the lowest number of species and exhibited a decrease in diversity over time. • No DNA sequence retrieved from the carpet tile was closely related to bacterial pathogens, suggesting that the carpet tile was protected from pathogens. • Samples from the resilient flooring, a nurse's shoe sole, and a wheel of a patient's bed revealed DNA sequences from known or potential nosocomial pathogens.	(Alexandre, 1998)
• Specifically focusing on the flooring samples, this study showed that before cleaning, the inoculated carpeted surfaces had the best reduction of bacterial growth for vancomycin-resistant Enterococci (VRE) after 24 hours. • Rubber, linoleum and sheet vinyl did not have a reduction in bacterial growth of VRE at 24 hours. The level of contamination on vinyl composition tile (VCT) remained constant after one week. • All of the flooring surfaces had reductions of Pseudomonas aeruginosa (PSAE) at 24 hours and continuing after one week. • When evaluating the healthcare worker transmission of VRE, carpet samples performed better than smooth surface flooring. Sheet vinyl with welded seams was the poorest performer.	(Lankford, 2006)
• The commercial-grade, low pile, tightly woven carpet did not negatively impact static balance, suggesting that carpeting may not be a fall risk factor.	(Dickinson, 2002)

• Gait speed and step length were significantly greater on carpet than on vinyl (i.e., walking was more efficient on carpet). • After the flooring test, some patients indicated a fear of walking on vinyl, but were confident on carpet. • None of the patients studied expressed difficulty in walking on carpet	(Willmott, 1986)
• Most of the accidents happened within the hospital unit while they were moving or transporting patients and equipment because of falls due to a slippery floor.	(Alexandre, 1998)
• Surface stiffness affects the impact force of a fall, suggesting that compliant surfaces may prevent wrist injuries during falls at standing height or lower.	(Robinovitch S. N., 1998)
• Over a 2-year period, 6,641 falls and 222 fractures were recorded. • The fewest number of fractures per 100 falls were on carpet installed over wood floors. • The risk of fracture resulting from a fall on a carpeted area was significantly lower compared to all other floor types.	(Simpson, 2004)
• The differences between mean forces for each of the floor coverings were highly significant, with thicker coverings producing 7% lower forces.	(Gardner, 1998)
• During the first 2 hours, no significant differences were noted. In the 3rd and 4th hours, floor type had a significant effect on the number of subjective ratings, including lower leg and lower back discomfort and fatigue. • Objective ratings indicated that lower extremity swelling was greater on hard floor surfaces. Increased elasticity, decreased energy absorption, and increased stiffness resulted in less discomfort and fatigue, supporting the suggestion that flooring properties do affect lower back and leg discomfort and fatigue after 3 hours of standing.	(Cham R. &., 2001) (Redfern M. S., 2000)
• Coefficients of rolling friction were estimated at 2.2, 2.4, 3.3, and 4.5 MM for hard rubber wheels rolling on smooth concrete, tile, asphalt, and industrial carpet floors, respectively. • Although the results varied, the differences were not statistically significant between the push and pull forces based on the flooring materials.	(Al-Eisawi, 1999)
• Consider using carpet in patient rooms and/ or corridors in an effort to (a) minimize air borne bacteria; (b) help mitigate the survival of bacterial pathogens on the floor; and (c) reduce transmission of infection from flooring surfaces to people. • Consider using carpet in patient rooms and/ or corridors in an effort to (a) help elderly patients feel more confident while walking with less fear of falling on a slippery floor (b) reduce patient and healthcare worker falls; and (c) reduce the impact force when a fall occurs by providing a softer surface. • In an effort to reduce stress and create a positive healing and work environment design with a goal to limit sound transmission and noise as a priority for all users and use as many sound absorbing interior materials as possible, such as carpet in patient rooms and corridors. • Consider using carpet in patient rooms and/ or corridors in an effort to encourage visitors to stay longer with patients in their rooms for social support.	(Harris D. D., 2013)
	(Topf, 1985)

• Sensitivity to noise was found to significantly influence the level of patient disturbance. • Results suggest that well-being may affect a patient's sensitivity to environmental stressors in addition to the stressors themselves. • Findings indicated that acoustic modifications in the design of the hospital, furniture, and equipment should be a consideration in limiting stress from noise.	
• Of all the researchers' recommendations, only one is linked to flooring that materials and surfaces should be chosen to limit sound transmission from the nursing station.	(Solet, 2010)

Operating room flooring, radiology, and X-ray rooms, CT scan and MRI rooms, hospital recovery, computer rooms, rooms containing electrical equipment, clean rooms, etc., which leading equipment consists of electronic devices must have flooring with anti-electrostatic conductive properties (anti-static flooring). Conductive anti-electrostatic flooring is necessary to conduct electrical potential to the ground. Due to electrical disturbances and fluctuations, both devices and equipment may be damaged in such environments, and there is a risk of death for operators and employees.

Anti-electrostatic flooring is also more durable and has high abrasion resistance, stain resistance, and easy cleaning in busy places. Integrated and seamless coating, including pigments with different colors, waterproof, containing free solvent, including conductive fillers for electrical conductivity is another advantage of this type of flooring. Due to advanced electrical conductivity properties by black and white carbon particles injected into the vinyl flooring, transmit static electricity to the building's earthling system through an electrically conductive adhesive and a working copper mesh embedded under the flooring (at runtime) (HFG, Part C-2015). Vinyl flooring has many advantages over other floorings. The operational requirements of a hospital environment are inherently complex. The choice of flooring should meet the standards of application and aesthetics in different spaces. Hospital vinyl flooring is available in a wide range of appearance, texture, and functional characteristics. Many medical centers today choose vinyl due to its durability, waterproofness, and ease of cleaning. The smooth surface is suitable for wheeled and moving loads. Vinyl flooring is a multifaceted floor because of its flexibility, durability, performance, and efficiency. The interesting thing about vinyl flooring is that it provides a reasonably uniform coating due to the weld seam of the flooring. Commercial vinyl flooring with technical specifications such as durability and stain resistance (especially in the hospital) is functional. Some commercial grade vinyl flooring is used for high-traffic, non-slip public areas (Harris D. , 2017) (Table 3-8).

3.4 FINITE ELEMENT MODEL-FEM AND SOFTWARE IMPLEMENTED

The finite element method (FEM) is a numerical resolution technique for receiving approximate solutions to extensive diversity of engineering issues. A finite element model of a subject presents a piece-wise approximation to the controlling equations. The fundamental premise of the FEM is to provide a solution area that can analytically be modeled or approximated assemblage of separate parts (discretization). Since these parts can be put together in different approaches, they can be used to model complex shapes and geometries (Figure 3-32). Typical applications for this simulation method include *ANSYS*[87], *ANSYS LS DYNA*[88], *MSC/NASTRAN*[89], *RASNA*[90], *SDRC-Ideas*[91], and *ABAQUS*[92].

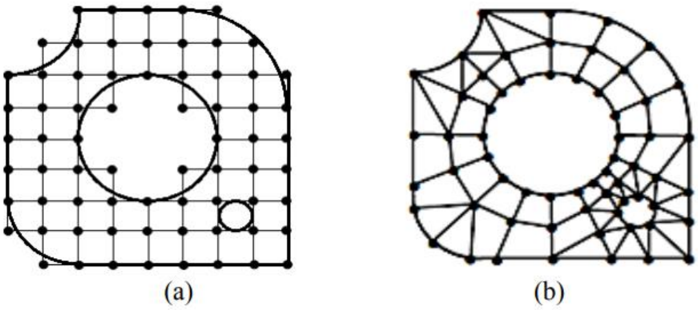
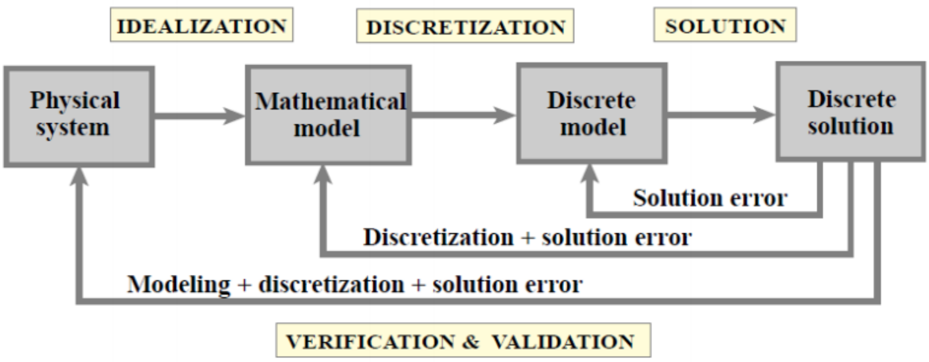


Figure 3-32 (a) Plate geometry finite difference model and (b) Finite element model (Taskaya, 2021).

Although the title finite element method-FEM was first stated by Clough (Clough., 1960) in 1960, in an article, the FE analysis date goes back to long before. The first efforts to use piecewise continuous functions were defined over triangular domains by Courant (Courant., 1943) in 1943. The general schematics of a model-based simulation (MBS) by computer are displayed in a diagram in (Table 3-9). For mechanical systems such as structures, the Finite Element Method (FEM) is the most widely used solution method in the field of discretization. Historically the background of the FE method is taken from the MSA[93], as shown in (Figure 3-34). "Human-computer" describes computations under the direct control and supervision of humans, possibly with the help of analog devices (slide rule) or digital devices (desk calculator). The FEM configuration with a version of THUMS is shown in (Figure 3-35) was determined by the mid-1960s.

Table 3-9 Flowchart of model-based simulation (MBS) by computer (Felippa, A historical outline of matrix structural analysis: a play in three acts., 2001)



In FEM, the model is divided into smaller parts. Parts are linked to each other with nodes. The nodes have unique places and features, enabling the analysis of every single node. The size of the elements/parts depends on the model, and the problem must be calculated. Theoretically, the model can be divided into as many elements as needed. The whole process of elements and nodes occurs

[87] http://www.ansys.com
[88] https://www.ansys.com/products/structures/ansys-ls-dyna
[89] http://www.mscsoftware.com
[90] http://www.ptc.com
[91] http://www.sdrc.com
[92] http://www.hks.com
[93] Matrix Structural Analysis

under the function and title of the mesh, which split the large and complex systems into smaller systems to be solved easier. Modeling different materials in programs using FEM is very important because the material's properties are being modeled. Typical materials that follow Hooke's law, such as steel, carbon fibers, and aluminum, are generally known and considered as linear-elastic. In contrast, there are materials that the relationship between stress and strain is not following Hooke's law and known as non-linear elastic and hyperelastic materials and include rubber, polymers, and biological material with high strains property (Figure 3-33). Some standard hyperelastic material models are the Mooney-Rivlin model and the Ogden model (Mooney, 1940).

	Uniaxial tension	Biaxial tension	Planar tension	Volumetric compression
	$\lambda_1 = \lambda$ $\lambda_2 = \lambda_3 = 1/\sqrt{\lambda}$	$\lambda_1 = \lambda_2 = \lambda$ $\lambda_3 = (1/\lambda)^2$	$\lambda_1 = \lambda$ $\lambda_2 = 1/\lambda$ $\lambda_3 = 1$	$\lambda_1 = \lambda_2 = \lambda_3 = \lambda$

Where λ is the stretch in the loading direction. λ1, λ2, and λ3 are the principal stretches.

Figure 3-33 Deformed mode for analysis of rubber unit element (Song, Determination of the Properties of the Rubber Mounted Under the Agricultural Tractor Rollover Protective Structure Cabin Using a Hyperelastic Tensile Test and Finite Element Analysis., 2020)

This section briefly explains the substantial steps and logic of the progress process used to simulate the final FE model. The first step is 3D modeling of the geometry, which can be model both in CAD or FEM software environment. The pre-processing part was carried out in two steps. The first step includes creating a proper mesh for the model. The second step is to define an appropriate selection of material and assign the material properties to the different parts of the model. Finally, the parts will be assembled and contacted with each other.

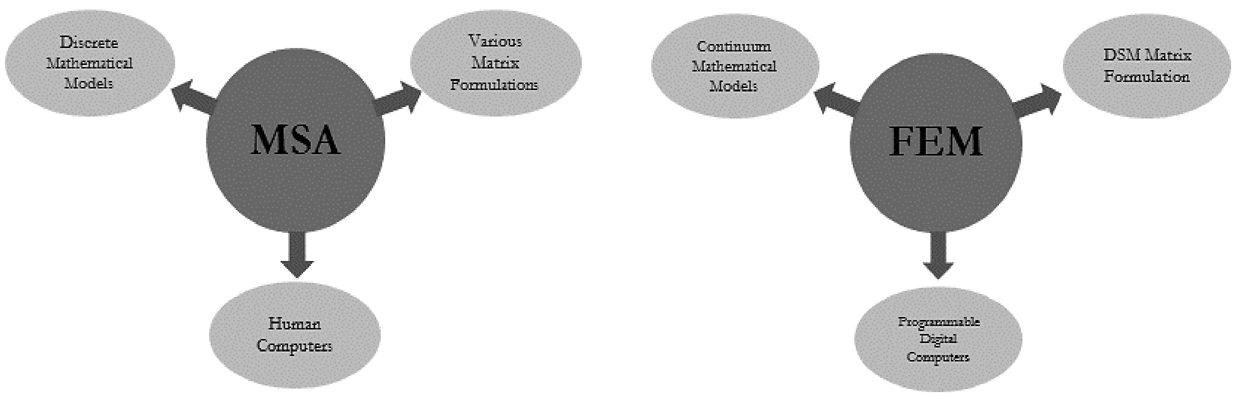


Figure 3-34 Morphing of the pre-computer MSA (before 1950) into the present FEM (Reddy, 2019).

In order to correctly define the friction and contacts between the parts of the complete model, from the start of the simulation, the tightening of the joints and connections was taken into consideration. Boundary conditions of some kind must carry out all simulations. The boundary conditions typically contain forces, displacements in the direction of the coordinate axes, or velocities applied to the model.

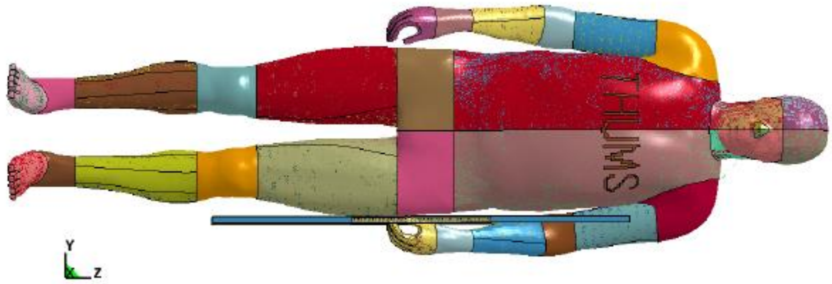


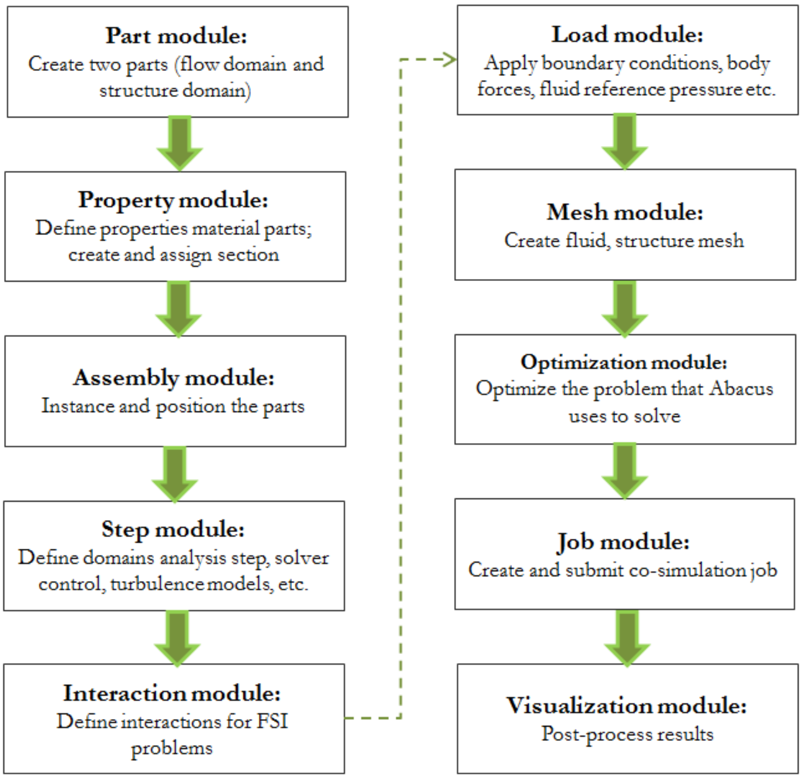
Figure 3-35 Fall simulations with the modified version of THUMS[94] and the model of the flooring system. (Okan J.-S. S., 2015)

The finite element discretization system diminishes the problem by partitioning a continuum into a body of material (solid, liquid, or gas) or simply a region of the area into elements and reduces the problem by providing approximate function variables in each element. The approximating functions are defined at specified points called nodes or nodal points. Nodes usually situate on the element borders where adjacent elements are linked. Besides, an element may have interior nodes as well. The nodal values completely specify the treatment of the field variable within the elements, which are unknown for the finite element representation. Once these unknowns are defined, the interpolation functions specify the field variable throughout the assemblage of elements (Reddy, 2019). Via a validation, it was stated by Dahlgren (Dahlgren, 2014) that: *"THUMS[95] did not accurately respond as cadavers, and modifications regarding contacts, material and the proximal femur were made. During floor-to-THUMS simulations, the position of THUMS was not considered, resulting in an impact that does not accurately describes a realistic fall of a person. As the angle of a fall influences the force acting on the proximal femur, no conclusion could be made whether this flooring system would reduce the force on proximal femur to a level below failure load."*

[94] Total Human Model for Safety

[95] The THUMS version 4 is not developed for use in fall simulations and thereby does not provide the details of the hip area as required (Okan J.-S. S., 2015).

Table 3-10 Process of simulation in Abaqus-FEM-By Author



An essential character of the FE method that separates it from other numerical techniques is the capability to formulate solutions for single elements before connecting them to express the entire problem. This implies that if a stress problem is being analyzed, the force-displacement or stiffness properties of every single element and then assemble the elements are found and the structure's stiffness. Thus, a complicated matter transforms into a series of very simplified issues or problems. Also, the FE method is a variety of approaches in which one can formulate the characters of single elements in three different ways. In (Table 3-10), the process of the FE method is expressed in the Abaqus software format in Appendix D . Modeling step till the final results in the Abaqus program divided into nine main modules. Abaqus helps the designer enter the configuration pages with a user-friendly environment by selecting each step and continuing his analysis process.

In the next chapter, the process of the research will be continued by explaining the methodology stages and tests defined.

CHAPTER 4

METHODOLOGY-STEPS IN THE INVESTIGATION PROCESS

CHAPTER 4

4 METHODOLOGY-PRACTICAL AND ON-SITE STUDIES

The methodological process used in this research is derived from five general phases. 1- Library studies, 2- On-site analysis, 3- Laboratory trials, 4- Modeling and simulation by software, and 5- Final results and suggestions.

Keywords: MUTUAM Group, Nursing Home, , Fall Protocol, Footwear, High-Risk Hour, High-Risk Area, High-Risk Floor, Fall Factors, Gender, Balance, Comfort, Energy Dissipation, Friction, Contact Area, Fujifilm, Pressure Area, DWI, HIC, SLP, CoR, VPA, Force Attenuation, Energy Dissipation, Biomechanical Test (BIO), Insole Pressure Sensor (IPS), Force Plate System (FP), Drop Jump Test (DJ), Ground Reaction Force (GRF), Strain Energy Models, Impact Velocity, Mass, Mechanical Data, Geometry, Simulation, Tensile Test.

1. **Library study:** Includes review of statistical rates, norms, standards, review of similar or related studies, and analysis of methods used. Search about physic and mechanic science of materials and vertical impact force. Study about human gait and ground reaction force during jumping or falling. Correspondence with manufacturers and collection of similar products (proposed flooring) was the time-consuming process that eventually led to selecting some flooring products available in the market with shock absorption ability.

2. **On-site analysis:** At this stage, some health centers, hospitals, and nursing homes in the province of Catalonia were inspected and photographed in person. With the cooperation and assistance of *MUTUAM Group*, one of the nursing home centers was proposed as a case study. Statistical data from the last three years were evaluated at the proposed *Collserola Center*. With continuous attendance, every day for two months, the environment, existing problems, the behavior of the elderly, spaces with a high risk of falls, etc., were monitored. The proposed floorings, which were collected from Spain and other countries, were installed in an area offered by the manager of *Collserola* center. In five stages, five different tests were performed on proposed floorings, two of which were ruled out due to lack of credibility and sufficient trust in their results. One of the remained three accepted tests was performed by an expert from *Sanpe engineering company*[96]. The other two were done with the help of Fujifilm technology and the physics science of the Coefficient of restitution. In addition, with the cooperation of *Applus company*[97] and the expert help sent by this company, the slip rate of the current floorings of some predetermined spaces of the center was measured (the slip resistance test was conducted with pendulum slip test device).

To better understand the mood of the elderly and employees, two series of questionnaires were prepared, which were done in interviews and recording their voices. The first questionnaire was designed about each person's personal experiences in the face of the fall, their views on the current floor of the center, and environmental problems. The second questionnaire focused on their opinions about the proposed floorings, which were asked of people while walking on them. The questions were tailored to each person's position and occupation at the center. Because everyone looked at the issue and commented according to their job and sometimes the opinions of cleaning and service personnel with physiotherapists or nurses were not opposite but different. The views of the elderly were different according to their past living environment and experiences. Thanks to Ximena Aguire

[96] https://www.sanpeingenieria.es/
[97] https://www.applus.com/es/es/

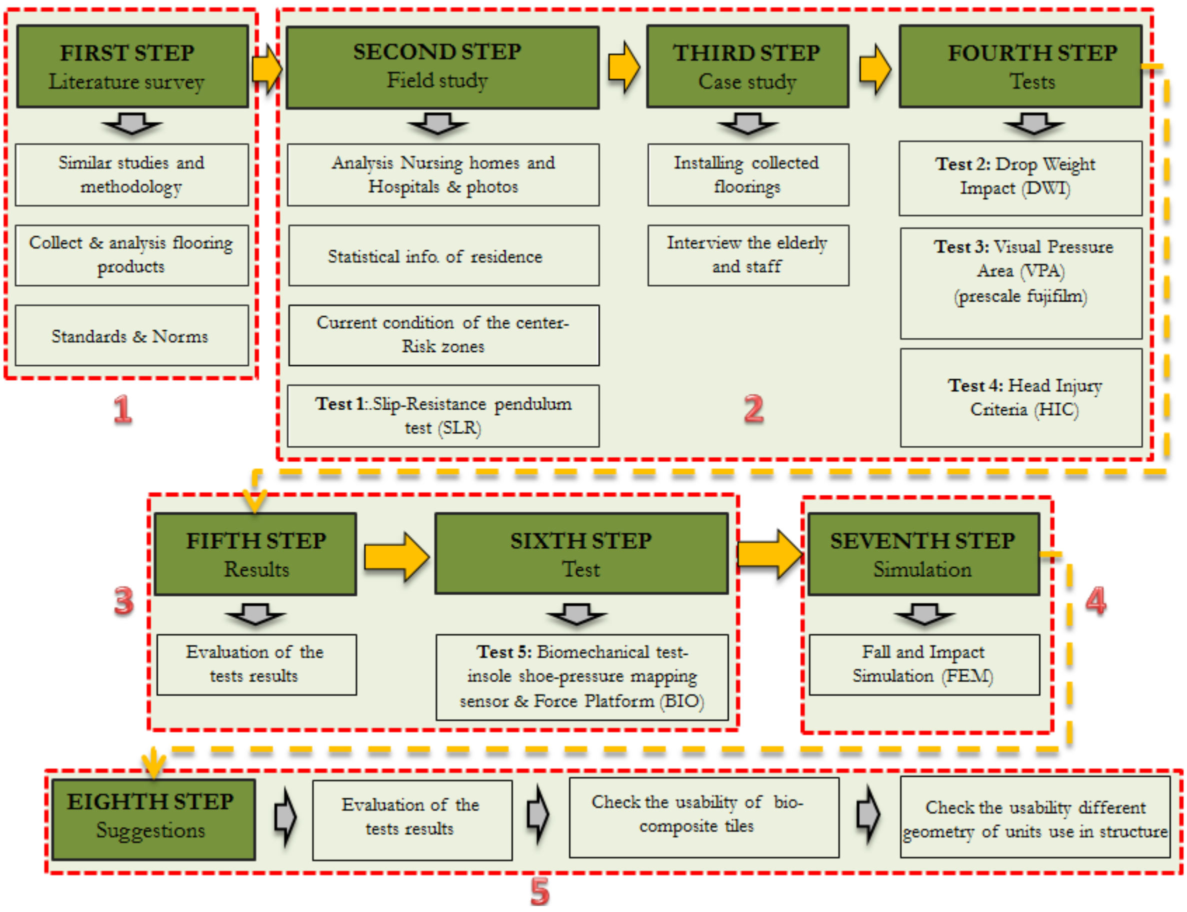
Suarez, a graduate student of architecture from UPC University, who collaborated with me in this research stage (Suarez, 2019) (Leila Mashhouri, 2019).

3. **Laboratory trials:** After selecting samples of floors with a high percentage of force reduction, biomechanical tests were performed. These experiments were performed with the assistance and collaboration of the Departmental section of the Podiatry Lab at UB University. This test method was performed to validate the performance of the floors in real conditions and measure the amount of force reduction applied by the participants through the force plate and the foot insole sensors systems. The foot insole sensors method measured the force applied on the flooring surface, and the other measured the force applied to the bottom surface of the floorings. Due to the specialization of this method and the special and sensitive devices that had to be used, this research method and all the settings of the devices were done with the help of one of the professors in the podiatry field and under his supervision.

4. **Modeling and simulation by software:** To better understand the behavior of the compliant flooring system, it was decided to use software simulation. One of the advantages of this method was that we could model and optimize other geometric forms as suggestions. For this purpose, the finite element method and Abacus software were used. Because of the need to manipulate and go through a lot of forms, I learned this software so that I can model my ideas faster. To avoid errors and improve the simulation with minor mistakes, I was constantly consulting with two mechanics professors.

We had to know a lot of behaviors to start simulating with a finite element system. These behaviors include the mechanical and physical properties of the material to be simulated, the type of force applied, which was the impact and dynamics, the impact velocity, the colliding body, the dimensions, and the correct choice of units in the simulation.

Table 4-1 Steps of the investigation- By Author



To this end, I considered one of the floors (*SmartCells*) as a reference. On the one hand, manufacturers generally consider the specific information of their products to be confidential. On the other hand, due to rubber's special and complex behavior and the wide variety of production of this product, I had to find material properties to be most similar behavior to the desired tile. In this method, an attempt was made to evaluate and compare the energy dissipation, the amount of force reduction, and the vertical deformation of the simulated tiles after applying force.

5. **Final results and suggestions:** Geometry of structural units/cells, examined in the simulation section. Apart from the mentioned issues, the connection of adjacent flooring tiles and the possibility of using other recycled products (using agro-based industries raw materials as an option for recycling waste materials) with impact absorption are discussed and evaluated. The methodology section addresses the methods utilized in the thesis and explains further details of what has been performed. The section is classified into eight levels described in (Table 4-1).

4.1 FORMAT OF DATA

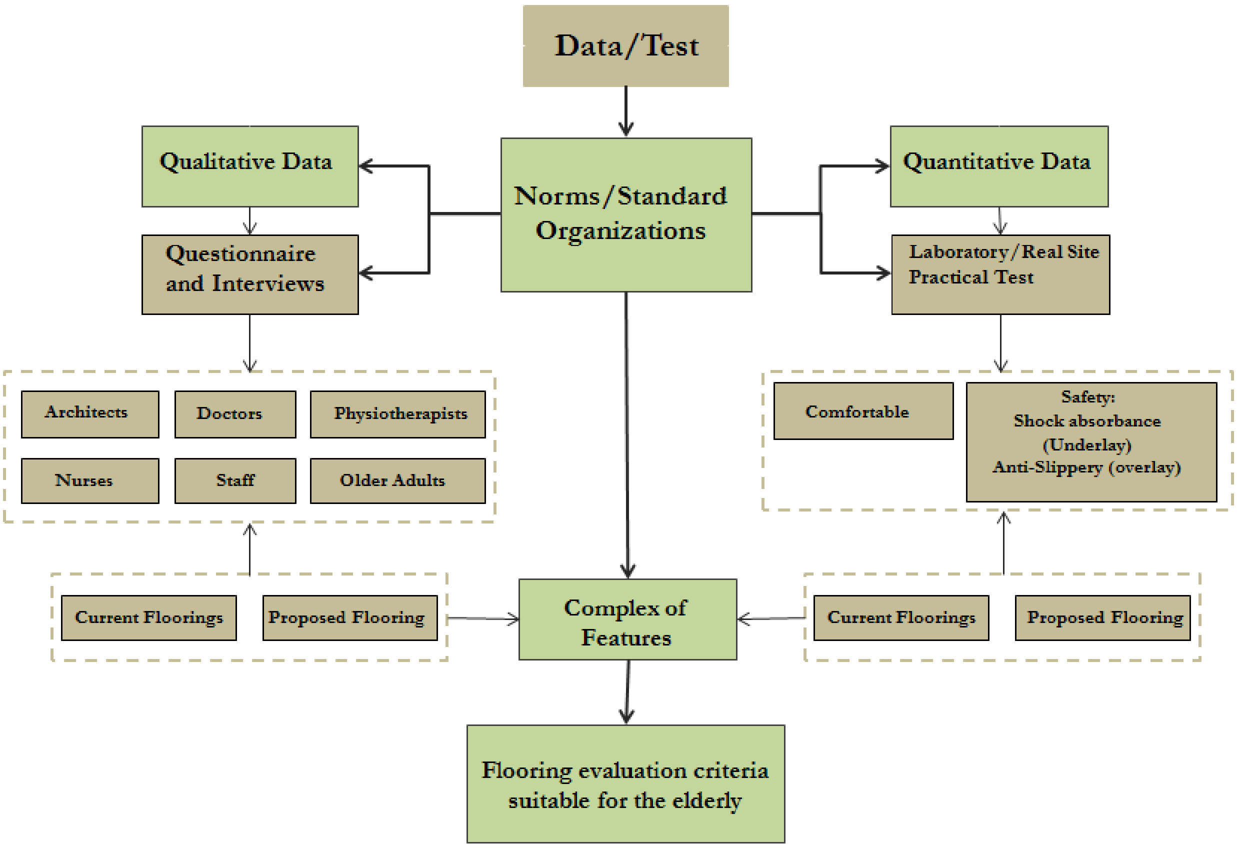
4.1.1 QUANTITATIVE DATA

The quantitative data are obtained through statistical information and practical tests carried out on the current pavement of the case study (Mutuam Collserola) to measure the slip resistance degree. The rest of the quantitative data gained from the tests carried out on proposed floorings to measure the shock absorption capacity of the tiles and simulation of models in software.

4.1.2 QUALITATIVE DATA

The qualitative data are obtained through a questionnaire to different professionals such as nurses, assistants, physiotherapists, and interviews with the elderly who live in residence and the apartments of the residential center (Table 4-2). As mentioned above, There are two types of questionnaires: Questions in the first type generally analyze the problems of the current pavement of the center, cleanliness, light reflection, slipperiness, and color. In the second type of questionnaire, participants were asked to walk on the proposed floorings and gave us their opinion on safety, comfort, and balance. In both questionnaires, the participants include the residence' professionals, staff, and seniors who live in residence and the apartment area of the Residential Center. All qualitative data and opinions of the participants and interviewees are presented in the form of figures and quantitative data in order to provide a better idea and understanding of the deterioration or relevance of the conditions and subject of the interview.

Table 4-2 Data Collection Process-By Author



In order to validate of proposed floorings and step in the experimental phase of the study, it was necessary to install the pavement samples in a real place to carry out the tests and know the opinion of the elderly who live in residences as well as the idea of all the personnel who work in these centers.

4.2 FIELD STUDY - INVESTIGATION OF HIGH-RISK ENVIRONMENT - THE COLLABORATION AND INTEREST OF THE MUTUAM GROUP AND - MUTUAM COLLSEROLA

The *Mutuam*[98] Group is part of the assistance entities that work in Catalonia, assisting in prolonging life expectancy. They provide health and social services to the elderly, chronically ill, and dependent people.

Thanks to the agreement between the *Mutuam Group* and the Polytechnic University of Catalonia in collaboration to search for new strategies and technologies that provide well-being to the elderly and previous associations in the research fields. A meeting was held with the Group manager Mutuam to decide which of all its centers would be ideal for this research. The plan of the contributions and results that it can give serves as a reference and can be applied in the other centers of the *Mutuam Group*. After the meeting with the director, the assigned residential center was the Mutuam Collserola Residential Center.

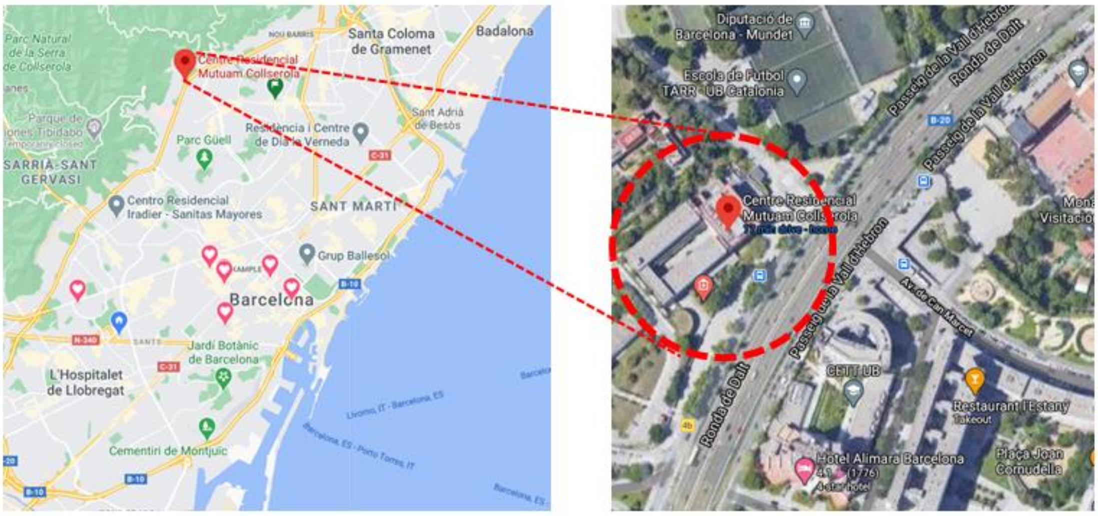


Figure 4-1 Location of Mutuam Collserola-Case study[99]

The Mutuam Collserola center (Figure 4-1 and Figure 4-2) is located north of Barcelona, close to Mundet metro station (Figure 4-3). The center includes three main sections of residential, suite-apartment, day center. The Mutuam Collserola residential center is a care complex that responds to all the care and residential needs of autonomous older adults or with any degree of dependency. One of its objectives is to eliminate physical restraints[100] to promote and regain mobility. The center

[98] https://www.mutuam.es/

[99] https://www.google.com/maps/place/Centre+Residencial+Mutuam+Collserola/@41.4347224,2.1471385,453m/data=!3m1!1e3!4m5!3m4!1s0x12a4bd58d9af3f7f:0x13dd68addd3fe30e!8m2!3d41.4353297!4d2.1468245

[100] Physical restraint is "any manual method, material instrument or equipment, physical or mechanical, that is applied or placed next to the resident's body so that it cannot be easily removed, in order to limit their freedom of movement or access normal to his own body"

works with the Libera-Care[101] (Quicios & Aretxabala, 2016) Standard promoted by the Dignified Care Foundation.

The *Mutuam* Collserola Residential Center keeps a record of statistical information of all the falls in the center. They provided us with all that information and, the data was extracted to create graphs of the falls recorded in the years three years of 2017, 2018, and 2019. The 2019 statistics show the falls recorded from January to July. The statistics received are only from the residential section since the adults who live in the apartment section are independent. Generally, if their fall is not severe, staff will not notify, and in any case, the center has no way of knowing if someone fell if they did not call for help or comment that they fell. For this reason, the staff does not keep a record of falls in the apartment section. It must be noted that some other issues, such as visual problems, have been briefly reviewed in this center, and few suggestions have been presented for optimization. More information has been taken in appendix D.

Centre Residencial
MUTUAM Collserola

Figure 4-2 Facade of apartment section-View Ronda de Delt

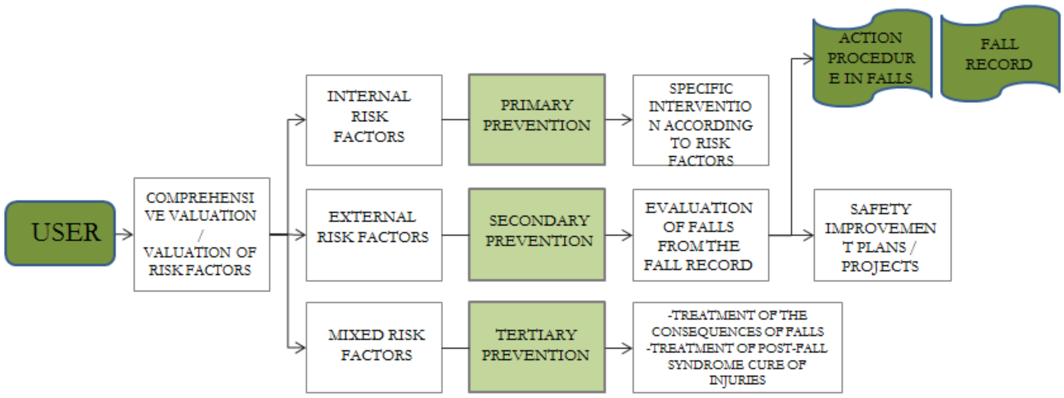
Figure 4-3 Main facades of the Mutuam Collserola Residential Center-View Av.d'Aturo Mundet

Fall protocol by Mutuam Group

The Mutuam Group provides a protocol called "Prevenció de les caigues (According to UNE-EN ISO 9001: 2015)102" (Table 4-3) to prevent falls and restraints. The protocol developed to promote users' safety and systematize the healthcare team's performance to prevent falls and their consequences, identifying the factors that have the most significant influence on these events and implement controls with which it is tried to reduce the risk of falls.

[101] The Libera-Care Standard is a new model of care, attention and intervention centered on the person and without restraints.
[102] PREVENCIÓ DE LES CAIGUDES (Segons): UNE-EN ISO 9001:2015) MUT-PRT-044

Table 4-3 Mutuam Group fall prevention protocol (Mutuam, 2015-2018)



All the information recorded was up to July 17, 2019, in which the number of older people living in the apartment section was 17 men and 38 women. There were 42 men and 83 women in the residence section, and 5 women were in the center by day.

The total number of falls recorded within years 2017, 2018 and 2019 in residence section:

- 362 from 01.01 2017 till 31.12.2017, that is 43.59% of total number of residences.
- 364 from 01.01.2018 till 31.12.2018, that is 37.39% of total number of residences.
- 142 from 01.01.2019 till 31.08.2019, that is 26.69% of total number of residences.

Graphics are classified into five main elements:

1. **Gender** (male or female)
2. **High risk hours** (06: 00-08: 00/12: 00-15: 00/20: 00-22: 00)
3. **High-risk areas** (dining room, bathroom ...)
4. **Fall factor** (extrinsic or intrinsic)
5. High-risk level floors (Ground floor ...)

This center has two healthcare services distributed in two blocks of four floors. One block of the building provides residential services, and the other block is apartments.

1. Residence section
2. Apartment section (there is no statistical information recorded on falls)

<u>Residence Section</u>
Residence Section includes four floors and depending on the dependency and/or physical or cognitive problems of the elderly. They are located on one floor or another.

<u>GENDER</u>

It is shown in the diagram (Figure 4-4) that in the years 2017 and 2018, the number of falls registered in female is greater compared to male. Although in general, we can see an acceptable downward slope in 2018 and 2019, which can be a good news of better handling and monitoring. In Collserola Centre, the number of female residents were higher than male which could be a good explanation for the higher number of falls in female in this center.

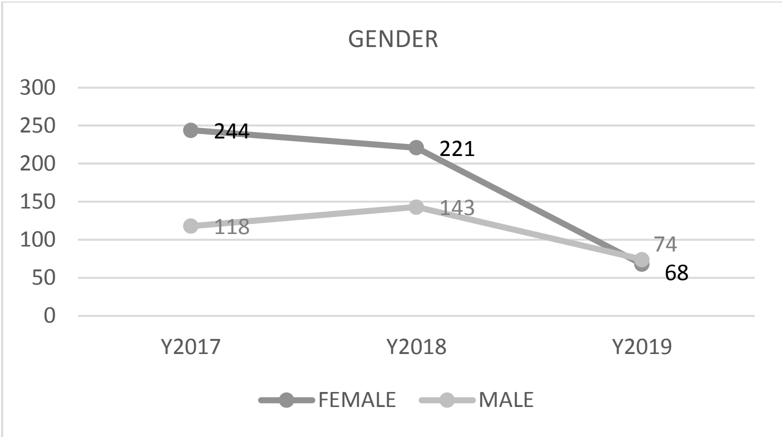


Figure 4-4 Falls by gender in 2017, 2018, and 2019-By Author

HIGH-RISK HOURS

We examined the time and place of the fall with the hypothesis that the probability of falling would be higher at times when the elderly are tired and drowsy or restless. Times like before breakfast (06:00-08:00), after lunch (12:00-15:00) and in the evening before bed (20:00-22:00) while they are waiting to be taken to their rooms. During the investigation, it was observed that a person who fell once fell again in the next two or three days. It should be noted that a person who has fallen once should be monitored within a few days after the accident and needs more care to prevent a recurrence of the accident. The recorded data of the center show that out of 362 falls that occurred in 2017, more than 200 falls are related to the designated risk hours. This rate in the range of high-risk times was about 179 events among 364 falls in 2018 and in 2019 it was 81 events among 142 falls. The remarkable thing seen in the Figure 4-5 was that between 12:00 and 15:00 pm the number of falls was obviously higher every three years.

By analyzing and knowing the most regular hours in which older adults have the greatest chance or risk of falling, different prevention and more monitoring can be exerted.

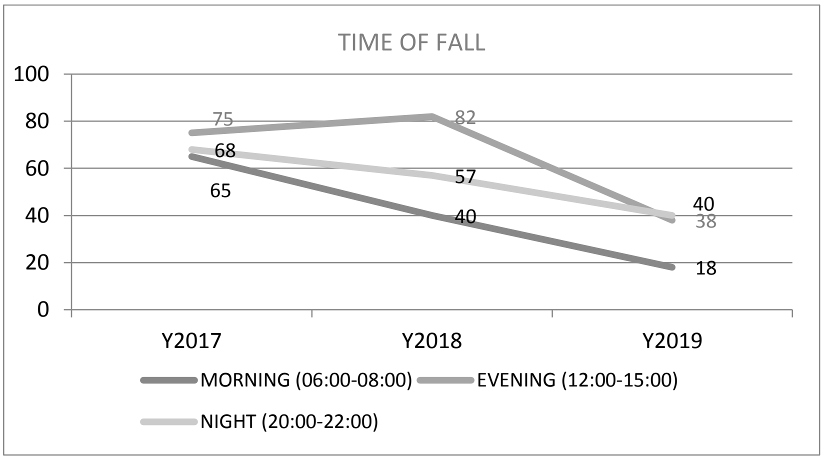


Figure 4-5 Number of falls by the time of fall in 2017, 2018, and 2019-By Author

In general, a downward slope is observed during the three years studied, which indicates a more serious supervision of the authorities or more favorable conditions in the elderly.

HIGH-RISK AREAS

From the following graphs, we can conclude that most of the falls occurred in bedrooms, bathrooms, and dining rooms, which means that it is necessary to consider what prevention measures to take to make these areas safer. Among 362 falls happened in 2017, approximately 53% were occured in bedrooms, 15% in bathrooms, 12% in dining rooms, and 10% in hallways. This rate, respectively, in 2018 (with 364 falls) was 45% in bedrooms, 10% in bathrooms, 25% in dining room, and 12% hallway. And finally, from 2019 until Augest (with 142 falls), this rate, respectively, was 59% in bedrooms, 12% in bathrooms, 16% in dining rooms.

The results show that bedrooms, bathrooms, and dining rooms are the most dangerous areas for older people. This is because the bathroom floor may slip due to getting wet. Or due to the presence of water vapor and heat, the elderly person's blood pressure may change and he may lose his balance. The elderly spend most of their times in dining room or bedroom and that may be the reason of more cases in such areas. Although most of the older adult bathe under the supervision and assistance of assistants and nurses, it is still considered a high-risk environment due to the significant number of falls in the years under review.

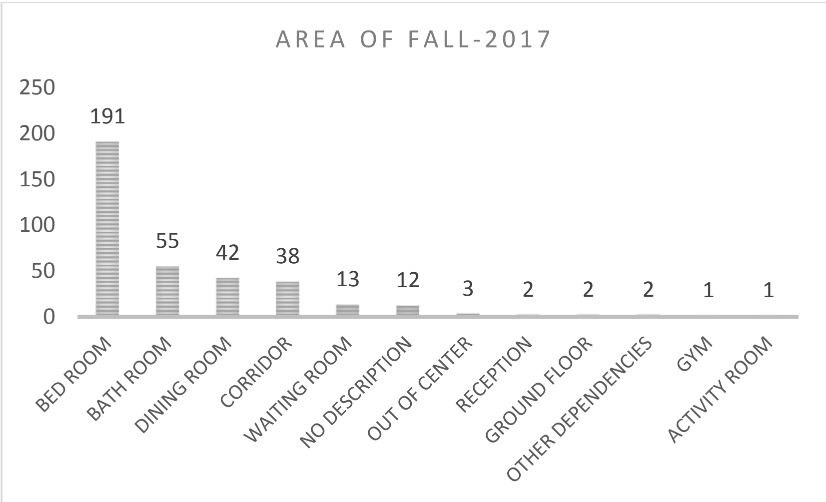


Figure 4-6 Number of falls by areas-2017-By Author

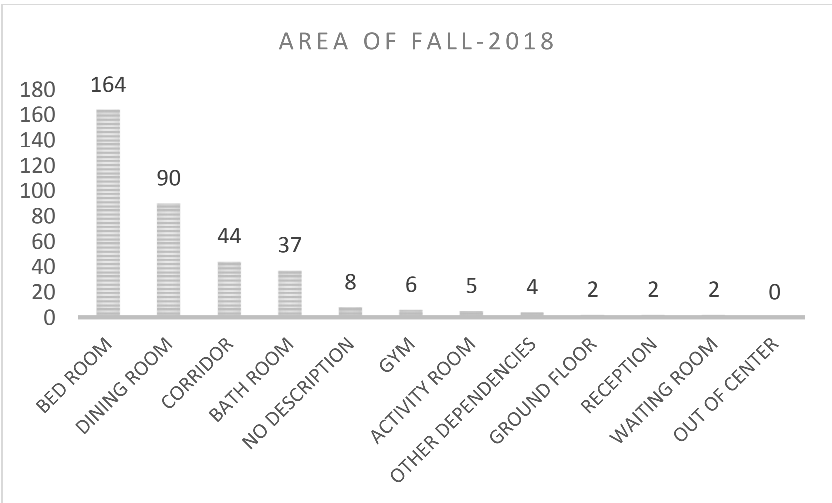


Figure 4-7 Statistics of falls by areas-2018-By Author

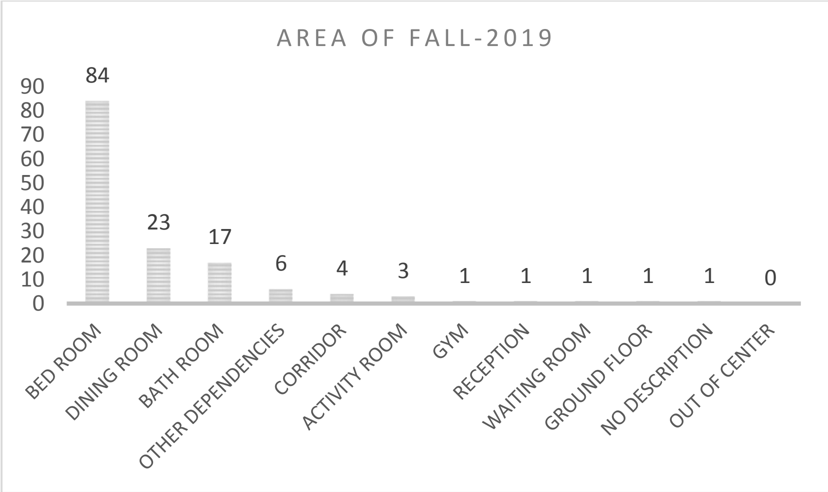


Figure 4-8 Statistics of falls by areas-2019-By Author

The rate of falls in corridors were high in 2017 and 2018 that because that is because the elderly get tired of sitting in the dining room and constantly want to walk or want to go to their room. The years 2017 and 2018 may have allowed them to walk in the corridors as well, but a one-month monitoring conducted in 2019 found that the elderly are constantly warned by nurses or assistants to sit and stay in the dining room. Except in special cases where they are taken to their private room with the supervision and help of assistants. Notably, these areas (bedrooms, dining rooms, and baths) must be optimized in terms of safety and pavements in order to reduce damage in the event of a fall. Due to the low traffic of older adults and the low number of falls, the rest of the areas seem current preventions are sufficient (Figure 4-6, Figure 4-7, and Figure 4-8).

FALL FACTORS

In this research, the fall factors were analyzed under two main groups of intrinsic and extrinsic, which are explained in Chapter 2. Each group has several reasons that cause the fall of the elderly. 17% of the falls were occurred because of extrinsic factors in 2017, and 61% were due to intrinsic factors, and 22% were not registered. The number of falls with intrinsic factors were registered about 24% in 2018, 58% due to extrinsic factors, and 18% did not mention the factor. In 2019, 32% of the falls were due to extrinsic factors, 63% were because of intrinsic factors, and 4% were not registered any reason. It can be seen that most of the falls in the last three years occurred due to intrinsic factors. Of all that information recorded on the factors, only the extrinsic factors are taken into account to make the explanatory diagrams. Most of the extrinsic factors are able to be controlled or be completely eliminated due to constant monitoring and architectural design. are the factors that we can influence, such as slippery pavements (Figure 4-9).

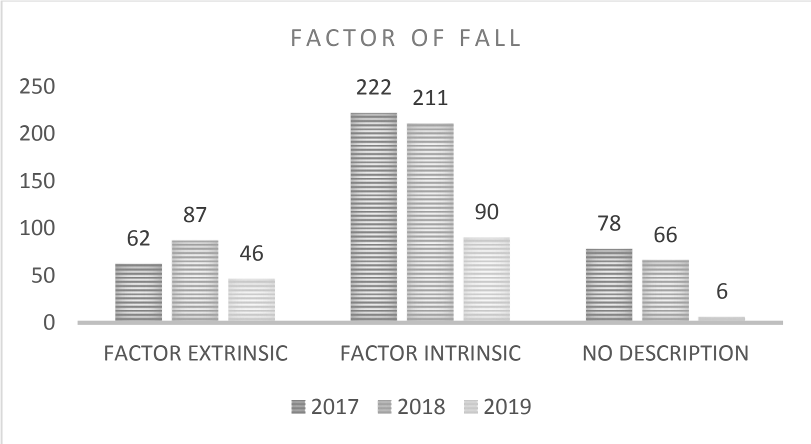


Figure 4-9 Number of falls according to the influencing factor-By Author

As shown in the following figures (Figure 4-10, Figure 4-11, and Figure 4-12) of extrinsic factors, in 2017, 32% of falls were due to slippery pavement, the same reason in 2018 was 30% and, in 2019 showed about 15%. The slippery pavement was the second most influential factor in falls after unsafe footwear in the center. Unsafe footwear had the highest fall rate in all three years, which showed 51% in 2017, 35% was in 2018, and 48% occurred in 2019.

Diagrams of Extrinsic factors

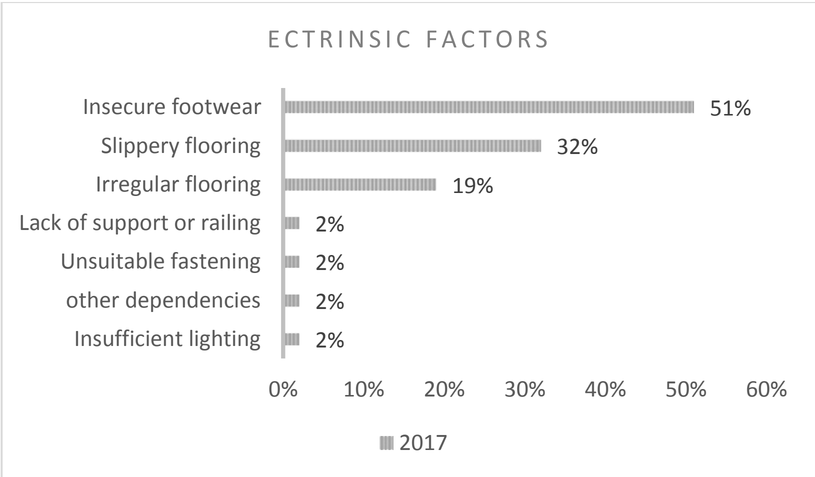


Figure 4-10 Extrinsic Factor 2017-By Author

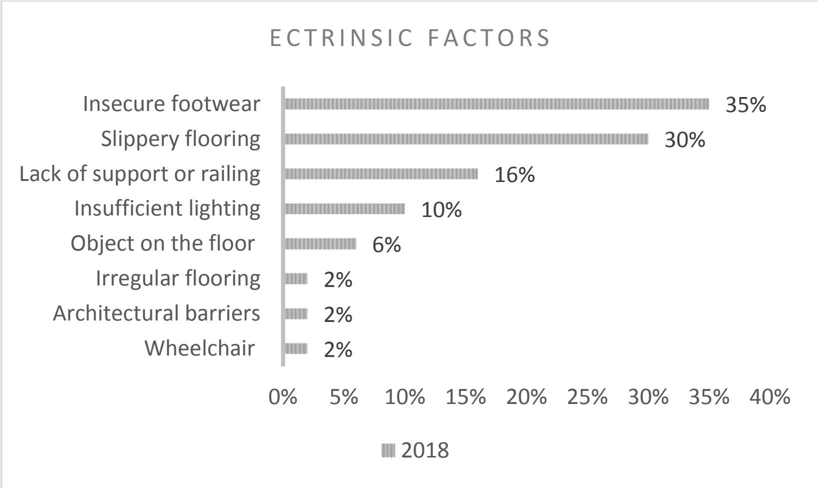


Figure 4-11 Extrinsic Factor 2018-By Author

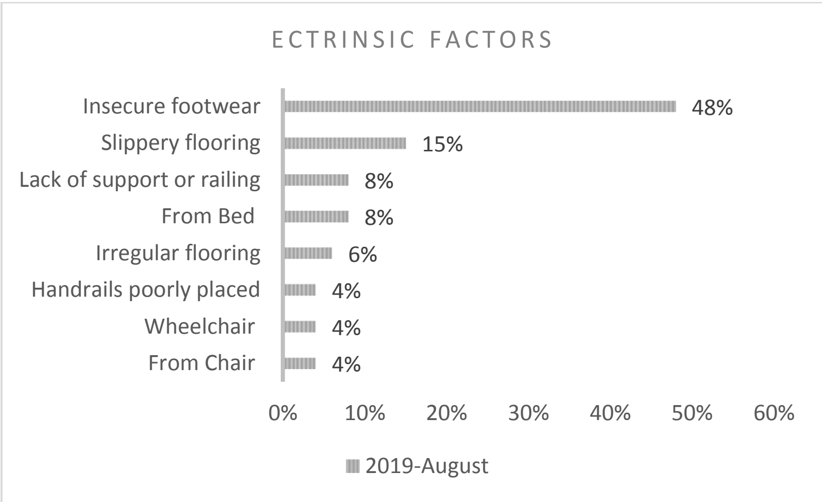


Figure 4-12 Extrinsic Factor 2019 until August-By Author

As a general result, the center should have more monitoring and follow-up on footwear, flooring, and supports to prevent a fall.

HIGH-RISK LEVEL FLOORS

For better and faster care, the elderly has been organized and settled on different floors according to the problems they face. The first floor belongs to older adults who have some motor problem or use a wheelchair, walker, or cane but do not have any cognitive issues and go independently everywhere. On the second and third floors are older adults with mental problems who need more help, vigilance, and depend on aides. With mental problems, some older adults can be prone to elopement. Due to that problem, the travel to other floors of these two levels were blocked with electric gates. Older adults in the fourth level are the most independent without any cognitive issues and the majority without any motor problems (Figure 4-13).

Table 4-4 Number of fall in different floors of the center- By Author

YEAR	NUMBER OF FALL	FIRST FLOOR	SECOND FLOOR	THIRD FLOOR	FOURTH FLOOR	GROUND FLOOR
2017	362	98	147	45	57	15
2018	364	61	138	107	51	7
2019-till August	142	35	52	38	17	-

However, given the number of falls in such centers with a high risk of falls among vulnerable generations, more consideration should be taken into account to minimize the damage.

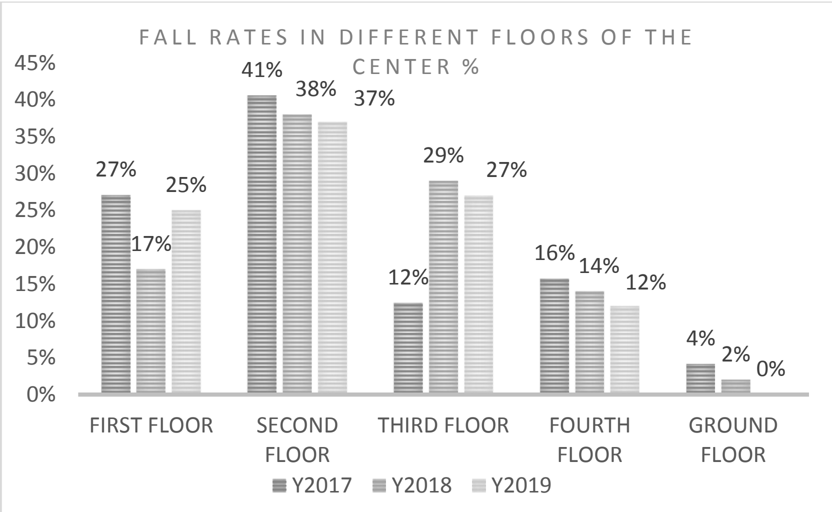


Figure 4-13 Fall rates on different floors of the center %- By Author

The diagram shows more information about falls that occurred on the first and second floors in recent three years. As can be seen, the number of falls on the second and third floors is higher due to the problems mentioned above. Those who live on the second and third floors have mental issues, which means that many intrinsic factors influenced falls. The second floor has shown more falls compare to the third floor because more elderly is settled on this floor. 41%, 38% and, 37% are the rate of fall in second floor during 2017, 2018, and 2019 respectively. Therefore, these floors should be safer even along the connection corridor. The rooms, accessories, and flooring conditions are the same on all floors, except that the number of staff and the elderly living on the second floor that is slightly more than on the other floors (Table 4-4).

<u>FLOORING MATERIAL OF COLLSEROLA CENTER</u>

After examining for several days in different spaces of the center, we came to the conclusion that the Collserola center includes five other flooring materials (Table 4-5).

The flooring material of the Collserola is as follows:

1. Black terrazzo installed in most areas of the center, such as in dining rooms, lobby, common areas, and corridors. Cream terrazzo use for the rooms of residential and hole suites and corridors of apartment section;
2. Non-slip mosaics or ceramic use in all bathrooms and pool except numbers of public toilets that have black terrazzo;
3. Parquet (wood) installed in the physiotherapy and administrative section;
4. The dining room on the first floor and gym covered by vinyl (pattern of wood); and

5. Open areas such as the entrance, connection open spaces between the apartment and residential sections, balcony, and central yard have concrete tiles.

Table 4-5 Flooring material of each area of the Collserola center- By Author

Section/Pavement	Terrazzo (Black or cream)	Ceramic (Blue or grey)	Concrete	Vinyl-PVC-rubber	Parquet	Soil
Day center	×	×				
Residence	×	×				
Suite-Apartment	×	×				
Area/Pavement	**Terrazzo (Black or cream)**	**Ceramic (Blue or grey)**	**Concrete**	**Vinyl-PVC-rubber**	**Parquet-wood**	**Soil**
Swimming pool & Jacuzzi		×				
Physiotherapy					×	
Gym				×		
Club	×					
Neurological unit					×	
Occupation therapy					×	
Dining room-Residence	×					
Living room-Apartments	×					
Bath room-WC	×	×				
Open area for the walk			×		×	×
Rooms	×					
Central yard			×			
Corridors	×					
Administrative section-Offices	×			×	×	
Lobby-Hall	×					
Public Restaurant	×					
Parking			×			
Service section-mechanical & electrical	×	×	×			
Public lobby and corridors	×					
Public bath		×				
Auditorium-oratory Saloon					×	

4.2.1 INTERVIEW ABOUT CURRENT FLOOR CONDITION – MUTUAM COLLSEROLA

The elderly, nurses, assistants, cleaning personnel, and those staff in direct contact with the elderly every day were interviewed about the current situation of the indoor floorings and some general questions about the center. The questionnaires of the interview are presented in Appendix C1. Some questions were common between different groups. Others are statistically or related to the profession and expertise of the interviewee. As mentioned before, all qualitative data and opinions of the participants and interviewees are presented in the form of figures and quantitative data in order to provide a better idea and understanding of the deterioration or relevance of the conditions and subject of the interview.

OLDER ADULTS

The total number of older adults surveyed was seventeen; three were from the daycare center, seven from the residential sector, and seven from apartments. They were asked general questions about the current state of the flooring in all areas of the center. To find out their opinions, the questions related to safety, balance, history of fall and their interests. The number of seniors interviewed was a number of those who were completely independent at the time of the research and had full awareness of their physical and mental health in understanding the environment and answering questions. However, with the increase in the number of elderly people, more reliable results can be achieved.

- Approximately 24% of the older adults affirmed to have fallen at least once in the center, 18% suffered at least one fall outside the center, and 59% percent never suffered a fall.
- 59% of older adults believed that the head has a greater likelihood of damage after a fall, contrary to what is often thought and evidences shows that the hip is the most vulnerable but only 12% of adults consider it a greater possibility. It is challenging to determine if the femur fracture occurred due to the fall, knows as the most common fracture consequence of adult falls (Figure 4-14).

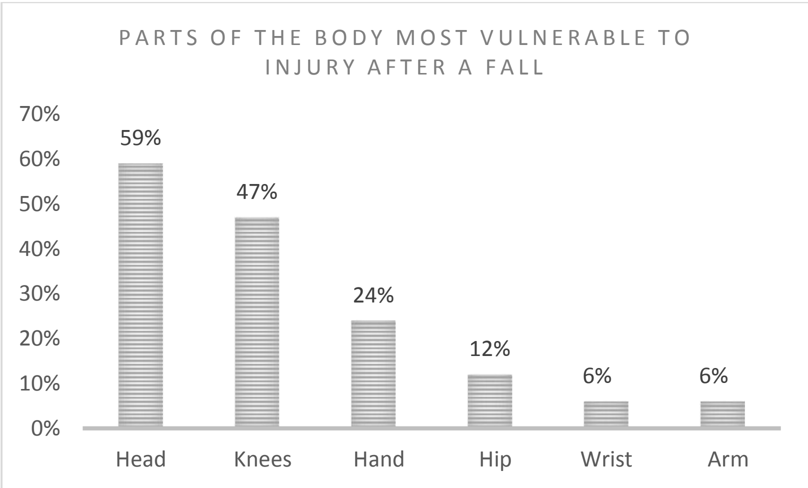


Figure 4-14 Opinion of the elderly about the most vulnerable parts of the body that will be injured after a fall-By Author

- Conversing with them about the risk factors showed that the medicine causes the risk of falling since some medications help them be calm and stabilize adults emotionally and psychologically. Still, some as a side effect can cause dizziness and thus make them lose their balance.
- They were asked about the prevention approaches they use to reduce the risk of falls. The majority responded to know the risks of a fall, so they always tried to walk carefully, slowly, and looking well where they are walking. An adult commented that before living in residence, she/he used the assistance tools but that it only worked when she/he was in her apartment, and that made her feel safer, and she/he could be left alone. Some of the older adults, as a preventive measure, began to use a cane and/or a walker to help them with balance and avoid falls. The rest of the older adults commented that they always determine the type of shoe they will use according to the activity they are going to carry out. They try to wear shoes with non-slip soles.
- 54% of them prefer to walk without shoes, stating that they feel more comfortable and safe, and 46 % said that they always prefer to walk with shoes; some commented that they do not know how to walk without shoes. They prefer to walk with shoes because of the type of flooring of the center, which is cold, rigid, and slippery. But in general they did not like to use carpet even in their private home.
- They were asked about the type of pavement they would like to have in their room or apartment in terms of comfort and safety. 54% of the older adults responded that they prefer wood/parquet, and refuse using carpet or rug, which maybe because of the Mediterranean climate and the culture to which they are accustomed (Figure 4-15).

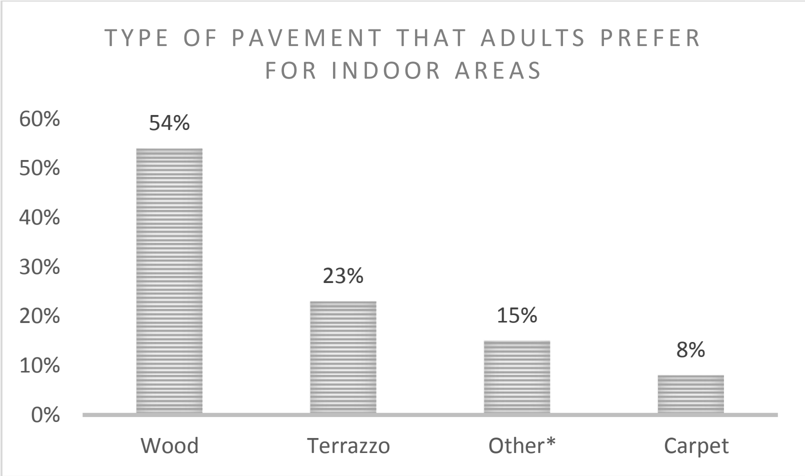


Figure 4-15 Type of pavement that adults prefer for their leaving areas-*Marble, ceramic, PVC, linoleum- By Author

HEALTH PERSONNEL

Cleaning Staff

The interest in interviewing the cleaning staff (Ten cleaning staff interviewed) was to learn more about the current state of the pavement, in terms of, sound, safety, heating, cleaning and maintenance required by the five indoor types of pavement mentioned above.

In general, all the floorings of the residence center were cleaned once a day. The dining rooms are cleaned three times a day, which was after each meal. In addition to the general cleaning, the evening shift staff maintains and cleans if any liquid is spilled or due to adult incontinence problems. They were allowed to use a disinfectant and hot water to clean the floorings since bleaches and some strong detergents contain toxic gases and annoying odors.

They were also asked if it has ever happened that the product they use causes any damage to the surface of the pavement or has affected its appearance. The answer was negative since the disinfectant product they use is suitable for all pavements and as it is not a strong chemical. But the area where the pavement looks the most worn and stained in dining rooms or corridors belongs to those seniors that sometimes vomit they did mention. In their opinion the elderly's stomach acid, along with the medication they take, contains a very acidic substance. For this reason, some parts of the existing pavement are quite porous, or white spots remain.

Assistants, physiotherapists, occupational therapists, psychologist

Eleven persones include assistance, Physiotherapists, Occupational therapists, and head of section were interview. The assistants are the staff with whom older adults have the most significant relationship since they are the ones who accompany them and help them carry out their activities throughout the day. Physiotherapists work with adults to strengthen their muscles and recover from injury. Occupational therapists are with adults during the day, giving them manual activities.

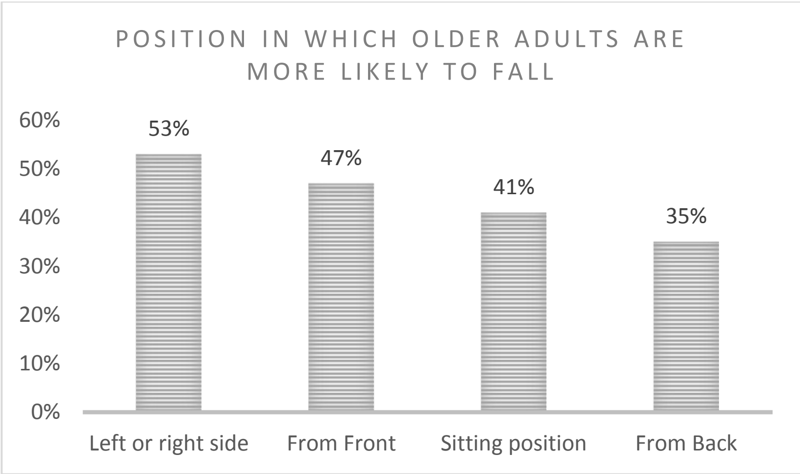


Figure 4-16 Opinion of the personnel about the position in which older adults tend to fall-By Author

The most relevant questions in interview asked of these eleven staff were about the day-to-day with the elderly and the falls of the residents that occurred in the center. All the interviewees affirmed that mental disorders and cognitive problems are the main factors that increases the probability of falls. The medication that some take reduces their alertness during the day and can alter their balance. These reasons being part of the intrinsic factors involved in the risk of falls. All staff belived that there is no gender difference and that it depends a lot on the physical and mental state of the older adult. This is also one of the reasons why comparing the residence and apartment section. There is a higher number of falls in the residential area, especially on the second floor, where older adults have cognitive mental problems. According to the staff's responses, 53% thought that the position in which older adults typically fall is on their side (Figure 4-16).

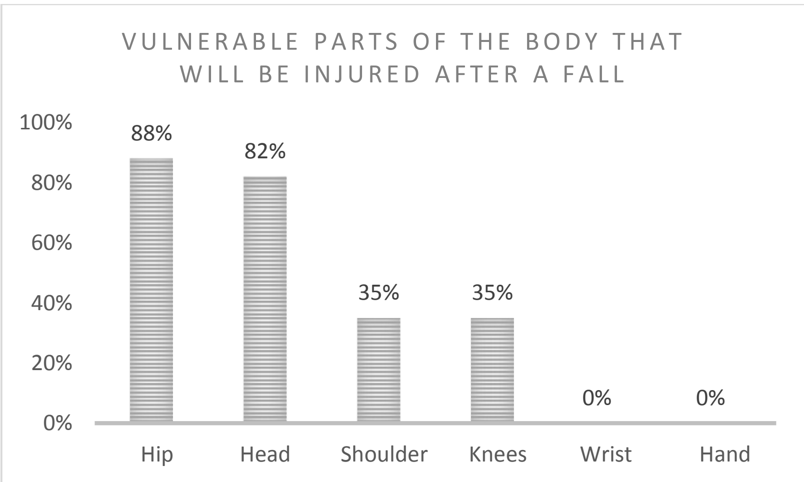


Figure 4-17 Opinion of the staff about the most vulnerable parts of the body that will be injured after a fall-By Author

Unlike the response of the elderly, 88% of staff responded that the hip is the part of the body most vulnerable to injury after a fall, and 82% believe that the head is the second most vulnerable part of the body (Figure 4-17).

PRELIMINARY DISCUSSION AND RESULTS

Statistical data shows that the number of falls in all three years were almost the same. Number of fall in female was higher because of the more female residence in the center. The number of falls during the year has been declining, which indicates proper monitoring and reducing the causes of falls in the center. Evidence shows that the number of falls occurred more in the hours we expected compared to other hours during the day. Hours before breakfast, after lunch and hours before bedtime are among the times when more monitoring of the elderly should be done. The most critical areas that need further consideration when discussing safety and fall hazards are bedrooms, bathrooms, and dining rooms, and in some cases busy corridors of the elderly. In the residence section, residents living on all four floors spend about 10-12 hours in the respective dining rooms on each floor. The bedroom is not a safe space when older adults are alone, especially at night when everything is dark, and they are still exhausted from being just awake to go to the bathroom. The atmosphere of bathroom can affect blood pressure or blood sugar, causing dizziness and even fainting due to wet pavement and the heat and water vapor in space after bathing. Regardless of the intrinsic factors, the lack of architectural support tools can be extrinsic factor of fall in the elderly. Considering the type of pavement use in areas and the kind of footwear worn by adults are not only affect the rate of falls recorded, but reduce fall-related injuries. These spaces not only require more comprehensive monitoring but also require suitable shock-absorbing flooring.

The data of the center indicate that intrinsic factors are ahead of extrinsic factors in the fall of the elderly. However, extrinsic factors still play a major role in the injury of the elderly during the fall, which can be controlled with safety measures and proper design. It should be noted that the center should have more monitoring and follow-up on footwear, flooring, and supports as more common factors to prevent a fall. Those who live on the second and third floors have mental issues, which means that many intrinsic factors influenced falls. The second floor has shown more falls compare to the third floor because more number of elderly is settled on this floor.

4.2.2 AREAS WITH HIGH RISK OF FALLING & EVALUATION OF SLIP RESISTANCE OF CURRENT PAVEMENTS OF THE COLLSEROLA CENTER

We categorized the risk term into four main classes to identify spaces with a high risk of falling in Collserola center:

1. Risk of falling due to the UNE-ENV 12633: 2003 standard, which measures the slippery rate of the surface due to the method and table explained in section 3.2.1;
2. Risk of falling due to the duration of stay of the elderly in space in 24 hours;
3. Users of spaces with similar function and application;
4. Time and Hours of fall

The following plans of the Collserola center colored in 3 rates of fall risk according to the norm of UNE-ENV 12633: 2003.

RISK OF FALLING DUE TO THE UNE-ENV 12633: 2003- MEASURING SLIP RESISTANCE (SLIP RESISTANCE PENDULUM TEST-SRP-T)

To evaluate the current pavement of the *Collserola* Center, a test was carried out based on the UNE-ENV 12633: 2003 standard explained in Table 3-4 (Slip Resistance) to determine the value of the resistance to sliding/slipping of polished and unpolished floors. The test was carried out with the partner company *Applus +. Applus + is* one of the companies specialized in the field of inspection, testing, and certification. It helps the clients to enhance the quality and security of their assets, infrastructures, and operations. Before starting the test, the entire center was studied, and the different areas were classified according to regulations due to risky places. Thus having class 1 areas in yellow, class 2 areas in green, and class 3 areas in red. Figure 4-18, Figure 4-19, Figure 4-21, and Figure 4-22 show five flooring levels that are classified according to the UNE-ENV 12633 with coloring.

Figure 4-18 Ground Floor of Mutuam Collserola Residence, Classification according to UNE-ENV 12633: 2003- By Author

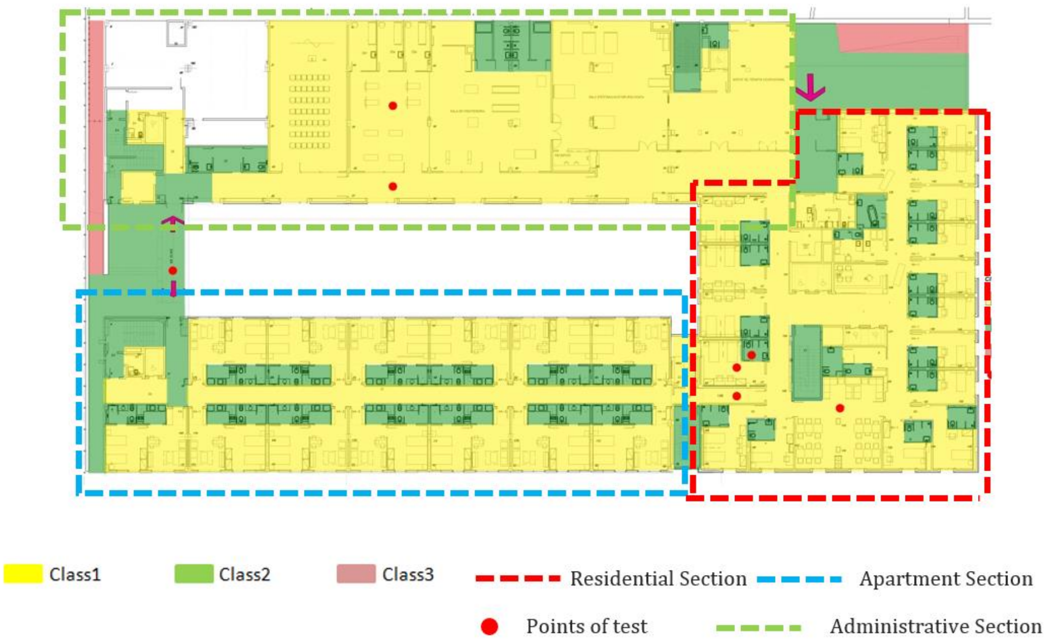


Figure 4-19 First Level of Mutuam Collserola Residence, Classification according to UNE-ENV 12633: 2003- By Author

Figure 4-20 Second Level of Mutuam Collserola Residence, Classification according to UNE-ENV 12633: 2003- By Author

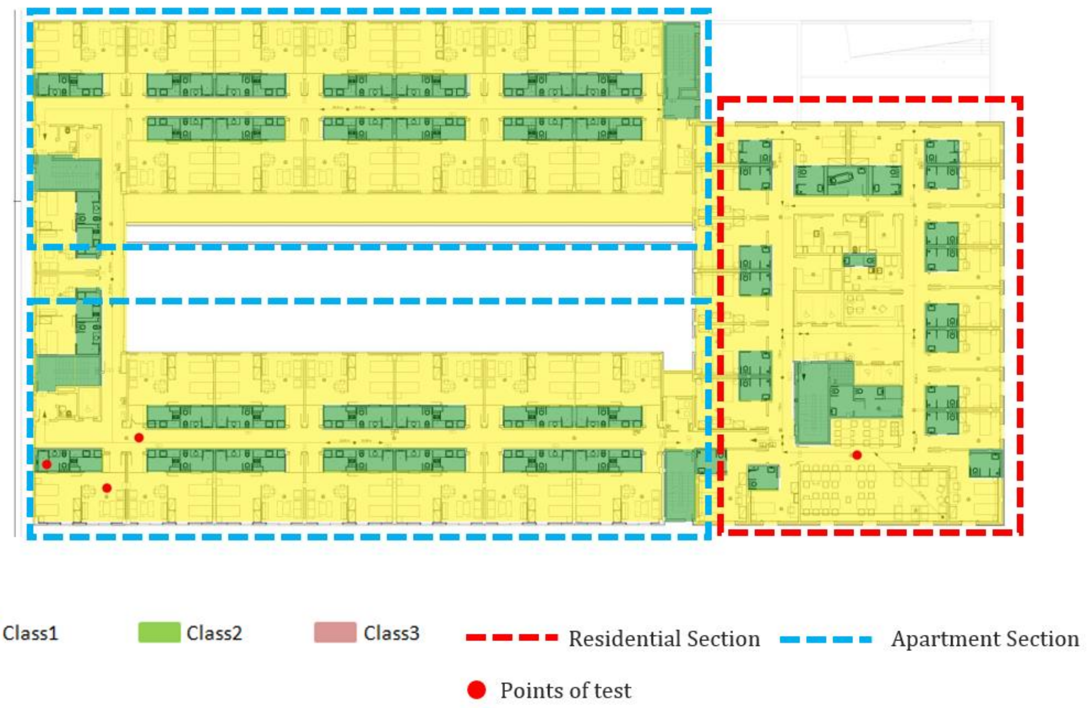


Figure 4-21 Third Level of Mutuam Collserola Residence, Classification according to UNE-ENV 12633: 2003- By Author

Figure 4-22 Fourth Level of *Mutuam Collserola* Residence, Classification according to UNE-ENV 12633: 2003- By Author

According to the previous analysis and standard classification[103]. We identified 22 points throughout the building to be tested, which were done according to the movement, application of the area, and flooring material. The results' tests were compared with the table of the regulations to see if they complied with the slip resistance. Thus marking the boxes in red for values below the standard requirement and in green for values within the standard. Of the 22 points analyzed, the results are the following:

Table 4-6 Area and facilities belong to each section- By Author

Area/ Section	Day center	Residence	Apartment
Swimming pool & Jacuzzi			×
Physiotherapy		×	×
Gym			×
Club			×
Dining/living room	×	×	×
Bathroom		×	×
Room	×	×	×
Toilet	×	×	×
Kitchen			×
Open area for walking			×
Conference hall-Watching movie	×		×

- Four areas (gym, indoor and outdoor ramps between two buildings, dining room covered by vinyl) meet the standard of slip/slip resistance according to the results shown in (Table 4-6) of appendix D(Slip resistance pendulum test).

[103] UNE-ENV 12633: 2003

- On the other hand, the rest of the areas are out of the ranges established by the UNE-ENV 12633: 2003 standard.

These indicators are consistent with the information presented regarding the statistics of extrinsic factors mentioned in section 1.4.1 in the information on the residence. It can be observed that there is a high risk of falls due to the type of pavement being this slippery.

*The red points in the maps show the location and points of the test.

In *Collserola* center, the elderly in each section are not allowed to go to other wards or use facilities. Due to the features of any types of flooring used in *Collserola,* none of them are safe for such sensitive and vulnerable users. Only positive points of such floorings relate to the long lifetime, easy handling of rolling devices, and ease of cleaning. They do not use carpet in this center, However, carpet is a perfect material of shock absorption character.

RISK OF FALLING DUE TO THE DURATION OF STAY IN AN AREA

Residens'activities were monitored for a few days in the *Collserola* center. Analyzed observations showed that the elderly sit in the dining room for about 10 to 12 hours (from 8 am till 8 pm or even more) and are generally warned not to walk (especially on the second and third floors). They are rarely allowed to go to their room except at the discretion of the nurses. Despite some entertainment and television, this time of sitting in a chair is tiring for them. Sometimes some elderly become impatient and disturb the rest of the elderly due to their problems. Independent seniors are allowed to go to the toilet themselves. But many of them use diapers during the day and night. Most of them take short and fast steps when walking and put their feet on the ground a little. Some are with shoes and some with sandals (Figure 4-23).

The staff does not constantly monitor them because they have to do other tasks in other sections after each meal, and the elderly are left alone in the dining room. Sometimes they are taken to other departments for examination or physiotherapy, or they are asked pre-determined questions and recorded on a piece of paper.

Shoe Type	Laced/ Velcro Sneakers	Special Velcro shoes	Sandal or flat shoes	Slippers, loafer, pantofle	Dress shoes
Photo					

Figure 4-23 Type of footwear used by seniors in the center-By Author

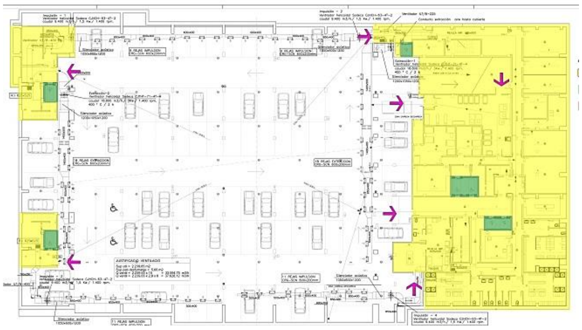
From about 8:00 pm, the elderly are transferred to their rooms. Transferring the elderly one by one to the rooms and preparing them for sleep is a little long. It may take 2 to 3 hours to take all the elderly to their rooms, and during this period, confusion can be seen in the elderly, and almost all of them start walking and doing extra activities to control themselves restlessly. And that's why two crashes happened while I was watching them. One in the same hall on the second floor as she tried to get out of her wheelchair and the other on the third floor (Table 4-7).

Table 4-7 Risk of fall due to the traffic and stay duration- By Author

Level	Class 1	Class 2	Class 3
Ground floor	• Administrative areas • Corridors • Stairs	• Toilets • Entrances • Lobby • Lifts	-
First floor	• Conference hall • Corridors • Stairs • Administrative room	• Gym • Day center salon • Occupational therapy • Toilets • Neurological unit • Corridor in Apartment and residential section	• Rooms and suites in Apartment and residential section • Toilets • Dining room
Second floor	• Stairs • Administrative room	• Corridor in Apartment and residential section • Club	• Rooms and suites in Apartment and residential section • Toilets • Dining room • Swimming pool
Third floor	• Stairs • Administrative room	• Corridor in Apartment and residential section • Club	• Rooms and suites in Apartment and residential section • Toilets • Dining room
Fourth floor	• Stairs • Administrative room	• Corridor in Apartment and residential section • Club	• Rooms and suites in Apartment and residential section • Toilets • Dining room

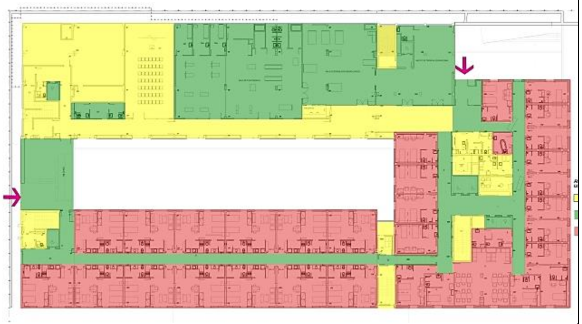
The CTE rules are a general standard for all pavements regardless of users and function. It was tried to look at the issue from the viewpoint of the users, activities, duration of presence in space. To classify high-risk areas with a new perspective(Table 4-8and Figure 4-24):

- It is assumed that all pavements are Anti-slip and the elderly are alone in that area.
- Falling probability rating is considered according to the type of activity (alone or under the vision of a specialist) and duration of stay in that space (more than 6 hours).



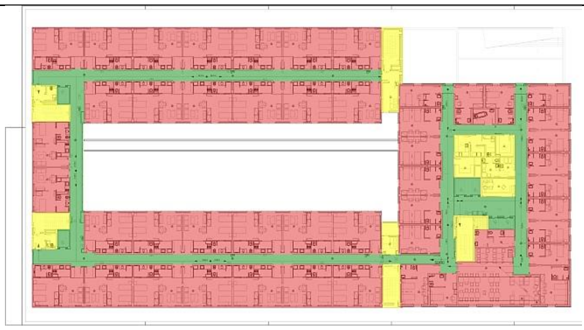
Basement Floor Mutuam Collserola Residence

Ground Floor Mutuam Collserola Residence



First Floor Mutuam Collserola Residence

Second Floor Mutuam Collserola Residence



Third Floor Mutuam Collserola Residence

Fourth Floor Mutuam Collserola Residence

Class1 Class2 Class3

Figure 4-24 Risk of falling due to the users, activities, duration of presence in a space-proposed by Author

Table 4-8 Risk of falling due to the users, activities, duration of presence in a space-proposed by Author

Section-User Main Areas	Day center	Apartment	Residential	Public areas	Administration areas	Services Mechanic
Main Entrance (with 7m radius)	2	2	2	2	1	1
Main Hall/ Lobby (with 7m radius from entrance)	2	2	2	2	1	1
Corridor	2	2	2	1	1	1
Stair	1	1	1	1	1	1
Lift	2	2	2	2	1	1
Offices	1	1	1	1	1	1
Bath/toilet	3	3	3	2	1	1
Kitchen	-	3	-	-	1	1
Restaurant	-	-	-	1	1	1
Dining/Living room	3	3	3	1	1	1
Room	3	3	3	-	1	1
Gym	3	3	3	-	1	1
Pool/ Jacuzzi	3	3	3	-	-	-
Club (Depend on the activity)	2	2	2	-	1	1
Physiotherapy	2	2	2	-	1	
Neurological unit	2	2	2	-	-	-
Occupation therapy	2	2	2	-	-	-
Laboratory	1	1	1	-	1	-
Locker/ Changing room	2	2	2	-	1	1
Hairdressing	1	1	1	1	1	1
Shop	1	1	1	1	1	1
Ware house	1	1	1	1	1	1
Parking	1	1	1	1	1	1
Laundry	1	1	1	1	1	1
Garbage/Waste	1	1	1	1	1	1

USER OF AREA

Many of the areas have the same function, but the users are different. For instance, bathrooms and toilets in administrative areas are not risky as the toilets in the apartment and residential sections. And similarly, we can mention the corridors and dining rooms.

TIME OF FALL

The elderly usually come to the dining room from around 6: 30-7 in the morning. Some who are independent come on their own, and others are brought in with the help of ward staff. After breakfast, they stay in the dining room, and a snack was served around 11:00. They have lunch at 13:00 and are in the dining hall until 17: 00-16: 30 when a light snack was served. They have dinner at about 19:00 and get ready to go to their rooms (Table 4-9).

In the hours between meals and especially after each meal, the environment is calm, and the elderly have enough energy. Still, from about 18:00, you can gradually see boredom in their behaviors, and this restlessness after dinner reaches its peak.

Table 4-9 Daily routine activity in the residential section based on hours- By Author

Hour/Section	Residence	Suite-Apartment
6:30-8:00	Waking up-taking shower	-
8:00-9:00	Taking to the Dining room	-
9:00-10:00	Breakfast in the Dining room	Breakfast in the Dining room
11:00-11:30	Snack in Dining room	Snack in Dining room
11:30-13:00	Stay in the Dining room	-
13:00-14:00	Lunch time in the Dining room	-
14:00-16:30	Stay in the Dining room	-
16:30-17:00	Snack in Dining room	-
17:00-19:00	Stay in the Dining room	-
19:00-20:00	Super time in the Dining room	Supper time in the Dining room
20:00-21:30	Taking to their room for sleep	*Rest of the time, they are free to go anywhere and use other centers or even go out of the center.

According to the author, high-risk hours among the elderly living in the residential area:

- In the morning before breakfast, they feel hungry, and the sugar blood in the elderly is low;
- After lunch due to drowsiness and;
- One hour before and two hours after dinner, which makes them boring and confuses to get back to their room themselves in the evening. At this time, the corridors are unsafe as well.

PRELIMINARY DISCUSSION AND RESULTS

During mealtime, all seniors are relaxed and feel comfortable in residence section. But sometimes, in the interval between meals, the nurses inspect them, and during these periods, they may fall. In the apartment section, the elderly has a better physical condition. They live alone and do their daily activities independently. This section has more facilities than other sections, like Gym, the Club, the pool, and the Jacuzzi, the more comprehensive fall-risk ranges. As the graph shows, the private apartment, pool, and gym are the most dangerous place for them because they are active without any observation in these areas. Activities in any section are different. In an apartment, due to the independent lifestyle, they are more involved in other places. But in general, due to the physical and environmental factors, it can be said that working in the kitchen[104], bathroom, pool[105], and gym[106] are the physical activities that increase the fall risk, among other conditions. If they have permission to go to their room during the day or wake up during the night to use the bath, the dining room, and their rooms are risky for them in the residential section because the beds are high guarded with protective bars. But generally, in physiotherapy and open areas, someone as assistance accompanies the seniors that decrease the possibility of falls.

The day center is located on the basement floor, and most of the activities take place in one big room with Intellectual and handicraft entertainment and a small toilet. In Residence and Day center, the activities are more limited because they spend most of their time in a steady room. They woke up, went to sleep, went to the toilet (if she/he is independent), and took a shower with staff help. Because of the activities and exercises without their assistive devices, the physiotherapy area is risky for seniors. Still, due to the presence and close supervision of nurses, typically, nothing dangerous happens.

[104] Setting coordination a and discipline in making food and permanently changing body positions from standing to head or body rotation, bending, raising the head, or even standing up on tip toe to reach something.
[105] Slippery floor and blood sugar or blood pressure
[106] Fast body reaction, forward and backward

Maybe some types of shoes would be comfortable for the elderly, but they are not safe enough to help them to maintain balance. The Velcro sneakers and Special Shoes for the Elderly are the best choices in keeping balance with a lower risk of falls.

4.2.3 INSTALLATION OF PROPOSED FLOORING FOR PRACTICAL ON-SITE TESTING

Figure 4-34 shows the installing of the floors received from flooring companies. The next step was to verify the impact absorption properties of the proposed floorings in the real environment and to know about the opinions of the users and employees of the Center.

Figure 4-25 First level terrace of the *Mutuam* Collserola Residence-By Author

Proposed floorings were installed on a covered terrace of the Collserola Center (Figure 4-25 and Figure 4-29), a space offered by the *Mutuam* Group. Since the 14 pavements provided by different companies are of different dimensions, characteristics, and thicknesses, a layout was designed before installation, thus generating two routes (Figure 4-26).

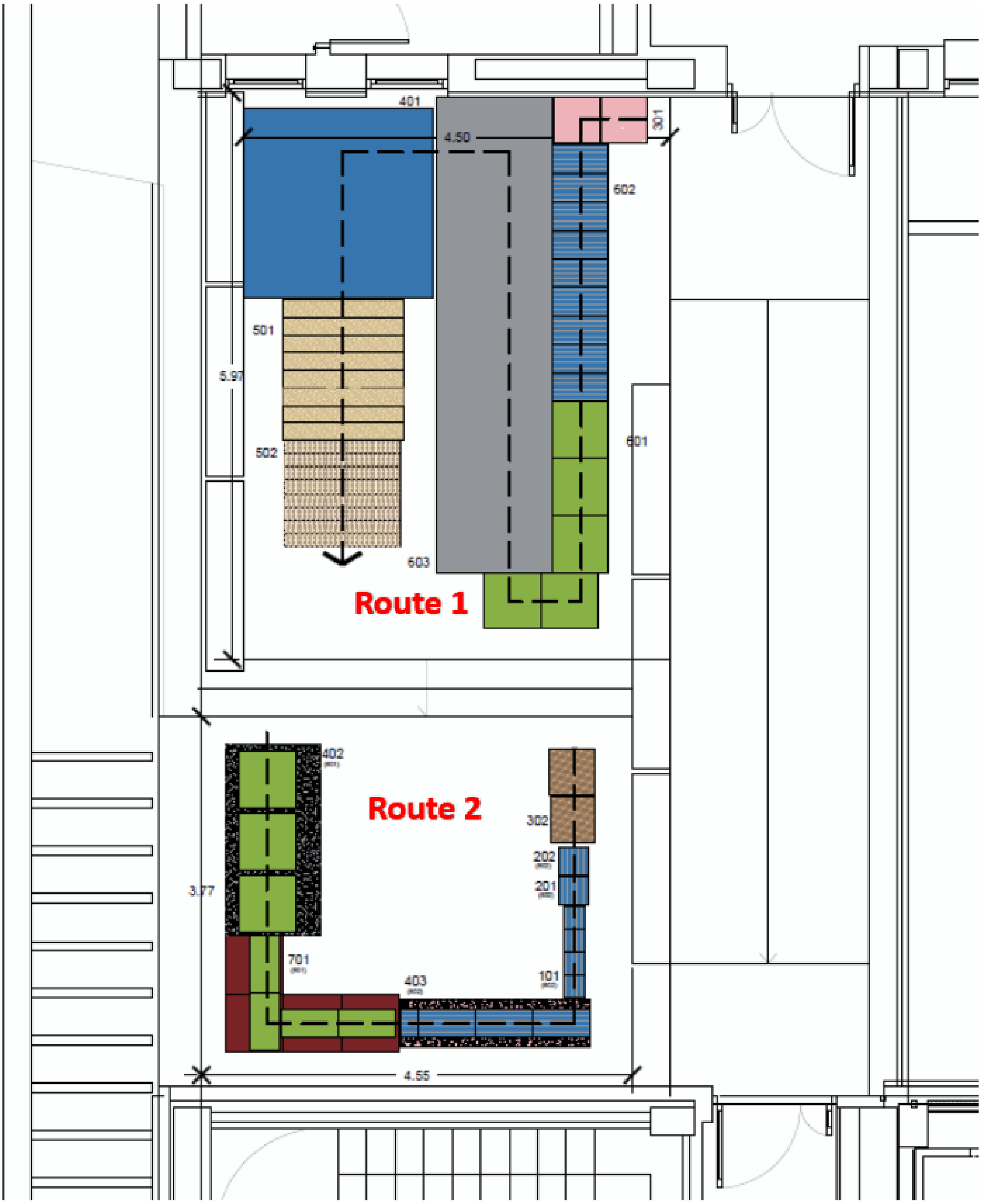


Figure 4-26 Layout of the flooring installation-By Author

The pavements were divided into two routes according to the size, and properties. The first group did not need a coating layer. It means they can be used in indoor areas without any surface problems. The second group was the CF system. These floorings do not provide a proper surface for indoor areas because of the porosity that they have. Thus they need another top layer to be suitable to be used in hospital, senior residence or clinic. (Figure 4-27 and Figure 4-28) with this method, we wanted to give the elderly the same feeling of other common floorings and avoid emphasizing and focusing on roughness and possible friction under the shoes of the elderly:

Route 1: Vinyl flooring and parquet

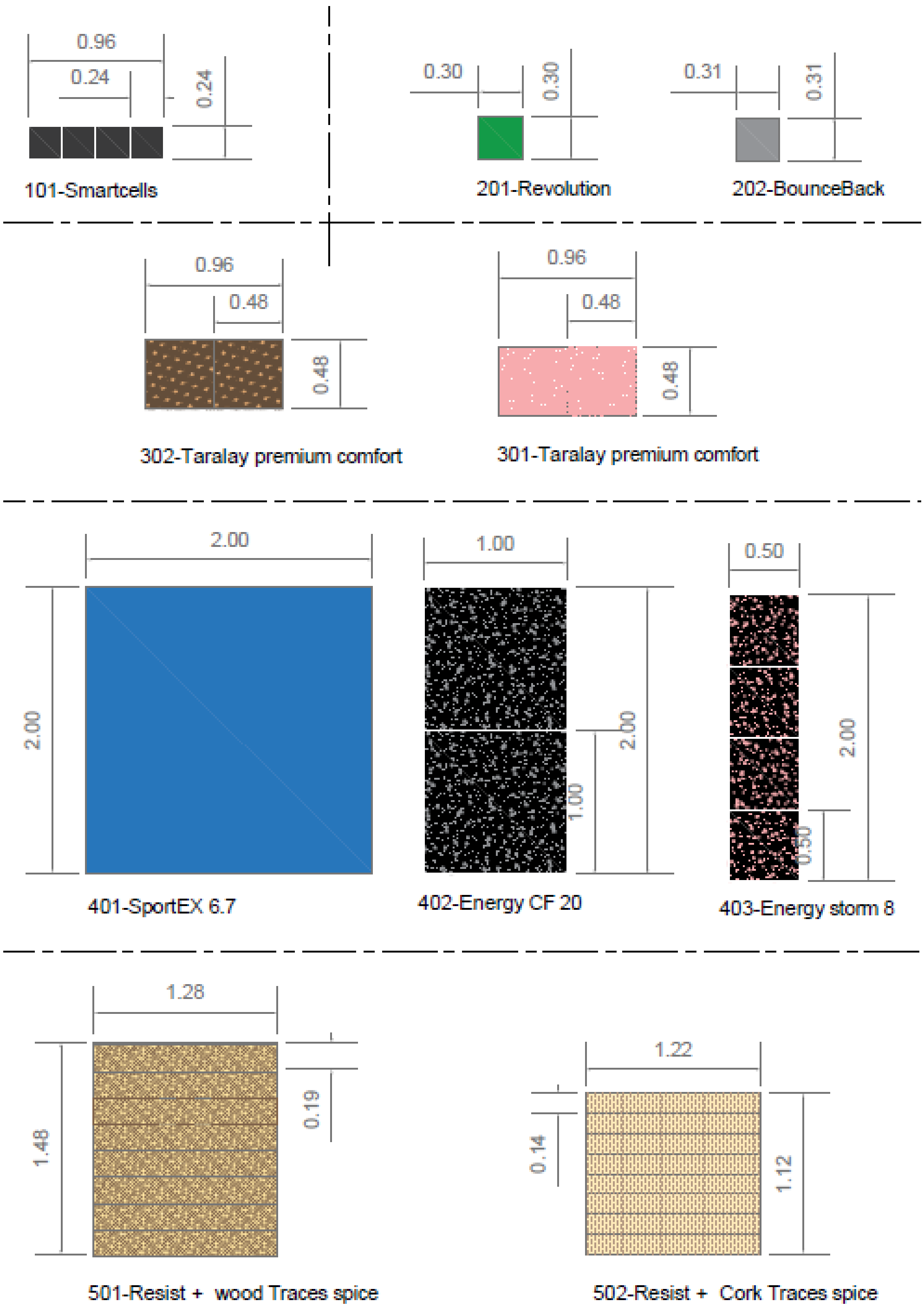


Figure 4-27 Vinyl Flooring and Parquets-By Author

<u>Route 2: Rubber and sports flooring</u>

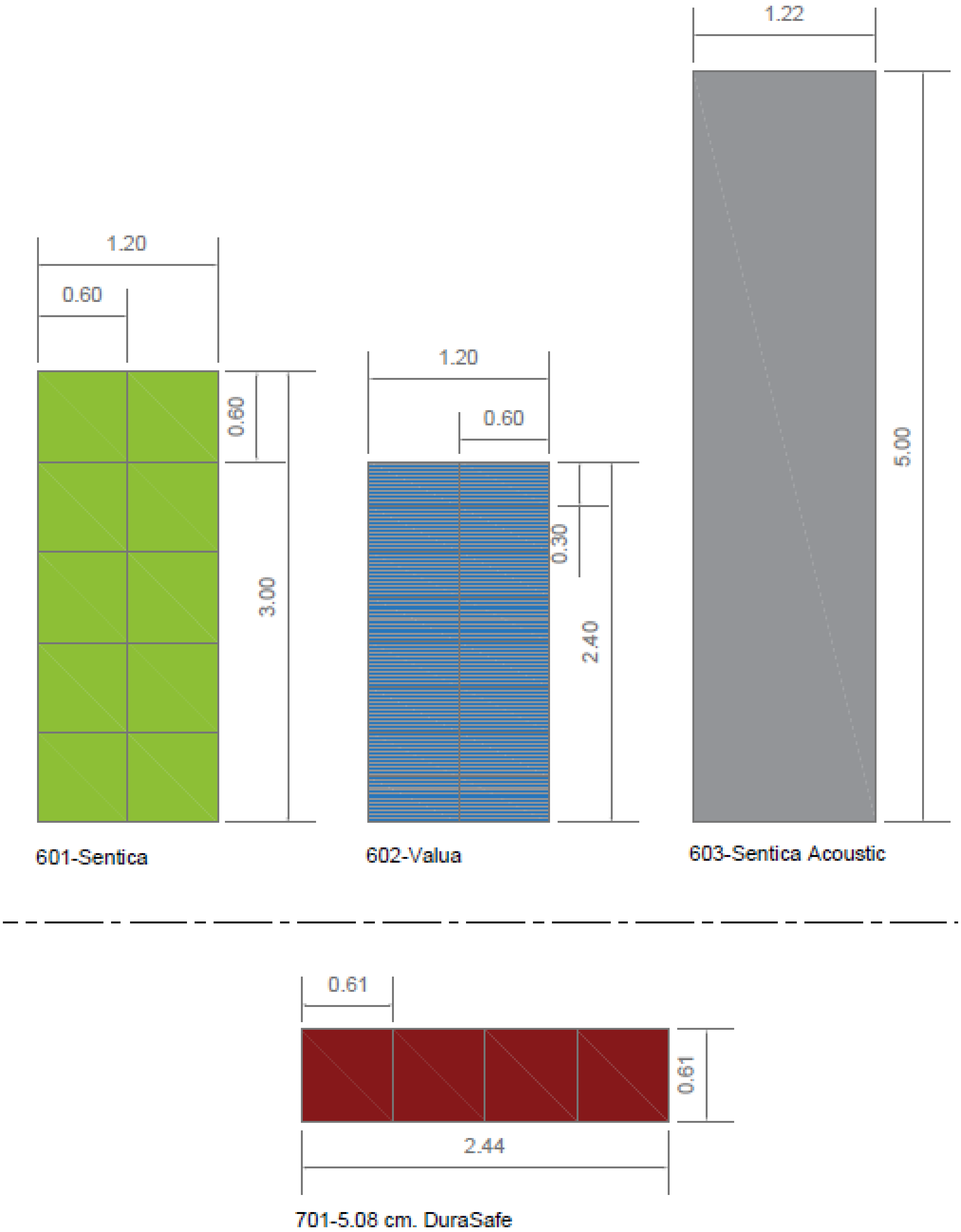


Figure 4-28 Rubber and sports flooring-By Author

The pavements were installed using double contact tape to adhere them to the terrace pavement (concrete tiles). Double side tape was used since, after all the tests, the pavements must be dismantled. Following the layout, it was possible to install the two routes with the 14 pavements.

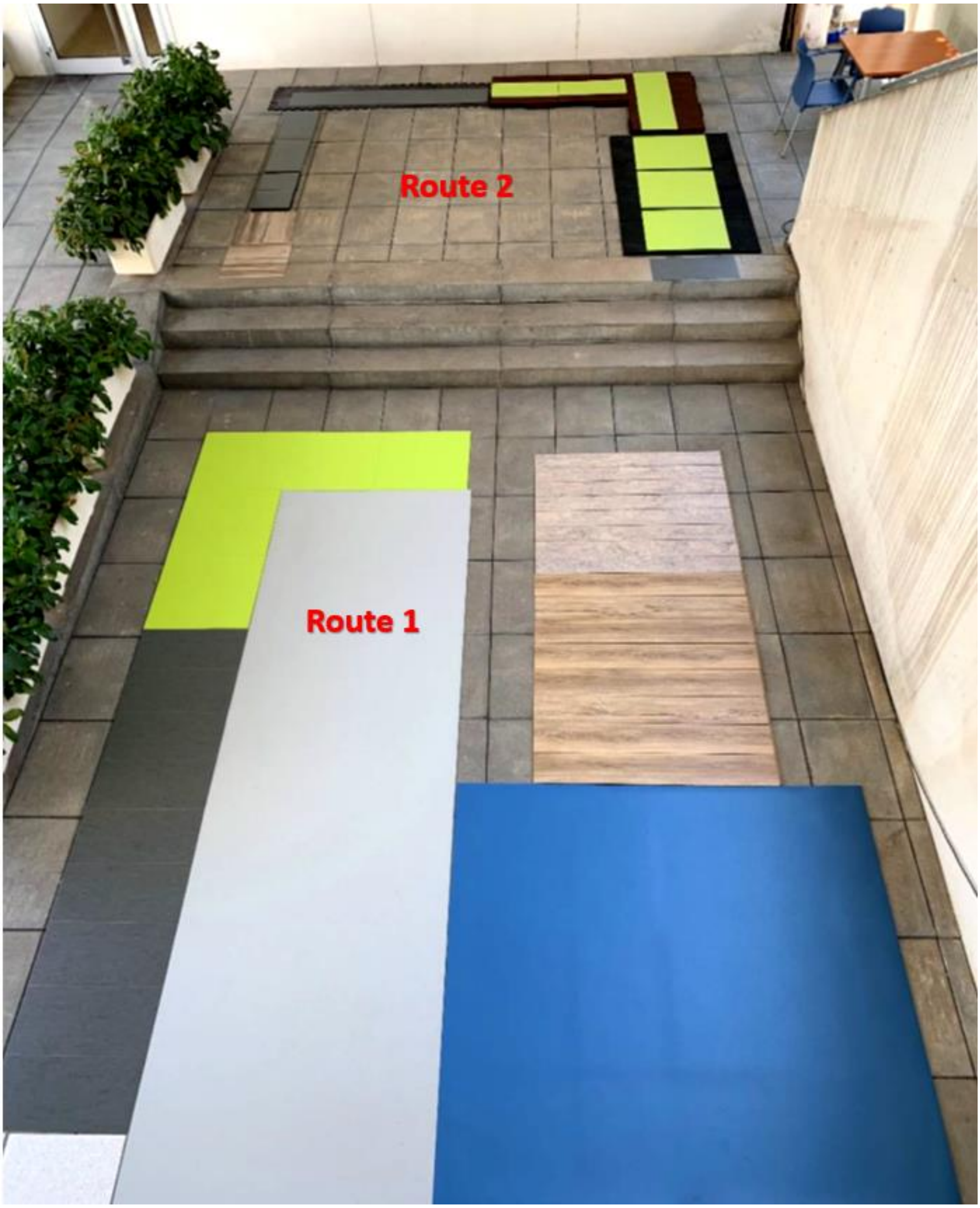


Figure 4-29 Final and complete installation of the fourteen floors-By Author

4.2.4 QUALITATIVE EVALUATION OF THE DIFFERENT TYPE OF PROPOSED FLOORING (INTERVIEWING THE ELDERLY AND STAFF)

HEALTH PERSONNEL

The second interview was carried out to find out the opinion of all the center's personnel about the proposed pavements installed in the center. 100% of staff believed that the use of specific shock absorption pavement is essential for social-sanitary spaces. Similar to the first interview all qualitative data and opinions of the participants and interviewees are presented in the form of figures and quantitative data in order to provide a better idea and understanding of the deterioration or relevance of the conditions and subject of the interview.

Each of the staff walked on the installed pavements while they were asked about:

- Their feeling during step on pavements and changing from one Pavement to another;
- About the flexibility of the pavements;
- Appearance and aesthetic of the surfaces;
- Balance and safety;

Finally, they were asked to choose one or two of the pavements based on their experience as the ideal surface to install. That would help both the elderly reduce injuries in the event of a fall and staff's daily activities (Figure 4-30).

Figure 4-30 Health personnel walking on the proposed pavements-By Author

OLDER ADULTS

The older adults were asked to walk on the installed pavements similar to the health personnel, while were asked about the importance of using a pavement with shock absorption. In any interior space in which older adults operate, the response was positive from 100% of those interviewed.

While they were walking only the proposed pavements, they were asked to explain their feelings about each one and their different routes. 70% of the older adults did not notice any difference in the flexibility when walking on the types of vinyl, even though each had a different thickness (Figure 4-31 and Figure 4-32).

Figure 4-31 Seniors walking on the proposed pavements (route one)-By Author

The biggest concern they had was whether they were slip-resistant. 80% of adults ruled out the pavement with COD. 603, since being a completely uniform, smooth, and very slippery vinyl, which generated a lot of insecurity when walking.

When they walked on the second route, where the rubber (Molded rubber crumbs) and sports floors were installed, approximately 50% of the adults felt very soft, which gave them the feeling of instability since their knees or ankles were swaying reason, they chose stiffer pavements.

Figure 4-32 Seniors walking on the proposed pavements (route two)-By Author

As most of these floorings were new for them, 30% of the adults chose parquet flooring (code 501) as they were familiar with this material because it reminds them of when they lived in their apartments and valued the warmth that gives them wood to space. Based on this, some also commented that they liked the wood-printed vinyl flooring (code 302) even though it did not have any cushioning. 14% of the adults commented that the current floor of the center covered by terrazzo, was fine, and they did not want to change it. The pavements with codes 301,401,402,403, 603,701 represent 42% of the total sample, each one of them was chosen by 7% of the elderly (Figure 4-33).

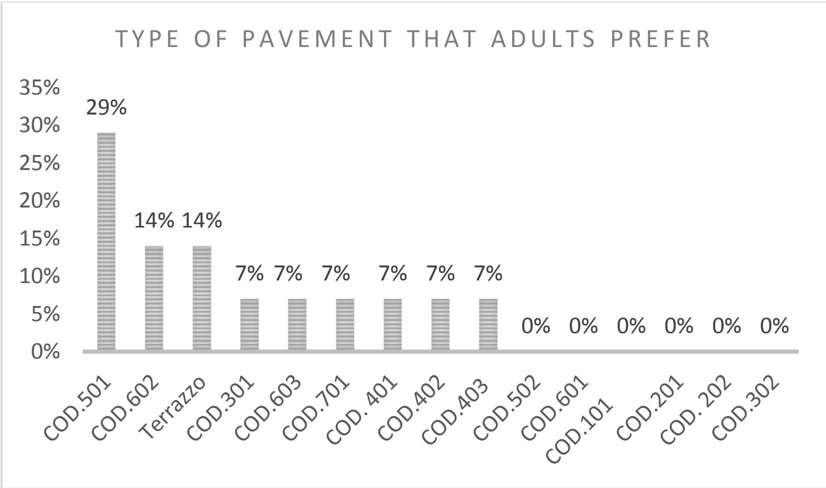


Figure 4-33 Selected proposed floorings by the elderly-By Author

Figure 4-34 Proposed floorings installed on-site

INTERVIEWS WITH A NUMBER OF EXPERIENCED ARCHITECTS

In this research, I also interviewed two architecture companies (Estudi PSP Arquitectura and LA (H) B). Both companies had projects focusing on medical centers and hospitals. The architects of both architectural firms had no idea about impact-absorbing flooring for interior use. Floors were generally divided into five main parts in their design:

1. Hard material with proper durability (Terrazzo or Ceramic) use in outside, corridors, main entrance and lobby, stairs and areas with high traffic;
2. Soft and delicate surface (Rubber, Vinyl or Linoleum, Carpet or Synthetic material) mostly use in consultations, Inpatient ward;
3. Anti-slip surfaces (Ceramic, terrazzo) mostly use in wet areas such as bathrooms, kitchen, laundry, pharmacy;
4. Conductive floors use in isolated areas and introduce a hazard of electrical shock such as Operating room, labs, radiography;
5. Hard material such as concrete use in services, mechanical places with heavy machines, stores, parking;

They usually ordered their flooring from the types available in the market and the brochures offered.

According to the opinion of the interviewed architects, the use of shock-absorbing flooring for the elderly and high-risk spaces can be a good idea, provided that they are cost-effective in terms of durability, purchase, maintenance and upkeep. Otherwise, the employer will not be willing to use such products. In public projects, simple, cheap and durable flooring products were used (terrazzo, ceramic ...) while private projects had a greater variety of products (carpet, vinyl ...).

PRELIMINARY DISCUSSION AND RESULTS

Due to the difference in the size and number of floorings sent, unfortunately, the desired method in the implementation of this part of the study was not fully realized. For instance, some products were provided as just one sample tile about 30x30 cm, and its performance evaluation is practically almost unreliable. Another issue was about the surface of the products. Those with a smooth surface such as parquet (wood) and vinyl are suitable to be used in indoor areas, especially in the nursing home or health clinics. The products with a rugged surface (crumb Rubber) with pores must be covered by another layer like vinyl or carpet to be adapted for such spaces. In this case, we covered the second route (tiles with rugged surface) with a layer of vinyl tiles to prevent the transmission the feeling of surface roughness to the elderly or staff.

Despite of reminding to not to pay attention to the flooring color (because they can be any color) and just focus all their attention on the feeling underfoot, but in the process, the sense of pleasant atmosphere and habit was more important for the elderly, and they tended parquet (wood), and a rigid surface because they felt more secure when walking. But the staff looked more closely, preferring to clean the vinyl surfaces, and felt some of the floorings under their feet were a little elastic, which could cause to fall. Of course, the collected floors were by no means so flexible and this feeling was only because of the small size of some product tiles, which caused the person not to feel the necessary endurance under his/her feet.

When we talked to architects about safe flooring, most of them were concerned about the non-slip flooring. And by mentioning the type of shock absorption flooring, their first example was a children's playground. It seems that despite the importance of the subject and the many studies that have been done in this case, but the promotion of shock-absorption flooring and the variety of this product has not been enough that architects, designers and investors are aware of the existence of such products.

4.3 METHODS USED IN EVALUATING SHOCK ABSORPTION OF PROPOSED FLOORINGS

the following tests were carried out:

ON-SITE-TESTS:

- Drop weight impact test (DWI)-Measurement of the coefficient of restitution (own execution)-CoR
- Visual verification test of the pressure distribution (own implementation and analysis of the results carried out by QBM)- Visual Pressure Area (VPA)
- Analysis of the color distribution with a sandbag (own implementation)*
- Reaction to impact with Slime (own implementation)*
- HIC test (executed by *Sanpe* Engineering and supervised by the author)

*Color distribution with sandbag and Reaction to impact with Slime were two tests designed and implemented by the developers to simplify the quantification of impact on the surface and were not included in this doctoral thesis. If you are interested in knowing more about these two issues, refer to the Master thesis of Ximena Aguirre Suarez[107].

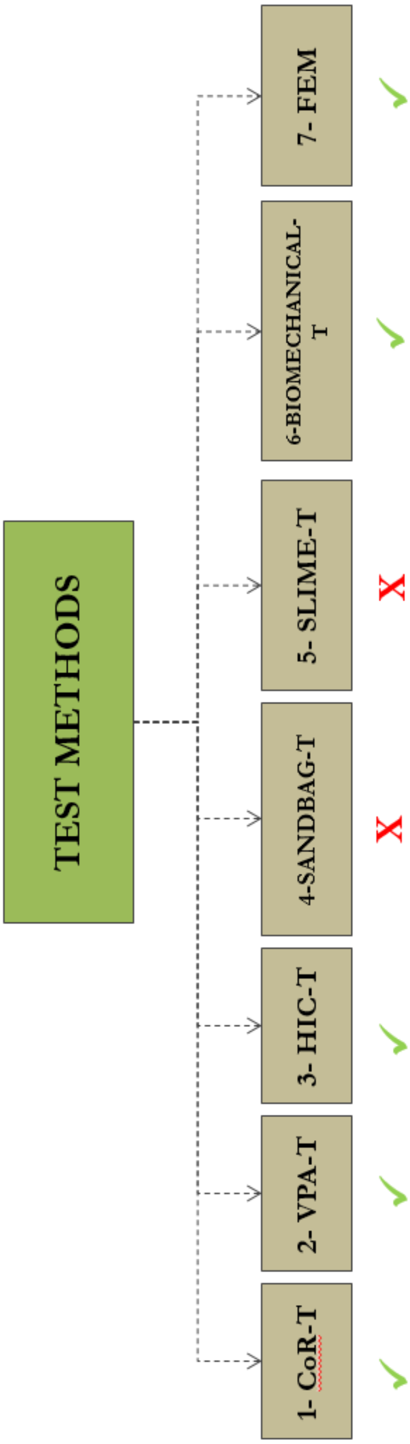
LABORATORY TESTS:

- Biomechanical test using the force plate and insole pressure mapping (own execution and in collaboration with UB University Department Section of Podiatry and supervised by Dr. Carles Verges Salas[108])

MODELLING AND SIMULATION:

- Using Finite Element Method-FEM to simulate the impact on proposed tiles (own execution)

[107] https://upcommons.upc.edu/handle/2117/171363
[108] https://es.linkedin.com/in/dr-carles-verg%C3%A9s-salas-77991234


TEST METHODS
1- CoR-T
2- VPA-T
3- HIC-T
4-SANDBAG-T
5- SLIME-T
6-BIOMECHANICAL-T
7- FEM

TEST 1 : DROP WEIGHT IMPACT TEST (DWI)

MEASUREMENT OF THE COEFFICIENT OF RESTITUTION (CoR)

4.3.1 TEST 1 – DROP WEIGHT IMPACT TEST (DWI) (MEASUREMENT OF THE COEFFICIENT OF RESTITUTION- ISO 10545-5)

MATERIALS AND METHOD

The ISO 10545-5: 1998 standard has established a method for determining the impact resistance of ceramic tiles by measuring the coefficient of restitution; we used the evaluation process established in the standard as a guide to calculate the coefficient of restitution with the equation (Dondi, 2016) (Sarıışık, 2016) explained in point 1 of section 3.2.2. In this method a white sheet was fixed to the wall, and the measurement was marked on the sheet. A metal ball was dropped from a height of 100 Cm (h1) above on each surface and was allowed to bounce. The procedure for each flooring was repeated three times.

A metal ball was used since it was the material used in the standard test explained in section 3.2.2. and rigid enough that it does not deform and does not bounce under the influence of the nature of its constituent material. Therefore, it can make reliable to show the flexibility and elasticity of the floors. A fixed professional camera with a tripod was placed at 130cm distance to the wall to film in slow motion all the falls and the moment of bounce (h2) to be able to stop the video at the highest moment of bounce and thus be able to measure the height of the bounce with an accuracy of + / - 1mm and calculate the coefficient of restitution (e) with the following formula:

$$C_R = e = \sqrt{\frac{h}{H}} \quad (4.1)$$

The procedure was repeated with the fourteen floors. The metal ball used weights 55 gr. and a radius of 3.5 cm (Figure 4-35).

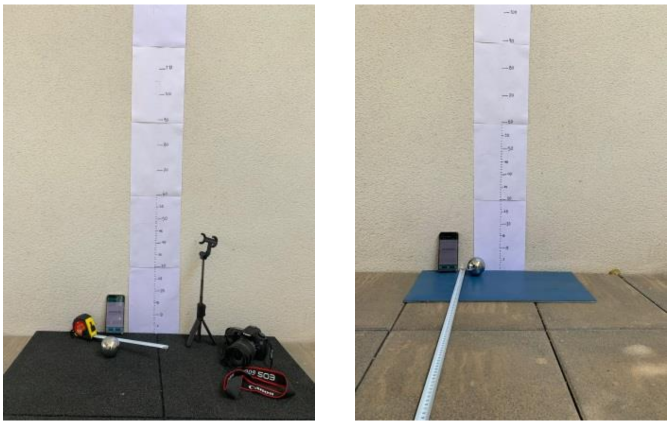


Figure 4-35 Materials used in test one-By Author

After withdrawing all the rebound heights from all floorings, the coefficients of the restitution were calculated. The results are given in the following table as results:

Table 4-10 Comparative results of coefficient of restitution (e)-By Author

CODIGO	301	302	602	Con	601	603	401	702 RF	501	502	202	201	403	701	402	101
e	0	0	0	0	0.1	0.17	0.28	0.34	0.4	0.4	0.48	0.49	0.51	0.64	0.65	0.71

The coefficient of restitution is affected by the nature of the impact, the speed of impact, and the composition, temperature, and elasticity of the colliding object.

The coefficient *e* presents values in the interval of real numbers that go from 0 to 1. If the value is zero, a perfectly inelastic collision[109] is assumed, while if e = 1 it is considered a perfectly elastic collision[110].

If *e* = 0 perfectly inelastic collision.

If 0 < *e* < 1 semi-elastic collision.

If *e* = 1 perfectly elastic collision.

PRELIMINARY DISCUSSION AND RESULTS

All the values were compared with the value of the CoR test on the Concrete as a rigid surface. As it is seen in (Table 4-10and Figure 4-36), ***e*** in products with code 301, 302, 602, and concrete is 0, which means that the impact is perfectly inelastic, as there is no loss of kinetic energy, the metal ball does not bounce. The other pavements have a value between 0 and 1 in which the shock is semi-elastic. The pavement with codes 101, 402, and 701 have a higher coefficient of restitution. More photos and details are presented in appendix D. The pavements with codes 101, 402, and 701 have a higher rebound height compared to the other pavements, which means that all the potential energy Initially, has been transformed into kinetic energy after the impact, without losses due to friction with the air due to the effect, this being an elastic impact.

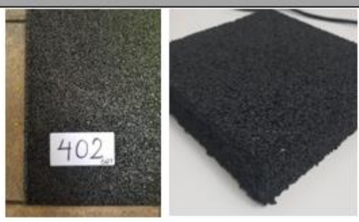
COD.101	COD.402	COD.701
***e* = 0.71**	***e* = 0.65**	***e* = 0.64**
		

Figure 4-36 Comparative results of coefficient of restitution (e)-By Author

[109] Inelastic shock is one in which there is a loss of kinetic energy. While in this type of collision the moment of the system is conserved, is not the kinetic energy. This is because a part of the kinetic energy is transferred to something else. Thermal energy, sound energy, and deformations of materials are likely culprits.

[110] An elastic collision is a type of collision with no loss of kinetic energy in the mechanism as a result of the collision. Both momentum and kinetic energy are values that are stored in elastic collisions.

*Hint:

It should be noted that the rule," The higher the ball rebound after drop, the more energy absorption does not apply to all materials and surfaces such as sand or soft foam rubber because of vertical displacement. While, code 702 showed the fome rubber result with 0.34 of *e* with 12mm thickness and soft surface and structure.

TEST 2 : VISUAL PRESSURE AREA (VPA)

4.3.2 TEST 2 - VISUAL VERIFICATION OF PRESSURE AREA (VPA) BY MEASURING THE COLOR DISTRIBUTION

MATERIALS AND METHOD

The second test was performed with the "*prescale*" technology that explained in point 2 of section 3.2.2 provided by Fujifilm. Fujifilm offers a series of films (sheets) with different sensitivities to measure pressure (Figure 4-37) to verify the result of the pressure distribution in a visual format. The materials used in this test were two rolls of the 4LW *prescale* sheets (A&C), a tape metric to measure the height of fall in each of the tests, a metal ball with a weight of 55gr and a diameter of 3.5 cm (use the same metal ball in the first test, measuring the coefficient of restitution). The whole process was filmed and photographed with an iPhone XR fixed on a tripod to maintain the same filming height in the 14 tests (Figure 4-38).

(A) (B) (C)

Figure 4-37 Materials used in test two and Prescale pressure measurement film (PMF): (A) Camera fixed on tripod (B) Metal ball (C) A and C rolled sheets of 4WL film-By Author

"Prescale" is a sheet/film that could easily measure the distribution and the amount of pressure visually by the color density. As explained in section 3.2.2, Fujifilm's advanced technology of coating a thin film was created. It visualizes the pressure distribution of the whole surface by changing its color to red according to the applied pressure.

The two rolls of the 4WL *prescale* sheets were cut to have square sheets of 15x15 cm. They were placed on the visible face of each of the pavements, coding each of the sheets with the pavement code. The metal ball was dropped onto the 4LW Fujifilm *prescale* sheets from a height of 100 cm on each pavement. This test was performed twice on each pavement. The results were scanned with Fujifilm's special slide scanner and analyzed with the FPD-8010E software (Table 4-11) (Figure 4-39).

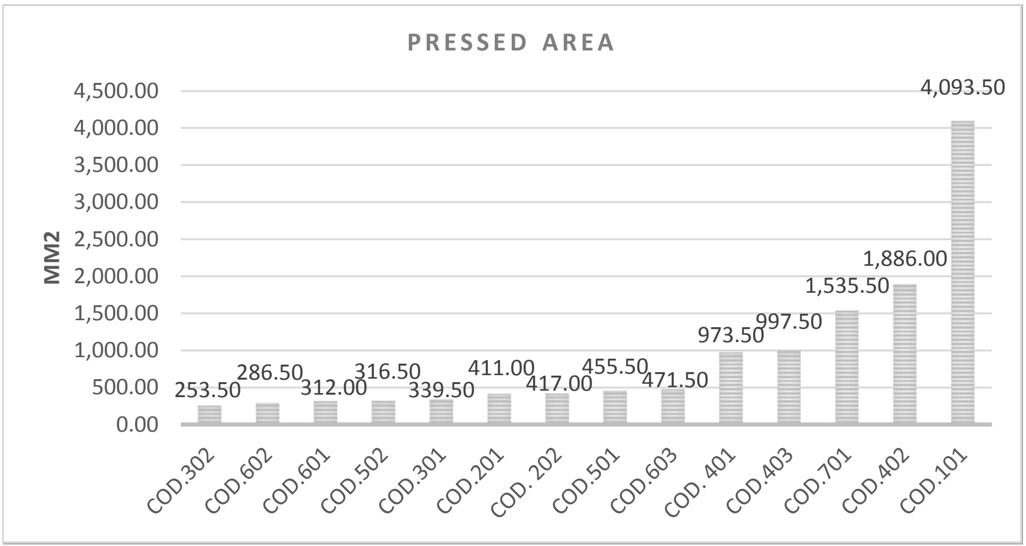


Figure 4-38 FPD-8010E Software Results of Pressured Area-By Author

The scanned sheets are presented in appendix D with pink color and the image of sheets in the FPD-8010E software (with the color red, yellow, and green) before the analysis. To verify the final result, the test was run twice on each pavement. The graph shows that the yellow color has reached the highest impact of more than 0.25Mp and that the red and green colors have reached the lowest impact and energy from the fall of the metal ball.

Table 4-11 FPD-8010E Software Measurement Results-By Author

COD	VALORES										
	PRESCALE EFFECTIVE RATE (%)	AVE PRESCALE EFFECTIVE RATE (%)	PRESSED AREA (mm2)	AVE PRESSED AREA (mm2)	AVE PRESSURE (Mpa)	AVE PRESSURE (Mpa)	MAX PRESURE (Mpa)	LOAD (N)	AVE LOAD (N)	MEASURED AREA (mm2)	AVE MEASURED AREA (mm2)
COD.101 A	61.20	55.60	4,264.00	4,093.50	0.15	0.16	0.25	648	667.5	5289	4906
COD.101 B	50.00		3,923.00		0.17			687		4523	
COD.201 A	41.40	42.45	471.00	411.00	0.19	0.18	0.25	89	74.5	486	486
COD.201 B	43.50		351.00		0.17			60		486	
COD. 202 A	36.61	36.12	421.00	417.00	0.2	0.2	0.25	89	85	486	486
COD. 202 B	35.62		413.00		0.2			81		486	
COD.301 A	59.09	48.48	429.00	339.50	0.13	0.15	0.25	56	49.5	486	486
COD.301 B	37.86		250.00		0.17			43		486	
COD.302 A	35.60	36.50	255.00	253.50	0.14	0.15	0.25	45	42.5	484	482
COD.302 B	37.40		252.00		0.16			40		480	
COD. 401 A	39.30	35.65	1,023.00	973.50	0.19	0.195	0.25	198	193.5	1164	1102
COD. 401 B	31.99		924.00		0.2			189		1040	
COD.402 A	44.74	40.02	2,063.00	1,886.00	0.18	0.19	0.25	373	356.5	3250	2647.5
COD.402 B	35.29		1,709.00		0.2			340		2045	
COD.403 A	39.60	36.51	1,093.00	997.50	0.19	0.195	0.25	204	193.5	1286	1159.5
COD.403 B	33.41		902.00		0.2			183		1033	
COD.501 A	40.05	37.76	466.00	455.50	0.19	0.195	0.25	88	87.5	486	486
COD.501 B	35.46		445.00		0.2			87		486	
COD.502 A	35.26	34.81	357.00	316.50	0.19	0.2	0.25	69	63.5	486	486
COD.502 B	34.35		276.00		0.21			58		486	
COD.601 A	33.54	30.90	309.00	312.00	0.2	0.205	0.25	63	65	486	486
COD.601 B	28.25		315.00		0.21			67		486	
COD.602 A	32.89	30.68	282.00	286.50	0.21	0.215	0.25	60	62.5	291	291
COD.602 B	28.47		291.00		0.22			65		291	
COD.603 A	28.36	27.42	471.00	471.50	0.21	0.21	0.25	97	98	486	486
COD.603 B	26.47		472.00		0.21			99		486	
COD.701 A	35.69	36.38	1,522.00	1,535.50	0.2	0.2	0.25	303	604	1821	1787.5
COD.701 B	37.06		1,549.00		0.2			905		1754	

We were looking for a method to simply recognizing those products with higher shock absorption rates with color distribution after impact. We assumed that the larger color distribution and the larger area of color appeared after the impact (Li N. E., 2013) (MacDonald, 1996), mean more shock absorption and better energy distribution the pavement has.

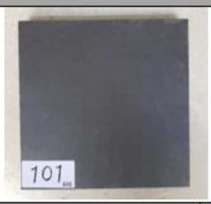
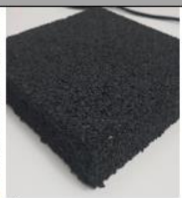
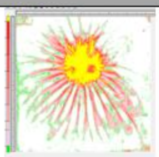
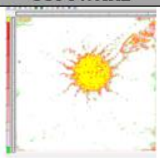
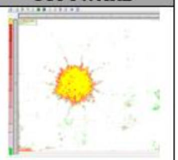
Hint: *Before using *Prescale* sheets, we tried two other methods (Impact reaction with slime material and color distribution with sandbag), which failed due to limitations in test execution.

PRELIMINARY DISCUSSION AND RESULTS

Since each pavement was tested twice, the average of each result was calculated. Among all these results, the helpful measurement to verify the pressure distribution is the results of the item “Pressured area.”

The more colored area that appears in each test shows the greater energy distribution in that pavement in the event of an impact. This indicates less pressure felt by the pavement's surface, and the pavement with the greater pressure area has a greater energy absorption property after an impact. The graph of the results of the pressed area shows that the pavements with codes 701, 402, and 101 have a greater pressed area. The test carried out on the 701 pavement has an approximate area of 410 cm^2, the 402 pavement an area of 190 cm^2, and the pavement 101 showed an area of 150 cm^2 (Table 4-11).

Table 4-12 The average of verification of pressed area-By Author

COD	COD.101		COD.402		COD.701	
Photo						
Scan	SCANNED SHEET	SHEETS ANALYZED WITH THE FPD-801E SOFTWARE	SCANNED SHEET	SHEETS ANALYZED WITH THE FPD-801E SOFTWARE	SCANNED SHEET	SHEETS ANALYZED WITH THE FPD-801E SOFTWARE
						
*AVE AREA (mm^2)	15000		19000		41000	
AVE PRESSED AREA (mm^2)	4,093.50		1,886.00		1,535.50	
AVE LOAD (N)	667.5		356.5		604	
**AVE MEASURED AREA (mm^2)	4906		2647.5		1787.5	

*This item was measured by Photoshop.
** This item was measured the more effective area by software.

Table 4-12 shows the average area of color distribution, press area, and load for three products with the highest shock absorption rate among 14 products. As can be seen, the results of this method confirm the previous method (CoR method), and in both methods, three products, codes 101, 402, and 701, were approved as the best shock absorber among 14 flooring types. To this end, we continued our research by focusing on these three samples of flooring and left out other options as rejected items.

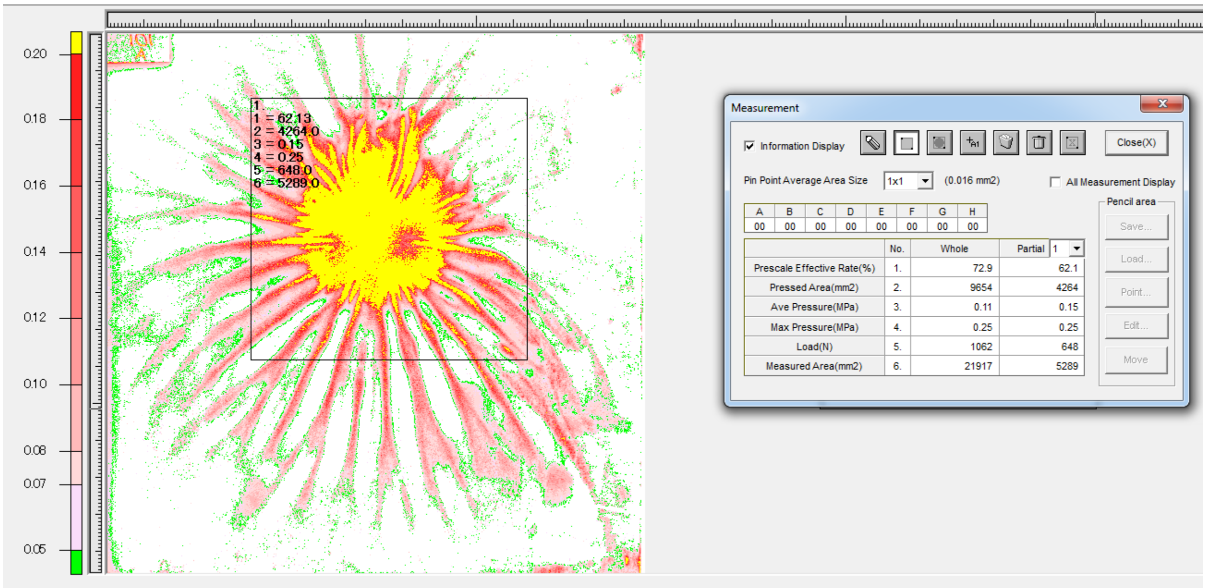


Figure 4-39 An example of the data analyzed (first trial) by the software (FPD-8010E) for flooring 101 after the fall-By Author

*Due to the variety in the sheets provided by *FUJIFILM* in accordance with the amount of pressure and force applied to the surface, this method is a quick and easy way with high performance to detect the amount of pressure applied by software analysis or approximate pressure detection according to the extent of the area the color spectrum is created.

The problem in this part was related to the behavior of the floor concerning the rebound of the metal ball. In some cases, the ball's rebound was so slight that it was difficult to grab the ball after the first collision, which created points or lines on the film that was not what we wanted, and the test had to be repeated.

TEST 3 : HEAD INJURY CRITERIA (HIC)

4.3.3 TEST 3 – HEAD IMPACT STUDY -HIC- EN 1177: 2018+AC

MATERIALS AND METHOD

Head Injury Criteria (HIC) is an index related to the probability of suffering some head injury due to an impact or violent deceleration of the head in some kind of accident (Gao, 2009). The HIC is used as a standard index in the automotive industry, the sports equipment industry, and children's play equipment[111] to predict possible brain damage.

The HIC value is obtained from the deceleration curve[112], generally obtained from tests using an accelerometer placed at the center of gravity of a crash test dummy head subjected to the typical forces of a frontal crash. The EN 1177: 2018 + AC standard specifies a method to determine the impact attenuation of the playing surface that defines a "Critical Fall Height-CFH" for the surface, representing the highest limit of its effectiveness in reducing head injuries using playground equipment. The test methods described in The European Standard are applicable for tests performed in a laboratory and for tests on site.

Figure 4-40 Pavements used in the HIC test-By Author

The collaborating company *Sanpe Ingenieria*[113] was the one who carried out the test on-site based on the standard mentioned before because it is a company accredited by ENAC[114] for the use of the new regulations for playgrounds. The application of these pavements was not adequate for our case study (nursing homes, residences), due to the finished surfaces with small pores. Therefore, the real condition must be verified. In this case, we covered the surface of three products (101-U1, 402-U3, and 701-U2) with a thin vinyl code 301 with 2mm thickness that can guarantee the properties of easy cleaning, anti stains, that allows wheelchairs to be easily moved, etc. (Figure 4-40).

[111] Swings, Slides, Seesaws, Playground Climbers.
[112] Deceleration: It is the negative variation in speed, that is, the physical magnitude that expresses the passage of a moving body from one speed to another lower speed, always following the same path. This term can also be defined as negative acceleration.
[113] For more information, visit the website: https://www.sanpeingenieria.es/
[114] Entidad Nacional de Acreditación - National Accreditation Entity- visit the website: https://www.enac.es/web/english/home?p_p_mode=view&p_p_lifecycle=1&p_p_state=normal&p_p_id=MensajeCookie_WAR_Gestionportlet&_MensajeCookie_WAR_Gestionportlet_javax.portlet.action=aceptarTodas

The test was carried out twice on each pavement. The first time on the original surfaces without any overlay to see the attenuation properties of each one. And the second time repited with the overlay (vinyl coating) to discover if any layer over the original surface of the pavements will affect the results.

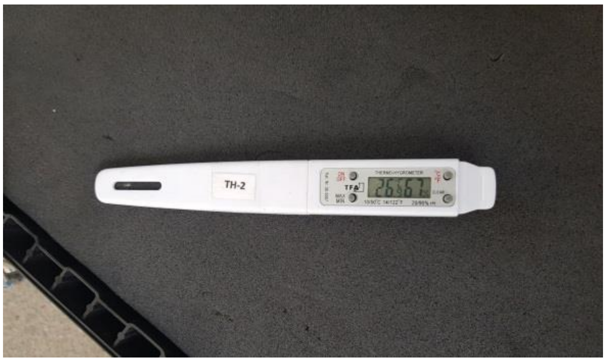


Figure 4-41 Thermometer used to measure ambient temperature and humidity-By Author

To begin the on-site test, the temperature and ambient humidity must be measured. The measurements gave at a temperature of 26 degrees Celsius and relative humidity of 67% since, according to the standard, the tests can only be carried out when the temperature of the surface of the product be between 5 ° C and 55 ° C and all relevant weather conditions should be measured and recorded throughout the test, e.g., humidity, dew, etc. (Figure 4-41)

Figure 4-42 HIC and Accelerometer Measurement Equipment-By Author

The device used in the HIC test can work with wire or wireless with a metal head of about 4.6±0.02kg. The specific and sensitive head of the device provided with the test equipment (Figure 4-42) is connected via the internet to the Lodometer Software, sending the results after each hits the pavements. (Figure 4-43)

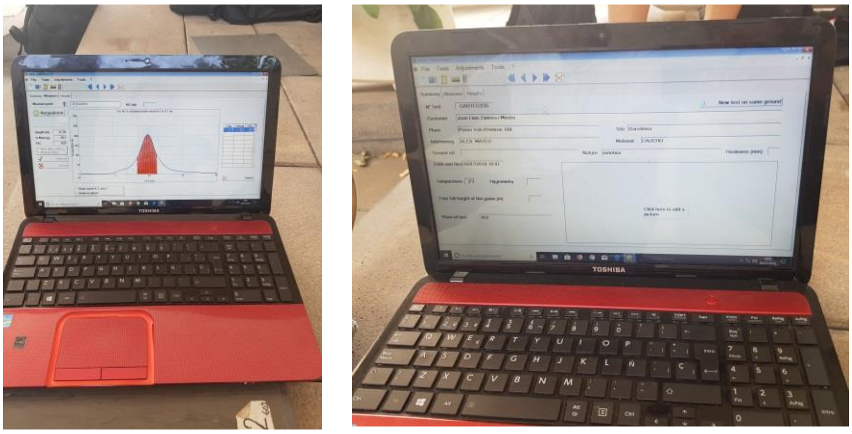


Figure 4-43 Laptop used with Lodometer Software-By Author

Impact measurement principle

The pavement under test is struck with the accelerometer head fitted with the test equipment instruments from different fall heights. Signals emitted by the head accelerometers during each impact are processed to determine the severity derived from the measured impact, which is defined as head injury criterion (HIC), and the acceleration peak of Gmax experienced. The falls continue till the magnitude of HIC shows over 1000, which means to stop fallings.

Table 4-13 CFH, Gmax and HIC (Original Surface Results / Vinyl Coated Result) results-By Author

N	CODIGO	CFH (m)	Gmax	HIC
PUNTO 1	402	0.68 ± 7%	188.6	1156
PUNTO 2	402-301	0.85 ± 7%	183.5	1161
PUNTO 3	101	0.87 ± 7%	196.4	1278
PUNTO 4	101-301	0.89 ± 7%	190	1305
PUNTO 5	701	1.86 ± 7%	149.7	1042
PUNTO 6	701-301	1.68 ± 7%	148.7	1089

The EN 1177: 2018 + AC standard or ASTM F355 defines the critical fall heights values of 1000 for HIC max, and this value for Gmax is 200 (Table 4-13).

PRELIMINARY DISCUSSION AND RESULTS

As shown in Figure 4-44, the Critical Fall Height (CFH) of pavement with code 402 with a thickness of 2 cm was 0.68m, the pavement code 101 with a thickness of 2.5 cm the CFH was 0.87 m, and the CFH was 1.86m in pavement code 701 with a thickness of 5.08cm. Comparing the three evaluated pavements results, showed that the pavement code 701 allows a better attenuation of the impact from a greater height. As shown in Table 4-13, the CFH for 402 with vinyl overlay was 0.85m, CFH for the code 101 with vinyl overlay was 0.89m, and code 701 with vinyl overlay, showed 1.68m. Except for flooring code 701, the coated floorings with vinyl overlay had a higher CFH allowing the same impact attenuation capacity as the original without overlay. However, the CFH in the pavement with code 701 was decreased from 1.86m to 1.68m. This height was still higher compared to the CFH of the other pavements evaluated.

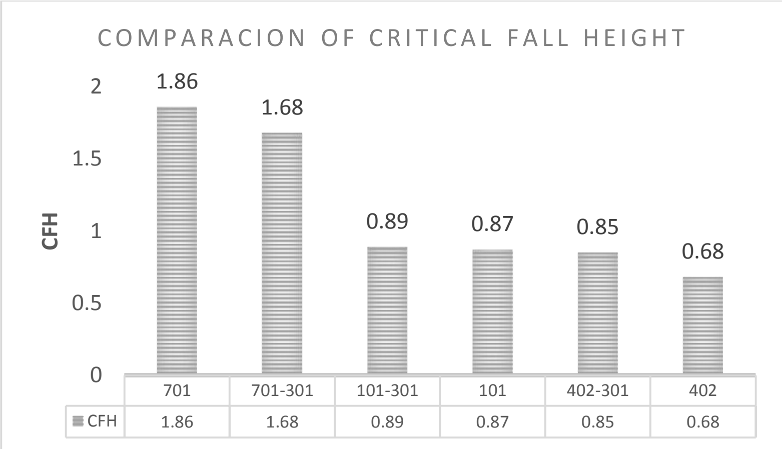


Figure 4-44 CFH (Original Surface Results / Vinyl Coated Result) results-By Author

The G-max test measures the impact energy attenuation performance after hitting the surface (Pisciotta, 2018). This test refers to a result expressed in gravity units, which is the maximum acceleration/deceleration ratio experienced after an impact. More explanation is provided in appendix D.

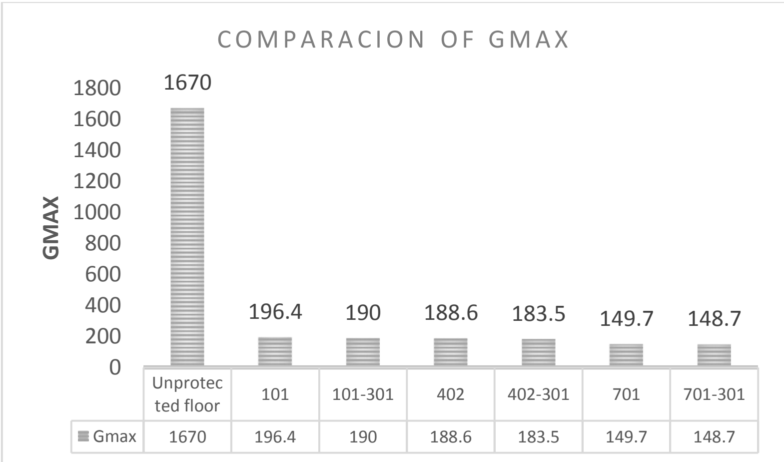


Figure 4-45 G-max (Original surface results/vinyl coated result) results-By Author

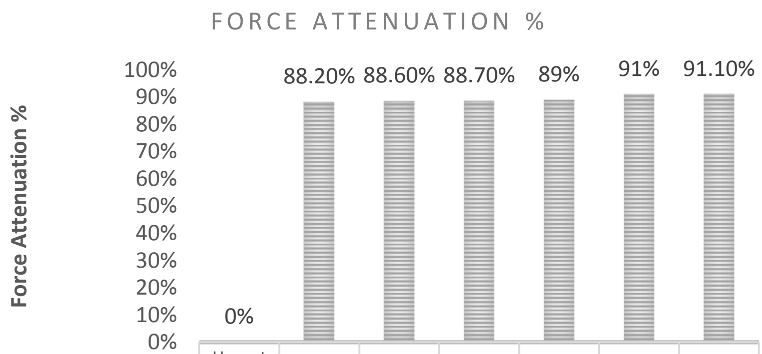
A high value of result means that a surface has low shock attenuation of energy (Ohue, 2014). According to the previous explanation in Figure 4-45, the pavement with code 101 has the highest G-max of 196.4 compared to the other two tiles. And the pavement code 701 showed the value of 149.7 as the lowest, however the one with the greatest impact attenuation property. G-max for unprotected flooring (concrete and hard surface) is about 1670. If we use the following formula, the percentage of shock absorption can be achieved.

$$\frac{(X * 100)}{Y} = D \qquad 100 - D = Z\% \qquad (4.2)$$

X = G-max of CF system Y = G-max of hard surface D = Force reduction%

It should be noted that there were no significant changes in the results of the G-max values in the tests to the pavements with the vinyl overlay (301).

It is notable to mention that the thickness of the shock absorber floor is very effective in the rate of impact absorption. And due to the hygienic environment and the hospital and the nursing home, the tiles in question should have the most negligible thickness with the highest impact absorption.



	Unprotected floor	101	101-301	402	402-301	701	701-301
Force Attenuation %	0%	88.20%	88.60%	88.70%	89%	91%	91.10%

Figure 4-46 Force attenuation after impact % -By Author

Approximately all three CF systems (101, 402, and 701) demonstrates perfect shock absorption of more than 88% of force applied with or without vinyl overlay. Floor code 701-U2, with almost twice the other two floors' thickness, reduces just 3% of the force more than two others (Figure 4-46) and provides a safe surface for children if they fall from a height of 1.86 meters.

TEST 4 : BIOMECHANICAL TEST (BIO)

4.3.4 TEST 4 – BIOMECHANICAL TEST (BIO)

MATERIALS AND METHOD

Except for the HIC test, the rest are mainly based on visual estimation of energy dissipation. In continue we decided to use biomechanical methods to reach more accurate data with numerical results and the performance of force reduction of the tiles. Thanks to the departmental section of podiatry of UB University (*Hospital Bellvitge*), who had a kind and patient cooperation that provided us with the facilities and equipment of their department. We decided to add a new soft and flexible material (Foam Rubber) to the tests process in. To this end, four different shock-absorbing floorings (known as *Compliant Floorings-CF*) use as an underlayment (*SmartCells* (U1), *SofTile DuraSAFE* (U2), *Energy CF 20* (U3) and, *Mottez foam rubber* (U4)) were tested once when covered by an overlay (vinyl, wood-parquet, carpet and, ceramic) and once tested without overlay. This strategy was intended to evaluate the performance of the floorings in order to measure their force attenuation capacity in the event of a fall. We simulate the falls by vertical jumping format in a safe laboratory condition. It means each CF tile was tested in five conditions to analyze the performance change in using four different overlays on the CF. This investigation compares the force and pressure attenuation between four CF with the same performance if covered with overlays. Insole sensors (Martínez-Martí, 2016) (Stöggl, 2017) and force platform (Moir, 2008) (Chiu, 2020) have been used as tools and technology to measure the amount of force applied after a vertical jump.

<u>Insole Pressure Sensor (IPS)</u>

The gait analyzing system is a method used in this research for our goals. Gait analysis is the systematic method of human locomotion as a clinical approach to rehabilitate and diagnose medical conditions and sports activities. In orthopedics and rehabilitation, gait analysis is applied to monitor the patient's healing progress (M, Steultjens, Dekker, Oostendorp, & Bijlsma, 2000) (Pope, Bevins, Wilder, & Frymoyer, 1985) by measuring, describing, and assessing quantities that characterize human locomotion (Ghoussayni, Stevens, Durham, & Ewins, 2004). The *F-Scan Insole system* includes dynamic pressure, force, and timing information for foot operation and gait analysis (Figure 4-47). Information taken from the F-Scan is applied and responded to in real-world requests, like testing orthotics, study the offloading of diabetic feet, and assessing footwear and technology in elite athletes (Tekscan, Tekscan, 2019).

Figure 4-47 insole pressure sensor system (Tekscan, Tekscan, 2019)

Force Plate System (FP)

A force plate composed of a motion capture system is used for motion analysis which contains both kinematic and kinetic gait changes. It is unsuitable for real-time gait data acquisition and immediate evaluation while walking on a treadmill (Yi-Hung, et al., 2015). However, these devices rely on professional analyses to gain gait factors. They can only operate in limited space because the platform is fixed to the floor, and the patient must walk on the surface (Figure 4-49).

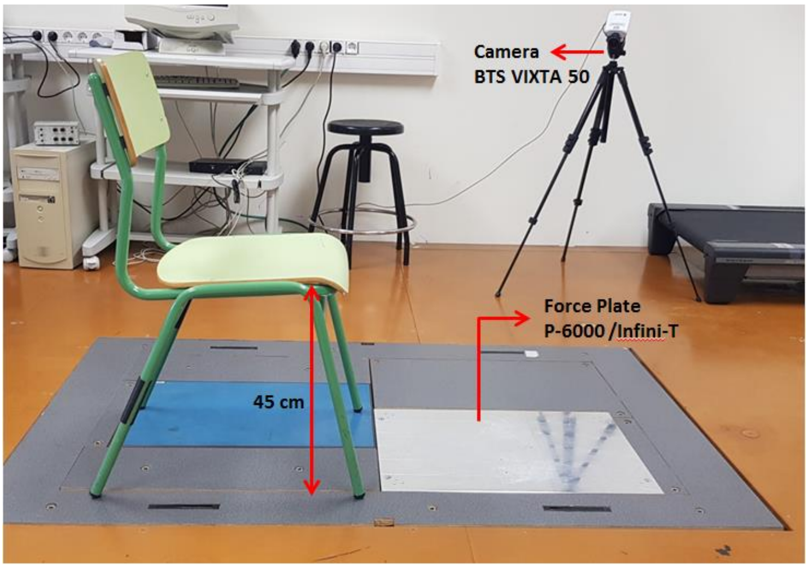
Drop Jump Test (DJ)

The *drop jump* was used in this research with a few modifications to fit the test and the result according to the expected expectations of the final results. One of the experiments frequently use with athletes is the *drop jump*. The drop jump test helps explore progress in an athlete's short distance speed and change of direction which analyze the reactive strength indicator and the ability of the athlete concentric muscular contraction, use the stretch-shortening cycle, and a strong relevance between the change of direction and velocity speed (Figure 4-48).

Figure 4-48 Position of Standing-Take off- Fly and Landing

To this end, a protocol was defined for the testing process. Participants consisted of 6 female and male who ranged in age between 18 and 29 years (mean, 23 ± 5 years), had a bodyweight between 47 and 80 kg (mean, 57.5 ± 7.8 kg). The body height was recorded between 1.60 and 1.80 m (mean,1.64 ± 0.09 m) with proper physical condition (without physical problems). Participants were asked to jump from a height of 45 cm on the force plate (BTS Bioengineering s.p. A, Model: P-6000 /Infini-T[115]) to measure the forces applied to the feet. Jumps were performed while a thin layer of in-sole sensors (TekScan, Model: F-Scan[116]) was placed inside the participants' shoes to measure the pressure and force.

[115] https://www.btsbioengineering.com/es/products/infini-t/
[116] https://www.tekscan.com/products-solutions/systems/f-scan-system



(A) (B)

Figure 4-49 (A) In-sole sensor embedded inside the shoe and Data transmitter unit (B) Position of tools in the UB laboratory-By Author

Both methods were taken place concurrently and similar to the technique used in testing and evaluating the Athletes' physical fitness called "*Drop Jump*." (Walsh, 2006) The drop jump method was used because the position and jumping style is similar to our research desire. The only difference is that in original Drop Jump test, the object must jump again after the first landing, which we do not need the second jump.

Two methods of Force Plate and Insole Sensors with approximately the same performance were used in this research because we want to validate the function of different floorings in the magnitude of shock absorption. Insole sensors were embedded inside the shoe (Figure 4-49Figure 4-50), and the pressure and the force were measured from the top of the floors after jumping and the force platform would measure the force transmitted to the underneath of the floors. In this case, the force and pressure received by sensors and force plate after jumping on each pavement were measured.

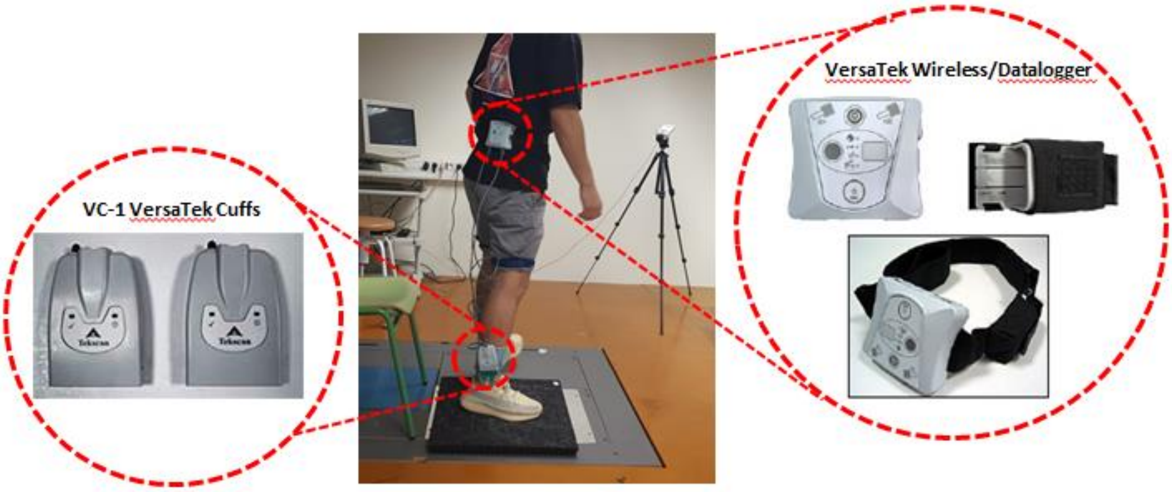
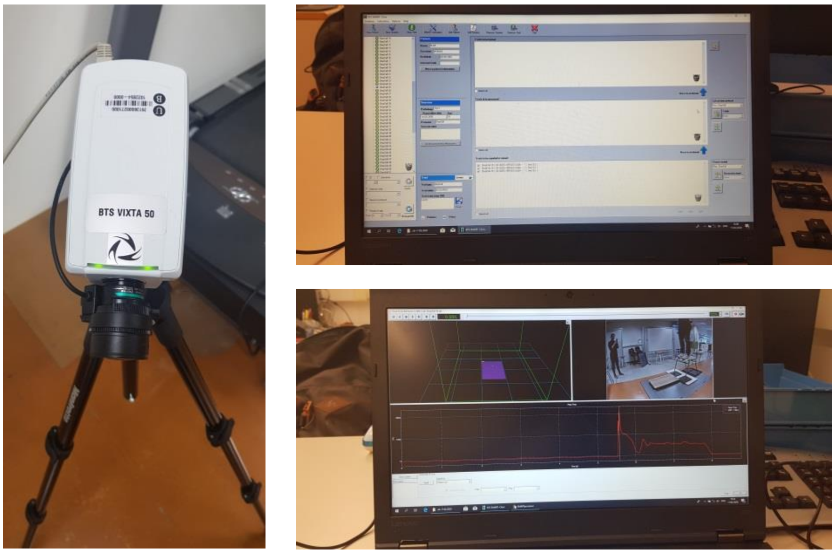


Figure 4-50 Data collection box-VersaTek Wireless/Datalogger and VC-1 VersaTek Cuffs in the UB Laboratory-By Author

All volunteers will execute the drop jump test from a platform with a 45cm height (Figure 4-49). They placed their hands in the waist while jumping with a relaxed body. The jumps were performed on a force plate while the f-scan sensors were embedded in their shoes. Three times jumps were made for each condition (with overlay and without overlay). The interface wire between the data collection box[117] and the transmitter data unit[118] (Figure 4-50) was fixed with a band around the leg. The data collection box is also fixed around the waist with a special belt.



(A) (B)

Figure 4-51 (A): Camera-BTS VIXTA 50 AND (B): BTS SMART-clinic software in the UB Laboratory -By Author

At the end of each jump, the data received by the insole sensor stored in the data collection box was transferred to the computer (*F-scan research 7.0 TAM software*) (Figure 4-51) for analysis. The camera[119] was recording the motion of the participants during the test and was compatible with the force plate. The data received by sensors of force plate were transmitted to a software (*BTS SMART-clinic software*) (Figure 4-52) to be analyzed.

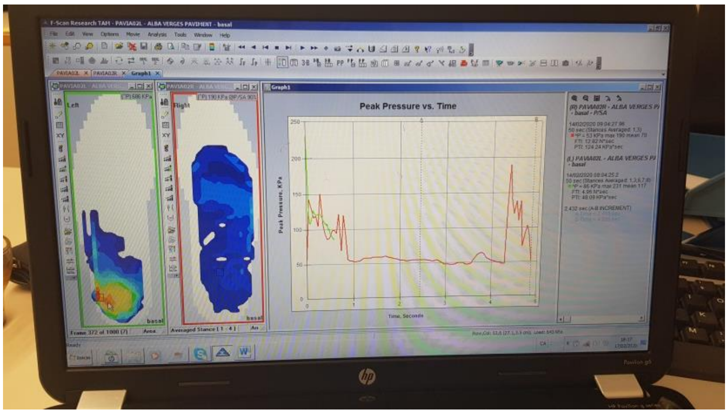


Figure 4-52 F-scan research 7.0 TAM software in the UB Laboratory -By Author

The average of the trials in each condition was taken. Subjects were performed jumps onto a force platform sampling at 100Hz the same frequency defined for in-sole sensors (N. E. FOWLER, 1994) (Artur Struzik, 2019). The estimated time for all jumps done by each object is about 2:30 hours, including equilibrating the devices and initial settings. The purpose of using these two methods was

[117] VersaTek Wireless/Datalogger (VW-1, VDL-1, or VWD-1 - with Battery Pack Holder and fixed Belt)- This Unit acts as a wireless gateway between the VersaTek Cuffs (and attached sensors) and the PC or laptop computer.
[118] The VersaTek Cuffs are used to transmit the sensor data from the sensor to the VersaTek Wireless/Datalogger (VWD-1)
[119] BTS VIXTA 50

to find the difference between the amount of energy damped or energy dissipated on the CF surface and under the CF tile.

Before the test measurements, the subjects were familiarized with the target of the study. They were informed of the activities they are supposed to perform and were motivated to fulfill the task properly. Only one person was tested daily in a saloon about $35m^2$. In order to keep the same condition for all tests and to prevent injury to the muscles and joints of the participants, we have defined a specific protocol. Participants stood on both legs on top of the platform with hand placed on the waist. They stretched straight one leg with which they can maintain a better balance, jumping and landing on both legs simultaneously without bending knees, keeping the straight balance for few seconds same landing condition. They have a 20-30 sec recovery between sets. All the processes occurred in the podiatry laboratory department of the University of Barcelona (Bellvitge hospital[120]). A code was allocated for each floor to speed up the work process.

TEST STAGES

To ensure the proper functioning of the related systems, initial settings and calibration system were checked before starting the main practical tests such as walking or rhythmic movements of the legs.

1. At the first stage, each participant jumped on the force plate (Unprotected floor) without any CF system or overlay to have a criterion for comparison and evaluation.
2. 45 cm (height of a chair) were defined as a height of jump platform.
3. In the second stage, participants jumped on each CF system (U1, U2, U3, U4) placed on the force plate without any overlay.
4. In the Third stage, participants jumped on each CF system which was covered by overlays (O1, O2, O3, O4) such as vinyl (soft), parquet (rigid), ceramic (hard), and carpet (soft).
5. To calculate the error coefficient in the fourth stage, participants were asked to jump again on the force plate (Unprotected floor) to compare the result of the first jump and the last jump on the force plate.

Figure 4-53 shows a glimpse of the process of a test on U1 flooring with O1 coating. Each step was repeated three times for each floor.

[120] https://bellvitgehospital.cat/en/home

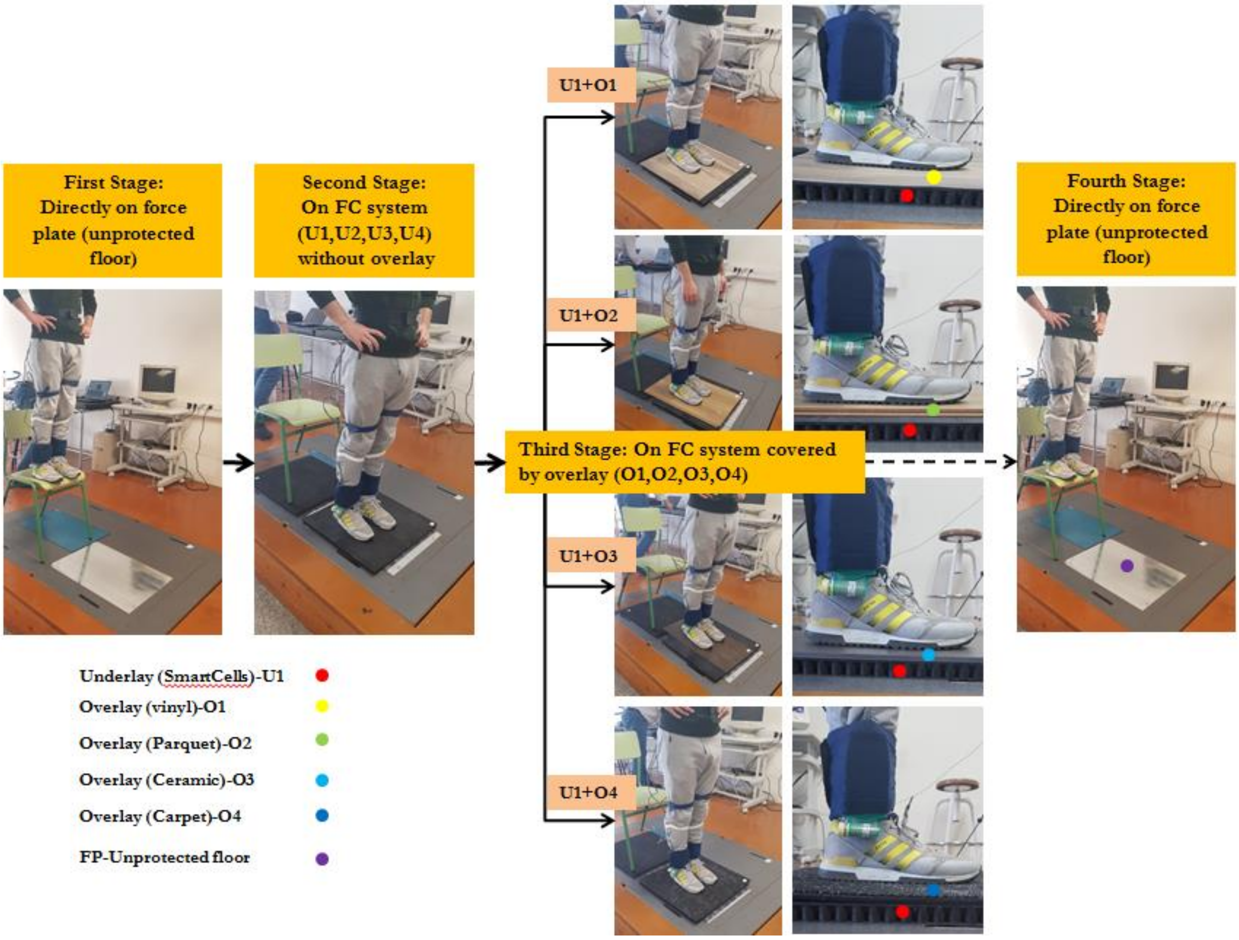


Figure 4-53 processes of a test on U1 (Smartcells) flooring with O1 (vinyl) overlay in the UB Laboratory -By Author

Hints:

*To avoid error and to calculate the average amount of force received after jumping, in all cases, 3 sequential trials were completed on each floor condition.

*Due to the flooring thickness, auxiliary tools under the seat have been used to maintain the jump height and level in some cases.

PRELIMINARY DISCUSSION AND RESULTS

The results of this section should be discussed into two different levels of Force Plate (FP) and Insole Sensors (IPS).

Force Plate - FP

P-6000 /INFINITI-T is the system used in this section. The frequency was set to 100 Hz (Gudavalli, 2013). All the personal information such as age, weight, and height were interred o the system. More details about the system and software are already described in section 3.1.2.

The results indicated that the peak forces received by the FP system (under the tiles) are more than the peak forces received by the IPS system (over the tiles) according to the data received from jumps. The twice crossing through the CF system after the vertical jump and participant's shoe can be stated as one reason for such an event. The FP sensors recorded the ground reaction force -GRF1 as the first vertical peak force transition. While, in-sole sensors recorded the second vertical peak force transition (GRF2) in the opposite direction (twice damping the participant shoe sole and twice damping the CF system) (Figure 4-54).

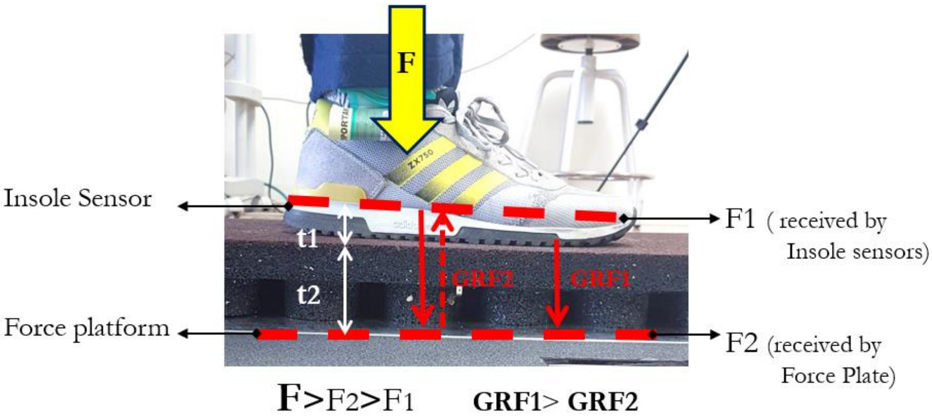


Figure 4-54 Graphic display of applied and received peak forces and the position of the sensors. d1: the thickness of shoe sole, d2: the thickness of CF system-By Author

The second reason due to the formula of 4-3 explained in section 3-1. If the surface is soft, *d* will have a value that causes the impact force (*F*) smaller. But if the surface is rigid, the value of *d* will be so small or even zero, which causes the impact force stronger.

$$W = PE = Fd = mgh \Longrightarrow F= mgh / d \qquad 4\text{-}3$$

W and *PE* are work and potential Energy, *F* is force, *d* is vertical dsplacement and *h* is the vertical jump height.

As can be seen in the table and Figure 4-55, the results recorded by the FP show that the peak forces applied on the FP system were between 2200-4000N. U2, U3, U1, and U4 can reduce the peak force up to 31%, 23%, 22%, and 15%, respectively.

Force (N)-Unprotected Flooring	CF	f-Decreased Force%
2200-4000	U1	22
	U2	31
	U3	23
	U4	15

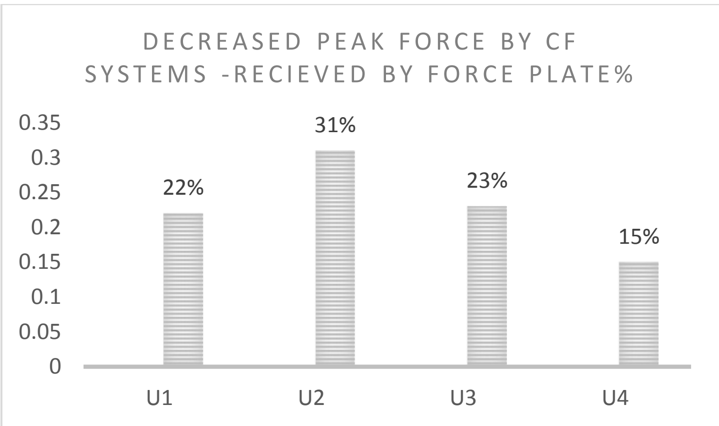


Figure 4-55 Reduced peak force value by FC system - Recorded by FP-By Author

The results have changed significantly after using the overlays on CF systems, and the impact absorption has increased. Overlay of PVC can reduce forces' value till 20-35% as the highest force reduction. Carpet as a soft surface worked almost the same on all four CF systems, and there was no significant difference in energy absorption. It showd about 23% as the lowest one over U4 system and 36% on U2 system as the highest rate. Parquet and Ceramic as hard surfaces demonstrated almost 13-30% over U1, U2, and U3 systems (Figure 4-56).

U2>U3>U1>U4

In general, the PVC, Carpet, Parquet, and Ceramic with 25-36% have the same results over U1, U2, and U3. But U4 has the lowest rate of absorption in the face of the four mentioned overlays.

Force-Unprotected Flooring	U1-N%	U2-N%	U3-N%	U4-N%
PVC,	7-30.6	13-35	30	20
Carpet,	4.3-27	11.5-36	28	23
Parquet,	4-27.5	11-29	22	13
Ceramic,	2.4-22	30	23	17

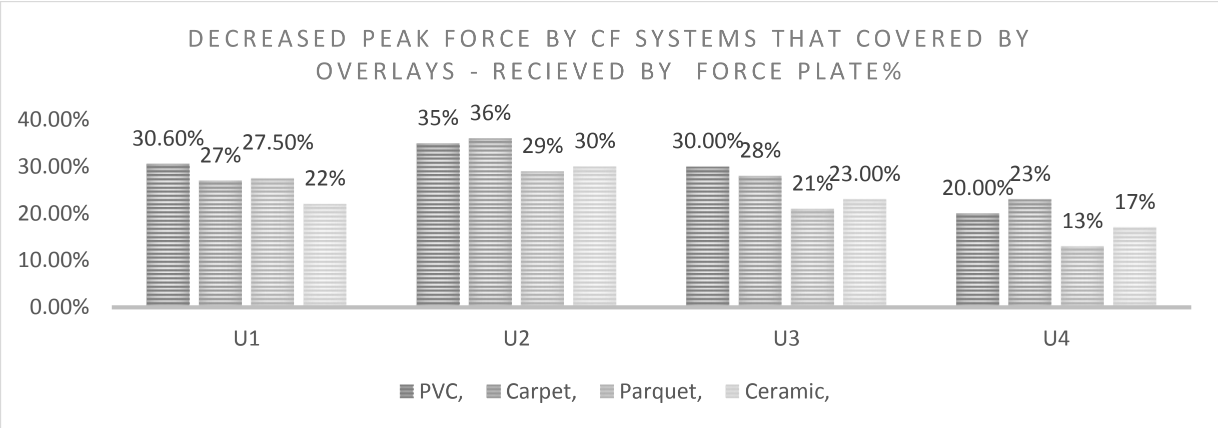


Figure 4-56 Reduced peak force value by FC system face with covered by overlays - Recorded by FP-By Author

<u>Insole Pressure Sensors - IPS</u>

Tekscan, F-Scan was used in this section, and more details about the system and software are already described in section 3.1.2.

In this method, the received Forces (F), Time duration from the first moment of contact to zero force (Δt), and Contact Area (CA) are calculated. The results of the last two items were not presented here since the acceptable accurate results dependenced on many parameters. According to the data, the final results in this method indicate the peak forces applied to the IPS were between 2300-4500N.

Force (N)-Unprotected Flooring	CF	Decreased Force%
2300-4500	U1	71-73%
	U2	68-77%
	U3	62-70%
	U4	45-58%

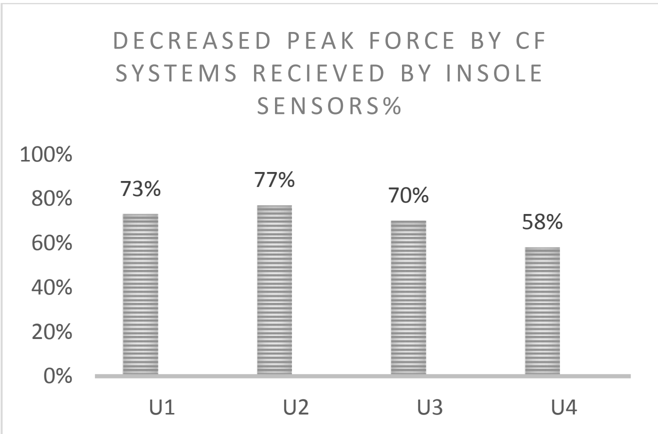


Figure 4-57 Reduced peak force value by FC system - Recorded by Insole sensors system-By Author

The data recorded by the Insole sensors was very different from the data obtained in the FP method. Insole sensors system showed that, unlike FP data, the CF system performs very well in the face of high forces. As can be seen in the diagram and table, uncovered CF systems significantly reduce the applied force. U2, U1, and U3, respectively, reduce forces up to 77%, 73%, and 70%. And U4 decreases the applied force by 58% as the lowest rate (Figure 4-57). And after using overlay on the CF system, the force reduction slightly increased and did not interfere with the performance of the CF systems even a hard overlay.

Force -Unprotected Flooring	U1-N%	U2-N%	U3-N%	U4-N%
PVC,	74-79	79-83.5	34.30-77.3	60-70
Carpet,	70-77	70-83.3	46.95-80.4	53-78
Parquet,	70-76	75-83.6	40.44-77.6	40-71
Ceramic,	68-72	68-82	29.32-79.5	35-63

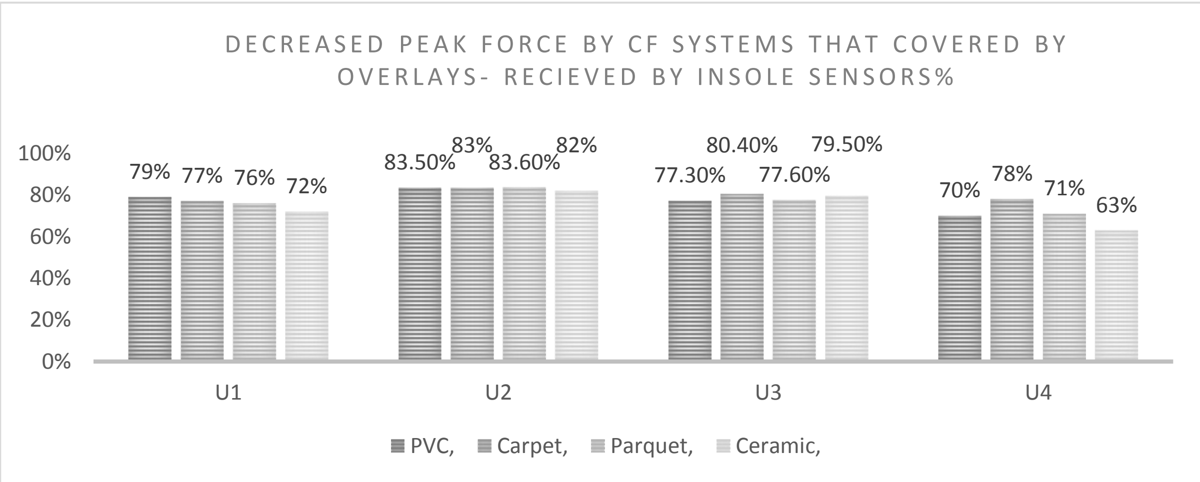


Figure 4-58 Reduced peak force value by FC system face with covered by overlays - Recorded by Insole sensors-By Author

PVC and Carpet as soft surfaces showed better performance compare to ceramic and parquet. PVC, Carpet, and parquet fixed on U2 can reduce force up to 82- 83%, as the best and highest value of force reduction. In U1, this rate was about 72%, with ceramic overlay as the lowest value and PVC with 79% showed as the highest value of force absorption on U1. U3 covered by carpet and ceramic show 80%-79.5% force reduction respectively as the highest value and reduced about 77% when covered by PVC and parquet. In general, because of the thickness and geometry of the structure of U2, this CF system reacts better than the three other systems. But in general, it should be mentioned that U1, U3, and U4 have shown sufficient safety to reduce the force. U2 > U1, U3 > U4 (Figure 4-58).

Results and Limitations

As the results showed, the CF systems performed well enough and significantly reduce the amount of impact. The mentioned results were presented with a small number of trials, and in order to reach more reliable results, the number of practical tests should be increased.

One of the limitations was the high price of insole sensors product. Only one pair of insoles was dedicated to each participant for all jumping trials. The error coefficient was considered since there was no any measurement index, evidence or study on the durability of sensors during frequent jumps. In some cases, some of the sensors could be disabled or show an error. The difference magnitude between the force received by the sensors in the first jump on the unprotected surface (force plate-as hard surface) and the last jump on the unprotected surface has been added to the results in proportion to the amount of absorption and energy received Flooring. This amount of added force as an error coefficient has been calculated by considering and comparing the process of decreasing or increasing the force received by the sensors in all participants in order to make reasonable values with the most negligible probability of error.

Secondly, participants did not have the same footwear during the test. They wore their personal sneakers, which may affect the results or damping energy by the sole's thickness or material. Although they were asked to jump without any bending joints, controlling all the conditions or habits of the participant's body is almost impossible and the style of the jumping may affect the results.

Despite the logical results, it should be noted that conclusive assessment of the effectiveness of these interventions and precise biases, was not possible due to the limited number of studies, and lack of insole sensors product.

The force plate seems not a good option for measuring the force applied to the CF system. One of the reasons for the anomalies and distortions in the results may be due to the geometric shape of these floors. It seems the sensors embedded in the FP system cannot receive the applied vertical force properly from the CF system.

In-shoe sensors provide a more acceptable result in terms of force received by the soles of the feet if they are active and not damaged.

TEST 5 : Finite Element Method (FEM)

4.3.5 TEST 5 – MODELING AND SIMULATION-FINITE ELEMENT METHOD (FEM)

This test seeks the manner of operation of the CF systems and the dissipation process of the impact force after the initial validation of the CF systems. It compares the performance, deformation, and energy dissipation of the CF tiles with different structures. The comparison is evaluated through a simulation process with the assist of the FE method. In order to optimize and match the flooring types with the intended application. The geometric and structures were inspired by several typical mats or floorings in the market used in sports clubs, fitness, children's playgrounds, and boat emergencies. We simulated some new ideas for CF tiles. The simulation attempt to evaluate the difference in force reduction with respect to the geometric deformation of the cells constitutive the structure of CF tiles. The geometry of cells includes Solid Rubber, Cylinder, Pyramid, Pins, Hourglass, Dome, Rectangle, and Square. The thickness of all tiles is considered to be 2.5 cm.

MATERIALS AND METHOD

To further develop the flooring system, we used the data of the biomechanical test (BIO) in this stage to simulate the drop jump test via the FE method. The focuses in most studies are on hip, femur, or head fracture. But as explained previously, due to the lack of sufficient equipment to create a safe environment to test the fall on the side of the body, the jump option was chosen. We continued the same method in software simulation to examine the CF system's behavior. In terms of material, structure, proportion, and thickness The *Smartcells* flooring has been founded a better option to be used as a criterion referable source among other CF systems since other CF systems were not suitable for use in the indoor area. Also, compressed rubber particles in the structure of other CF tiles made some difficulties in tensile tests and simulation.

Different versions of the proposed CF system, such as altered geometry of cells (with and without stiffener or with and without overlay), can be evaluated by simulating the drop jump test. In this work, the possibility of predicting the force reduction (FR), and characterizing the shock absorption capability of the CF system by finite element modeling was investigated. The mechanical reactions of SmartCells (NR) (Laing A. C., 2009) (SmartCells, 2021) are of reference material were characterized by uniaxial compression experiments and fitted by Ogden (N=3) hyperelastic models to select the more appropriate one. Furthermore, the dependent constitutive parameters such as thickness, hard and soft overlay, different geometry of the cells, velocity, and weight were examined.

*Although the type of material of CF tile is one of the factors defining the behavior of the system structure, in this study, we refrain from entering into this issue due to the complexity of the calculations (percentage of composite materials, shape of fibers, or matrix concentration) and specialization of composite materials, and the focus is on rubber materials.

Parameters in simulation that influence a fall

95% of hip and wrist fractures and 60% of head injuries in older adults happened because of fall. (Choi, 2015). Choi et al., stated that the risk for fall-related injuries is associated with the velocity at contact and the time available during the fall to generate protective responses. To achieve these values, they addressed the kinematic analysis of 25 real-life falls (mean age 80 years) using video in two LTC facilities, and the vertical velocities due to theoretical estimates were based on free fall of a falling mass (where v impact velocity = $\sqrt{2gh}$, g is the gravitational acceleration of 9.81 m/s^2, and h is the vertical descent distance of the body part). The vertical impact velocity averaged 2.14 m/s (SD=0.63), 38% lower than an inverted pendulum model for the pelvis and 16% lower than average pelvis impact velocity values reported previously for young individuals in laboratory falling experiments. They also reached the values of 2.91 *m/s* (SD=0.86) for the head and 2.87 *m/s* (SD=1.60) for the hand which is, 28%, and 4% lower, respectively, than the previous laboratory falling experiments on young individuals (Choi, 2015). The impact velocity during a fall has been evaluated in previous studies. In a fall from standing height, the estimated hip impact velocity among young adults was 3.17± 0.47 m/s, where no considerable differences could be recognized between standing and walking. (Van den Kroonenberg A. J., 1996) According to another study, the impact velocity was achieved to 3.01± 0.83 *m/s*. (Feldman F. a., 2007)

In a study by Parkkari et al. (Parkkari J. P., 1999) the hip fracture and fall position were characterized: 76% of the patients landed directly to the side, 12% fell obliquely backward, and 8% directly or obliquely forward. Because of the different position of falls (hand, knee, muscles…) and the factors that affect the severity of the fall impact, we have used the information and factors in the common and most dangerous type of fall (fall position) in other's studies and experiences (sideway fall on hip and the femur). The force reduction (FR)% output is conventionally defined as (Andena, 2015):

$$FR=[1-\frac{F_{max}}{F_{max,ref}}] \text{ x } 100 \qquad 4\text{-}4$$

$$\text{(Impact velocity) } v = \sqrt{2gh}$$

F_{max}: peak force on a track surface $F_{max,ref}$: peak force on a conventionally hard surface

Or

$$F_{max} = -\frac{mv^2}{2d} \qquad 4.5$$

F_{max}: peak force on a track surface *m*= mass *d*= deformation distance
v= velocity *g*= ground gravity

As the failure load is various between different loading conditions, it is essential to imitate the same impact loading conditions as during a real fall. To estimate the failure load of the femur during a fall, after first fall contact, a force-time curve is achieved, where the fracture load is defined as the first peak force measured.

TEST STAGES

With the Finite Element Method (FEM), impacts were performed with the impactor model (as the foot) on a flooring system. The reference for comparing the effects of the impactor is the hard surface of the ground with a specified velocity, mass, and density which will be fixed on other CF tiles in other trials simulation.

Participants

As previously explained, the speed of impact in a free fall depends on the height and gravity of the earth. Therefore, the speed of all 6 participants is exactly 2.97 m/s when colliding. The table below (Table 4-14) explains the physical condition of participants in test 4.3.4.

Table 4-14 physical characteristics of the participants-By Author

Participant	Age-yrs.	Weight-kg	Height-cm	Definition
1-Al	18	57.5	160	Height of platform: 45cm g: 9.8 v: 2.97 ~ 3.0 m/s
2-M.H	20	65	173	
3-R	24	74	171	
4-J	22	80	180	
5-M	24	47	173	
6-V	29	62	171	

Simulation of flooring system

The Abaqus program was used to simulate an impact, illustrating a human jumping on a floor. The simulation consisted of an impactor as foot simulation of a jumping person and a CF system representing the horizontal surface. This was performed to show how much force the jumping from a specific height is exposed to during impact with different CF systems. To achieve a good and reliable results, the focus has been on the development and improvements of the different parts. Three layers simulated the composition of the CF system. (Figure 4-59):

- A subfloor, representing the ground floor.
- An underlay structure was composed of the cell structure and geometry of the CF system.
- An overlay, representing the finishing surface of the floor.

The underlay (CF system) was constrained in three dimensions of x-, y- and z- displacements. In order to avoid movement of underlay over the subfloor (the ground floor) during impact, the underneath of all cells were fixed (tied) to the ground floor. Furthermore, the overlay (finishing layer) is supposed to be glued together with the underlay as these two parts were merged.

The geometry of the CF System

The CF system's primary and reference geometry and material properties were taken from one of *SATECH's* products (see Section 3.2.3) called *Smartcells* to achieve realistic measurements appropriate for restorations of buildings and new constructions.

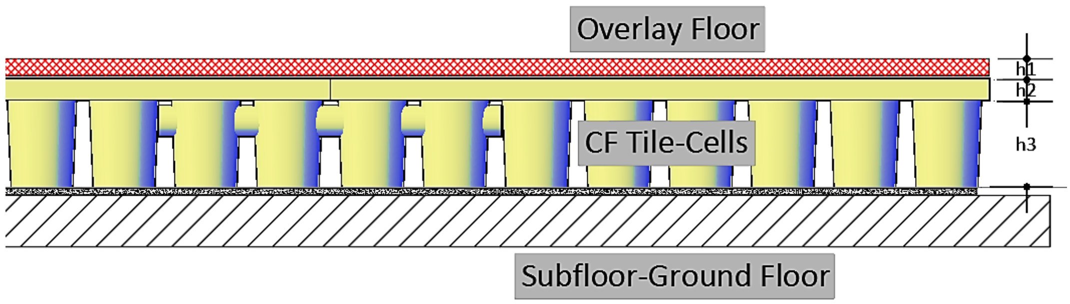


Figure 4-59 Layers of CF system-By Author

Parameters with constant properties were:

- The thickness of the overlying floor, h1, was set to 5 mm (Cork) and 6 mm (Marble), a standard measure of typical floors.
- The thickness of the top surface layer of the cells, h2 that was set to 5 and 10 mm
- Stiffeners: The role of stiffeners is to chain the cells and minimize deformation and vertical displacement when walking or falling. In addition to making the tile elastic, it creates a non-rigid but stable surface for walking without disturbing walking. For this purpose, the performance of

one of the samples (cylinder cells) has been simulated and evaluated once with a stiffener and once without a stiffener. The stiffeners have the same rubber properties of cells and the CF system's top surface, and all three mentioned parts are integrated and form a homogeneous tile (Figure 4-59).

Parameters with varying properties were:

- The height of the cells, h3 with 20 mm and, 25 mm were used in the simulations.
- The geometry of the cells, g1 with cylinder, pyramid, and semi-sphere, hourglass ... were used in the simulations. (Figure 4-64)

As these measurements were used, the CF system constitutes a total height of 15mm, 25mm, and 35mm.

Materials used in FE Method

A literature study was done to collect data regarding parameters for the CF system. A cell structure of natural rubber material was used as an underlay for structure. Cork as soft surface and marble as a rigid surface were used as overly fixed above of the CF system. The research data was mainly achieved from mechanical (Tensile) test for Smartcells rubber. But in some other general mechanical data, some websites such as scientific database *ScienceDirect, PubMed, MatWeb*, and *the meter* were used as a source for material information of soil, cork, and marble.

1- The material of the ground floor-soil was simulated with a rigid material, with constant parameters to be set such as density, Young´s modulus, and Poisson´s ratio (Table 4-15) (Luo, 2016)
2- The material of the cell structure was simulated by the hyperelastic material model Ogden. This material was chosen since the whole structure of the CF system was presumed to be constructed of a non-linear material and is exposed to large strains. Parameters to be set for Ogden material were density, Poisson´s ratio, and nine parameters: mu1, mu2, mu3 and alpha1, alpha2 and alpha3, D1, D2, and D3 or stress-strain Uniaxial data. (see Section 2.2.4) which due to the confidentiality of the information, we are excused from presenting it in this thesis.
3- The material of the overlying floor was simulated once with a soft material (cork) and once with rigid material of marble. Parameters to be set for both materials: density, Young´s modulus, and Poisson´s ratio.

Table 4-15 Parameters for overlay and subfloor- By Author

	Material	Density (kg/mm^3)	Young's modulus *(MPa)* N/mm^2	Poisson's ratio
Overlay floor	Elastic or soft material-Cork	1.8e-7	20-21	0.0
	Rigid and hard material-Marble	2.72e-6	54000	0.2
Subfloor	Rigid material-Soil	2.5793e-6	2100	0.3

Material Testing

Center Català del Plàstic (CCP)-the public R&D center of a consortium nature, made up of the Generalitat de Catalunya, the Universitat Politècnica de Catalunya conducted the tensile test on Smartcells rubber material to enable a better validation of the developed model of the flooring system. The tensile test data were used to increase the knowledge regarding the rubber and surface floors used in prototypes of the flooring system. The test device used was a *GALDABINI Suu2500*. To do an appropriate tensile test for the rubber material, either UNE-EN ISO 604:2002 were followed. Reference material was characterized by uniaxial tensile experiments and fitted by Ogden (N=3) hyperelastic models to select the more appropriate one. The young's modulus of the rubber was about 1.49 N/mm^2.

a b c

Figure 4-60 Specimen with dimension and measurement (a), Tensile test instrument (b), AMTEST Software (c)-By Author

Test setups with 100 mm/min were created in the software *AMTEST*. For the rubber, the extension was set to 60 mm to enable 200 % elongation. Four specimens were created for test setup. The gauge length of 20mm, the gauge width, and the thickness of the specimen was measured for each test sample inserted into the software. The specimen was mounted according to (Figure 4-60).1900 points were recoreded for a total time of around 60 seconds, which means a frequency of acquisition of around 30 Hz or a time step of 0.03 seconds. The results were exported in a raw file of excel with force, deformation, and time data. The stress and strain data were calculated to be used in FE Method. First, the number of cells was cut firmly, and the initial size of all four specimens was measured and then tested and analyzed separately. The mean value was considered in the research process. It is exempt from providing numbers and information obtained from tests due to the confidentiality of material data.

Impactor

Hence, as the group at highest risk of fracture in elderly women, the impactor was scaled a model with a weight of 60.7 kg. In Spain, the average weight of women between 75.2 (SD=6.9) years old was 67.4 (SD=12.4) kg and the average weight of men between 75.2 (SD=6.6) years old was 76.4 (SD=12.3) kg assessed during the last two months of 2005 with a total mean of 70.7 (SD=13.1) kg (Cuervo, 2009). Morin et al. (Morin, 2009) stated that fractures increase with decreasing weight.

Since we did not have the conditions to perform the fall simulation in the laboratory due to providing complete security, a low-risk method for observing and comparing the laboratory performance of the flooring and its software simulation was considered. For this purpose, instead of asking participants to fall on their hips, we simulated test conditions in section 4.3.4 (BIO Test) in the FEM software (Table 4-14). Six jump models with different weights were conducted in BIO test. To evaluate the conditions of forces, about 3200 N and the average mass of participants in the BIO test was used in the FEM simulation (64.25 kg) see section 4.3.4. Because of the many factors that will dampen the energy during impact, a layer of about 3cm rubber was used and fixed beneath the impactor, which will play the role of outsole shoe. It should be mentioned that the joints and tissue of the human body during jumping or falling will damp a vast amount of the force in real condition.

Floor-to-Impactor Simulations

The subject of walking and falling are very close to each other, but dealing with them must be completely different, which must be carefully considered in the simulation and evaluation of the proposed tiles. Walking is a natural and daily activity that humans are involved in unconsciously and constantly in indoor and outdoor areas as their lifestyle. Sometimes at night, we notice fatigue and bruising or even swelling of parts of the leg, which is one reason for the walking surface. This surface may cause fatigue in both hard and soft conditions and sometimes cause severe injuries in the long duration. But a fall is an accidental and emergency event that rarely happens to a person. Falls are more common in vulnerable people such as children or the elderly, and the risk of injury in these groups is very high due to physical weakness. Heel contact velocity (HCV-vertical velocity) of normal walking with a horizontal walking velocity of 1.54 m/s is about 0.8 m/s (Welter, 2007) (Parijat P. a., 2008) (Chi, 2005). In this case, the impact simulation was performed with three types of the velocity of normal walking with 0.8 m/s (walking vertical velocity), 2.97~ 3.0 m/s (BIO Test) (Van den Kroonenberg A. J., 1996) (Van den Kroonenberg H. H., 1993), and 5.1 m/s (high velocity) that were taken from the data from the studies measuring the impact-velocity at falls (Dahlgren, 2014).

Therefore, in this section, the hard velocity (velocity of impactor hit the surface) was simulated as a falling on the surface and a low velocity of heel vertical impact was simulated on the surface as a normal walking. Of course, there are many factors involved in accurately calculating them (muscle and fat tissue, bone density, hand control when falling, and many other biological factors) that have been avoided in this research due to the specialized nature of the subject. We tried to simplify the simulation as much as we could.

*A total of simulations were performed where the properties of the CF material were constant, but the test condition of the impactor was changing in tests.

The flooring tiles and impactor were provided in 15 x 15 cm and 14 x14 respectively, to minimize the calculation process and time requirement during simulations. Contacts were applied between the floor and the bottom surface of the impactor. During the simulations, time-frequency was set to 0.01 sec with 250 frames which provided enough time for the impact to be completed.

A simulation was initially made on the ground floor, with no overlay, representing a person jumping on a rigid surface with no CF system. The same test condition was repeated on filled and solid rubber tile (2.5 cm thickness) with no overlay or specific structure. The different situation performed on CF tiles, and the attenuation in force provided by each flooring system was calculated as the percentage decrease in Force compared to the rigid floor condition.

PRELIMINARY DISCUSSION AND RESULTS

The final results of the simulation are classified into five levels:

1. Influence of Stiffener (Narrow connecting components between cells) on Vertical Deformation: The test executed on cylindrical geometry with a velocity of 0.8 m/s and mass of 64.25kg

Table 4-16 Force received by Ground Soil and solid rubber with a different velocity of impact-By Author

TILE	V (m/s)	H (mm)	Geometry Of Cell	AVR. PEAK FORCE (N)	AVR. Force Attenuation (%)	AVR. Displacement (mm)
SOIL	5.1	25	-	7137	-	d<2
SOIL	3.0	25	-	3866	-	d<1
SOIL	0.8	25	-	2086	-	d<1
Solid RUBBER	5.1	25	-	5802	18.70	d<5
Solid RUBBER	3.0	25	-	2149	44.41	d<3.5
Solid RUBBER	0.8	25	-	1825	12.51	d<2

Vertical velocity of normal walking (blue)
Medium vertical velocity of fall (yellow)
High vertical velocity of fall (red)

It was essential to find out the function of the stiffeners uses in CF tiles with designed cells. As described in patent NO.7,575,795[121] the stiffeners prevent excessive vertical displacement of surfaces when walking. In this case, we simulate the CF system with cylinder cell once with and once without stiffeners between cells using the velocity of 0.8m/s. (Table 4-17).

Table 4-17 Vertical displacements and Force received by CF system (Smartcells) compare with Ground Soil with same thickness-By Author

TILE	V (m/s)	H (mm)	Geometry Of Cell	AVR. PEAK FORCE (N)	AVR. Force Attenuation (%)	AVR. Displacement (mm)
CF-Cylindrical	5.1	25	Cylinder	5204	27.10	12.5
CF-Cylindrical	3.0	25	Cylinder	1698	56.08	6.41
CF-Cylindrical	0.8	25	Cylinder	468	77.56	2-3
CF-Cylindrical- without stiffener	0.8	25	Cylinder	405	80.58	2-4
SOIL	0.8	25	-	2086	-	d<1

Vertical velocity of normal walking (blue)
Medium vertical velocity of fall (yellow)
High vertical velocity of fall (red)

The results indicated that the surface displacement without stiffener during walking (0.8 *m/s*) was doubled by about 4 *mm*. The displacement at high velocity (5.1 *m/s*) was about 12mm, and in medium (3 *m/s*), velocity was about 6.41 *mm* (Figure 4-61) and (Figure 4-62 and Figure 4-65).

[121] Scott, R. P., & Betteridge, B. L. (2009). U.S. Patent No. 7,575,795. Washington, DC: U.S. Patent and Trademark Office." ,IMPACT ABSORBING SAFETY MATTING SYSTEM WITH ELASTOMERC SUB-SURFACE STRUCTURE"

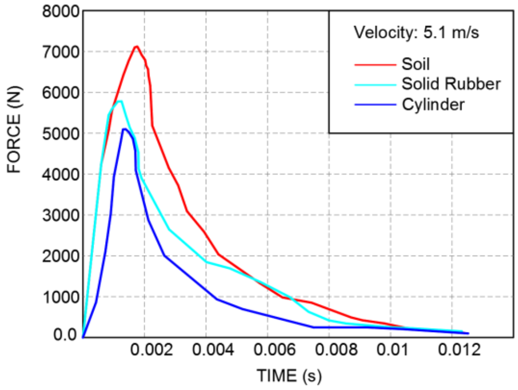


Figure 4-61 Comparison of Force vs. Time diagram of three material of soil, solid rubber, and CF system (cylindrical cell) with the velocity of 5.1m/s - By Author

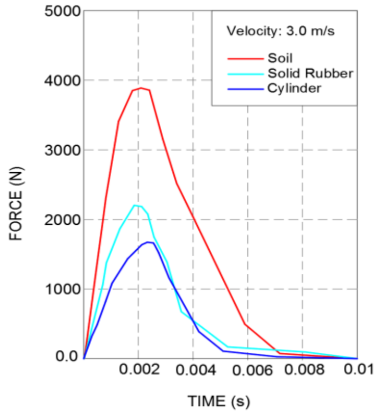


Figure 4-62 Comparison of Force vs Time diagram of three material of soil, solid rubber, and CF system (cylindrical cell) with velocity of 3m/s - By Author

2. Influence of Velocity on Force Reduction: three velocities of 0.8, 3, and 5.1 *m/s* were simulated on soil, solid rubber, and cylindrical cell (Table 4-17) and (Table 4-16).

As shown in (Table 4-18) and (Table 4-17), the force attenuation with an impact velocity of 3mm/s in the CF system with cylinder cell was about 56% but with impact velocity of 5.1m/s approximately 27.10%. This rate in solid rubber with the same material and thickness was 44.41% and 18.70%, respectively.

*Hint: It should be noted that all of these comparisons were based on the impact force on the hard surface (ground Soil).

3. Influence of Thickness of CF system on Force Reduction: three types of thicknesses were simulated on cylindrical cells. 25, 3, and 3.5cm with a velocity of 3 *m/s*.

With current thicknesses of 5mm top layer of tile and 20mm height of the cell, the force attenuation showed about 56%. When the thicknesses of the top layer increased by 10mm with the height of 20mm of the cell, the force attenuation increased by 61.56%. When the cell's height increased by 25mm with a top layer of 10 mm, the force reduction grows to about 69%. These results were gained in 3m/s velocity mass (Table 4-19). It should be noted that excessive thickness may cause problems during installation, especially for buildings that are currently active.

Table 4-18 Force received by CF system and vertical displacement with different thickness of the top layer and cell height of CF-Cylindrical type - By Author

TILE	V (m/s)	H (mm)	AVR. PEAK FORCE (N)	AVR. Force Attenuation (%)	AVR. Displacement (mm)
SOIL	3.0	25	3866	-	d<1
CF-Cylindrical	3.0	25 (5mm top surface thickness and 20mm height of the cell)	1698	56.07	6.41
CF-Cylindrical	3.0	30 (10mm top surface thickness and 20mm height of the cell)	1486	61.56	3-4
CF-Cylindrical	3.0	35 (10mm top surface thickness and 25mm height of the cell)	1175	69.60	3-4

4. Influence of Using Overlay on CF System and Force Reduction: two hard (marble) and soft (Cork) overlay were simulated on the cylindrical cells with a velocity of 3 *m/s*.

Hard or soft overlay on the CF system affects the force reduction. As can be seen in (Table 4-19), the force attenuation with an overlay of cork (5 *mm*) was about 73% and vertical deformation of 3-4*mm*. This rate with marble overlay was about 50% and vertical deformation of less than 2mm. The results implying that still using the rigid surface as an overlay cannot reduce the performance of the CF system. But we believe that more practical and on-site studies need to reach trustable results in this specific issue.

Table 4-19 Vertical displacements and Force received by CF system compare with resilience (Cork) and rigid (Marble) overlay-By Author

TILE	V (m/s)	H (mm)	AVR. PEAK FORCE (N)	AVR. Force Attenuation (%)	AVR. Displacement (mm)
SOIL	3.0	25	3866	-	d<1
CF-Cylindrical	3.0	25	1698	56.08	6.41
CF-Cylindrical +Cork (5mm thickness)	3.0	25+5	1025	73.48	3-4
CF-Cylindrical +Marble (6mm thickness)	3.0	25+6	1935	49.94	d<2

5. Influence of Shape of Cell-Geometry on Force Reduction: about eight different shapes of cell geometry were compared with solid rubber and soil with the velocity of 3 *m/s.*

Figure 4-64 and Figure 4-63 show the graphical information of different geometry of cells using the CF system structure. The results are brought in (Table 4-20). Approximately all cells can reduce the impact force between 50 and 60% with a very small difference. CF with square cell and Dome2 had the highest rate of attenuation, 58%. Rectangular, Dome1, and Pin cells can absorb about 57% of the impact. Cylinder and pyramid cells can reduce about 56% and 55%, respectively. For more details, please check Appendix D.

Table 4-20 Comparison of forces received, forces reduction, and vertical displacement of proposed CF system (cell geometry)-By Author

TILE	V (m/s)	H (mm)	Geometry Of Cell	AVR. PEAK FORCE (N)	AVR. Force Attenuation (%)	AVR. Displacement (mm)
SOIL	3.0	25	-	3866	-	d<1
SOLID RUBBER	3.0	25	-	2149	44.41	4.61
CF-Cylindrical	3.0	25	Cylinder	1698	56.08	6.41
CF-Cylindrical- without stiffener	3.0	25	Cylinder	1481	61.69	7.40
CF-hou	3.0	25	hourglass	1888	51.16	6.70
CF-pyr	3.0	25	Pyramid	1732	55.19	6.34
CF-pin	3.0	25	Pins	1656	57.16	5.90
CF-dom1	3.0	25	Dom1	1660	57.06	5.10
CF-dom2	3.0	25	Dom2	1613	58.27	6.33
CF-rec	3.0	25	Rectangle	1663	56.98	6.45
CF-squ	3.0	25	Square	1617	58.17	6.36

CF system with cylinder cells but without stiffeners absorbed over 61.70%, but it had the vertical deformation of 7.40mm as a highest displacement (Table 4-20) . Other cell's vertical deformation was lower than 6.5 *mm*.

The Figure 4-63 demonstrate the diagram of force-time received by CF systems with different structure. Approximately all the CF structures have received the forces lower than 2000N. which means the attenuate the 50% of applied force. The difference between the structures in a highest and lowest rate were about 10%

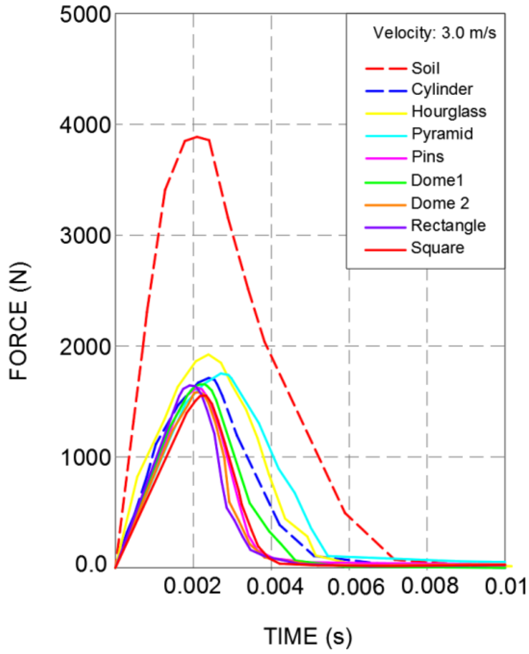


Figure 4-63 Comparison of Force vs. Time diagram of CF system with different geometry of cells with the velocity of 3m/s- By Author

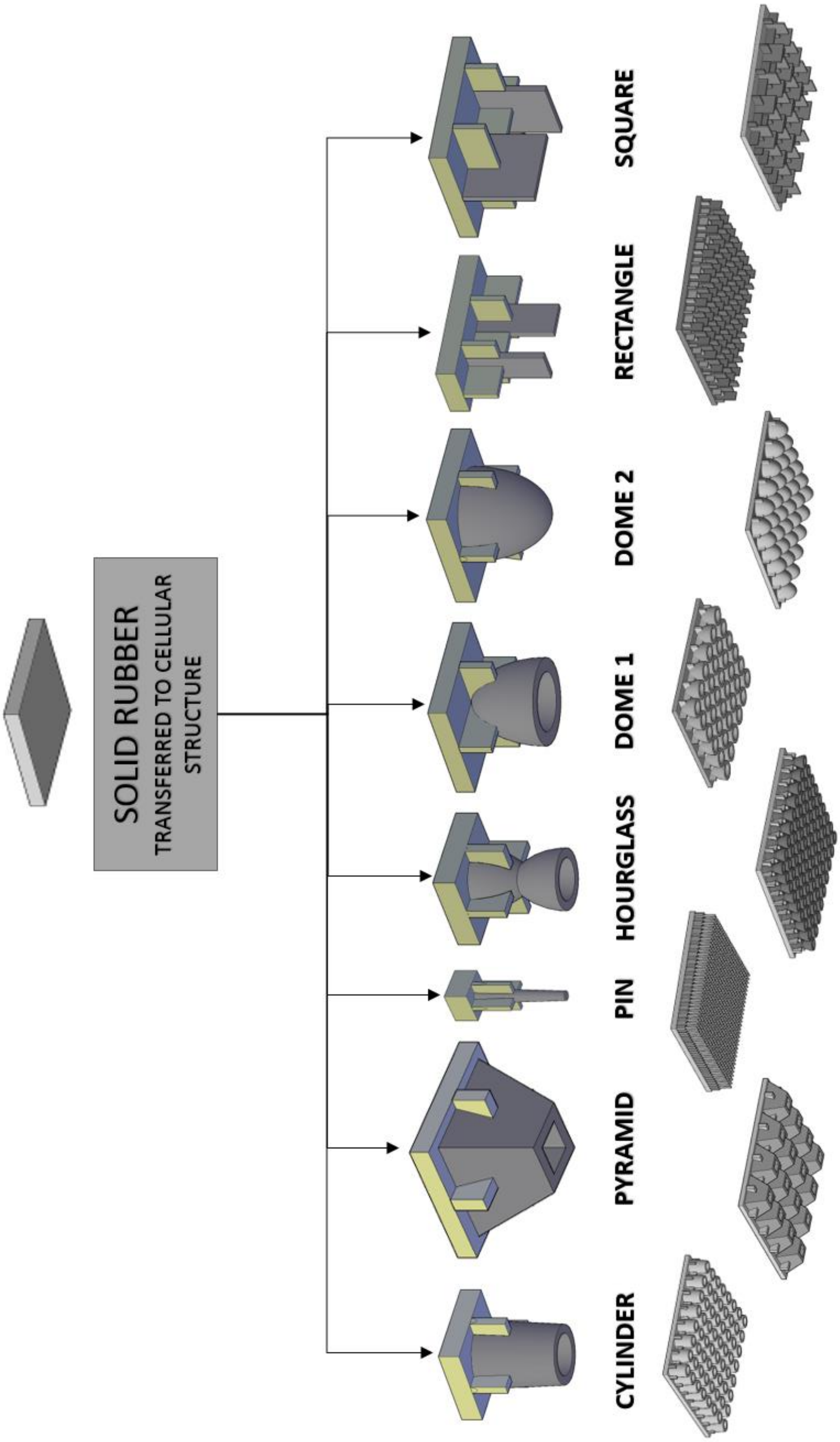


Figure 4-64 Numerical and graphical information about the CF system proposed in this research- By Author

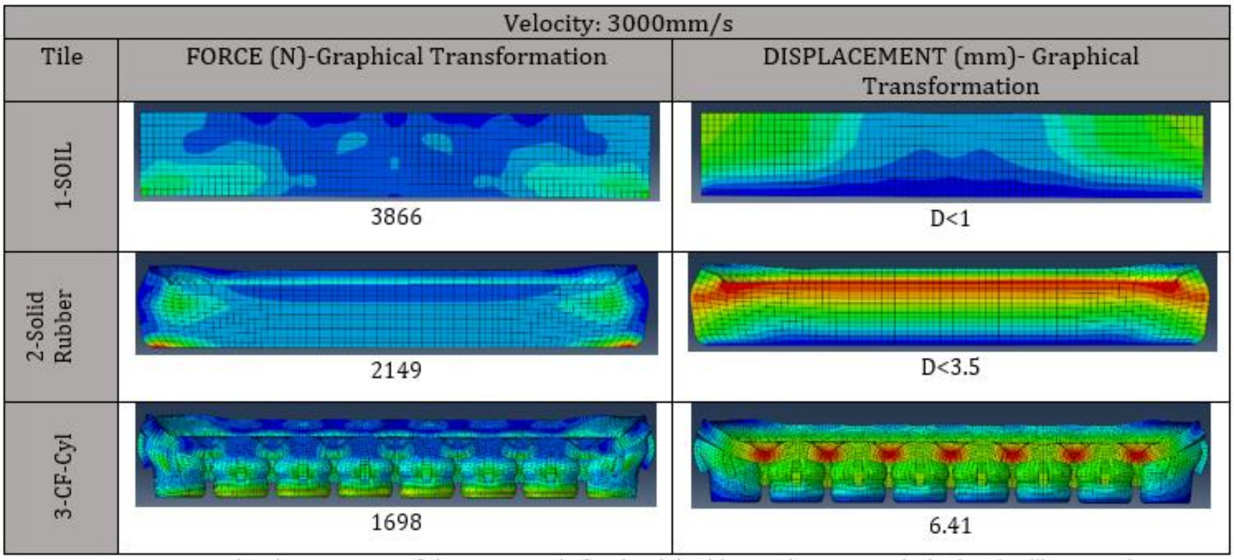


Figure 4-65 Graphical comparison of three material of soil, solid rubber, and CF system (cylindrical cell) - By Author

* Hint: The accuracy of this calculation depends upon the assumption that air friction is negligible.

Results and limitations

The results achieved from the FP method showed that *Smartcells* could reduce the peak force by 22% without any overlay, and the IPS method showed this reduction up to 73% without any overlay. And the simulation has shown about 56% force reduction without any overlay (Table 4-21).

Table 4-21 Comparison of FP, IPS and FE methods in applying force on CF system with Cylindrical cell geometry-By Author

CF System	Force Attenuation %
U1- FP Method	22
U1- IPS Method	73
Cylinder Cell - FE Method	56.08

Analyzing of using overlay on CF system with IPS and FE methods are shown good shock absorption with over 55% of applied force. With a soft overlay, the CF system can reduce the impact to 73-79%. The same techniques in the face with a rigid overlay can reduce lower force. IPS method showed about 72%, and FE method showed about 50% force attenuation. But the results indicated by the FP method with soft overlay was about 30% and in the face with hard surface showed about 22% force attenuation. (Table 4-22)

Table 4-22 Comparison of FP, IPS and FE methods in applying force on CF system with Cylindrical cell geometry covered by hard and soft overlays-By Author

CF System covered with overlay	SmartCells - N% FP method	SmartCells - N% IPS method		CF System covered with overlay	Cylinder cell - N% FE Method
PVC - 3.35mm	7-30.6	74-79		Cork - 5mm	73.48
Ceramic - 6mm	2.4-22	68-72		Marble - 6mm	49.94

All of the items mentioned above are compared with the force received by a hard surface such as ground soil and a solid rubber surface without any specific structure or geometry and with the same conditions.

One of the limitations is finding a way to model the impactor as a factor that is supposed to act similarly to the human body. The behavior of the human body is very complex. The human body comprises different materials (Volume of muscle tissue, fat tissue, joints, tendons, etc.), each with a different damping coefficient. In the face of injury, they have the ability to control and reduce a large volume of force. This dependence on performance between members manifests itself better and more when jumping. It was tough to simulate an individual weighing 64.25 kg with a weight of 64.25 kg in the software in the face of jumping. For this purpose, the impactor in computer simulation should be selected as more elastic with lighter weight which may not have been selected correctly due to computational errors. For this reason, the rate of adsorption of the target tiles may be higher than the simulated nannies, as was observed in BIO tests.

However, since in this study, more behavior (deformation, vertical displacement, reduction of force, and final overlay) of the CF system was considered, the desired results were achieved with this amount of information and simple simulation.

Among the limitations of this method, it should be noted the high capacity of executed files and long execution time.

CHAPTER 5

RESULTS, DISCUSSION, AND CONCLUSION

CHAPTER 5

5 FINAL RESULTS, DISCUSSION, AND CONCLUSION

The purpose of this thesis was partly to amass a complex of CF system properties for specific usage and users. The final results could be led to the commercial product. To achieve this goal, comparative methods, field studies, and simulations have been used. The discussion results are divided into two groups of preliminary and principal results. A set of demands developed in this thesis includes the matters discussed by staff working in the nursing homes and demands stated by the elderly. Since not many CF systems are used today, many demands concerned the overly of the flooring (top surface of the flooring). The greatest difficulties concerning a CF system are the functional requirements and the challenge of designer in such strategy is the floor should be rigid enough to walk on and not impair balance or daily activities but still deform enough when a large force is applied to reduce the impact force.

Final results classified in three groups:

- Preliminary Results - Fieldwork
- Preliminary Results - Validation Tests and Simulation
- Principal Results - With Respect to Hypothesis

5.1 PRELIMINARY DISCUSSION AND RESULTS - FIELDWORK RESULTS

Many risk factors are involved in causing the fall (intrinsic or extrinsic factors). Flooring and shoes are some of these factors. According to the survey and interview conducted at Mutuam Collserola center, about 54% of the elderly preferred to walk around wearing shoes. Still, it seems they may change their mind if the floor is warm and soft enough. It should be noted that inappropriate shoes are a factor in falling. Slippery soles, uncomfortable or unbalanced shoes are the common causes of falls (Ambrose, 2013) (Dunne, 1993).

Since this thesis did not investigate the impact of different kinds of mobility aids (cane, wheelchair), other studies have been given here the assumption of carrying the equal load by the wheels in the front and back is refused. To gain further trustable data regarding pressure, the pressure-sensitive film can, for example, be used (Dahlgren, 2014) . Regarding the relationship between the rolling resistance flooring system and rolling resistance, one of the suggested ways is to increase the size of the wheels of the equipment. The contact area between the wheel and the flooring surface will be increased, thereby reducing stress (Okan J.-S. S., 2015).

Due to the interview, the elderly preferred the rigid floors since rigid floorings give a trustable feeling to the elderly when walking. And of course, they preferred the appearance of wood or stone. The elderly 'lack of trust in the collected flooring could be clearly seen when walking. With very slowly and focused steps that always kept their eyes on the ground. Most uncertainty stemmed from the fear of slipping. Because many of the outdoor or indoor floorings are very slippery and increase the chance of falling even if they are not wet.

Examining the floor surfaces of the center showed that almost 90% of the points do not have sufficient safety (anti-slip) according to the norm UNE-EN 12633: 2003, and the critical review must be done in this particular case to solve the problem.

Places that are a priority for immunization include spaces where the elderly spend more time in these places. We should mention the dining room as a busy space were risky area that the elderly spend about 9 to 10 hours in the residential section. In the morning, before breakfast, they feel hungry, and the sugar blood in the elderly is low; After lunch due to drowsiness and; one hour before and two hours after supper, are risky hours for the elderly of the center. Since they are bored and confuses after supper and tend to get back to their rooms, even the corridors are unsafe during these hours as well.

The living room and bedroom (especially at night, there is a possibility of falling) in the apartment section of the center should also be secured for the elderly who live independently. But in general, all independent elderly should keep their bedrooms, living rooms and busy corridors safe since most of their activities are in these spaces. Wet spaces such as bathrooms are also considered areas with a high risk of falling.

Since the staff wore special footwear in the center during the activity, there was no annoying noise for the elderly and other staff.

The gym hall activities use shock-absorbing mattresses and do not require any other safe flooring. There is no need for safety flooring in the physiotherapy salon due to adequate supervision of the elderly and their accompanying staff. Corridors, lobbies, and other associated spaces should only be considered for their anti-slip.

After research and interviews, the characteristics of a suitable flooring for residential care home or private senior's residences can be noted as follows:

- Impact absorption (a surface that is not too hard to injure a limb after a fall, and not so soft and flexible that it has a high vertical displacement when walking, disrupting the elderly balance and falling.) → D ≤ 3.5 mm (see section 2.6.8). The FE simulation showed lower than 3 mm vertical displacement during normal walking.
- They could not use strong detergents since they create annoying odor and gas, noted cleaning staff in the interview. Only water or sometimes very mild detergents are allowed to be used. Therefore, the surface on the floor should not have any roughness or pores so that cleaning is simple and easy and does not leave any stains. That is because sometimes stains may remain on the floor due to spills of food, medicine, or vomit (stomach acid and chemicals).
- According to the latest research to improve recognition and definition of the visual information and to provide visual comfort[122] in aged people and better spatial comprehension (Delcampo-Carda, 2019):
- Older adults usually have dysfunction in visual sensitivity in the field of illumination and shadow contrast. Poor detection in the distance and proximity of objects, and depth perception (Harwood, 2001), are general problems in the elderly. So the use of moving patterns that cause deception of the vision and trick the mind should be avoided (Owsley, 2011)(checkered, diagonal, zigzag, wavy patterns, and all designs that instill motion visually).
- Older adults need much more contrast in the interior spaces, especially the contrast between the color of the architectural element and its background.

[122] "visual comfort," defined by the European standard EN 12665, as "a subjective condition of visual well-being induced by the visual environment."

- The primary colors are recommended to provide orientation because they are more recognizable than more complex and neutral colors.
- The elderly require high levels of saturation and lightness differences. (Wijk, 1999), it is essential to create separate zones by color contrasts.
- Research indicates that, remarkably, the ability to discriminate colors decreases by aging, especially in blue and green colors. (Wijk, 1999) especially when the blue is exposed on a gray 49 or green background (Lillo, 2012), and the response speed for gray and blue stimuli is significantly slower for the older than for younger (Zamora, 2008).
- The use of dark colors is not recommended because they generate the sensation of confinement. (Suzuki, 2012) and lighter colors are more preferred in confined and indoor spaces because they create the sensation of spaciousness and improve lighting conditions.
- Use matte surfaces that are not polished and do not reflect light and avoid glare (Delcampo-Carda, 2019). Some recommendations are presented in appendix B by the author.

It should be noted that the center should have more monitoring and follow-up on footwear, flooring, and supports as more common factors to prevent a fall. Those who live on the second and third floors have mental issues, which means that many intrinsic factors influenced falls. The second floor has shown more falls compare to the third floor because more number of elderly is settled on this floor.

When we talked to architects about safe flooring, most of them were concerned about the non-slip flooring. And by mentioning the type of shock absorption flooring, their first example was a children's playground. It seems that despite the importance of the subject and the many studies that have been done in this case, but the promotion of shock-absorption flooring and the variety of this product has not been enough that architects, designers and investors are aware of the existence of such products.

5.2 PRELIMINARY DISCUSSION AND RESULTS - TESTS VALIDATION RESULTS

Tests Validation Results of HIC, DWI, VPA Tests and impact simulation:

The Stiffness of solid material, vertical displacement, and impact area are three main factors involve in the shock absorption tiles. The defined test consists of the results of one or more factors.

Three simple and somewhat quantitative HIC, DWI, and VPA methods completely covered and confirmed each other to distinguish the impact force absorption of CF tiles in the current study. The tests showed that the CF systems with codes 101(U1), 402 (U3), and 701 (U2) have the highest energy absorption values with a slight difference.

Tile U2 in test HIC showed the height of 1.86m as the highest CFH rate in terms of safety at fall height. Followers U1 and U3 with the heights of 0.87m and 0.68m were the second and third levels. It should be noted that tile U2 with twice the thickness of two other tiles is widely used in open playgrounds. And similar to this product with various structures available in the market. And U2 with 2cm thickness and without any specific structure is widely used in gyms and fitness rooms. The performances of the CF tiles were even grown after using a thin layer of vinyl flooring over them.

$$U2 \geq U1 > U3$$

With the manual calculations and the formula given in section 4.3.3 (HIC test), we concluded that tile U2 attenuates the force about 91% and with vinyl overlay reached up to 91.10%. Tile U3 attenuated approximately 88.70%, and with vinyl, overlay comes to 89%. And tile U1, with a very close result to tile U3, reduced the force up to 88.20% observations. While with vinyl overlay, it increases the output up to 88.60%.

The DWI and VPA tests with the value of *"e*[123]*"* and area of color distribution (impact area) showed the U1, U3 and, U2 tiles as proper CF systems in force reduction and force dissipation, respectively. The results of U3 and U2 were very close.

U1>U3≥U2

It should be noted that more metal balls rebound height is not necessarily the reason for better force absorption property for the flooring tile. Because VPA tests showed a lower rebound height of the metal ball on rubber foam material (34 cm), which was less than other codes 501, 502, 201, 202, and 403, showed much better force absorption with the height of 40, 49 and 51cm, respectively. It can be concluded that one of the potential factors for reasonable force absorption is related to the surface, material, and internal structure of the tile, which causes elastic or resilience behavior to better force dissipation. We could not use the HIC test for rubber foam (12mm) since the thickness and the extra soft texture of the tile were not safe for the device and may damage the sensors.

Results of BIO test:

FP Method: The FP method demonstrated that the force absorption in U2, U3, U1, and U4 (rubber foam) was about 31%, 23%, 22%, and 15%, which were remarkably lower than the results showed in IPS and FE methods. After covering the tiles with vinyl and carpet, these values increased up to 3-5%, more than without overlay. It can be seen 35% force reduction in U2, 25-30% in U3, 30% in U2, and 20-23% in U4. In the face of parquet and ceramic, these values were not notable.

U2>U3>U1>U4

IPS Method: The IPS method showed the tiles U2, U1, U3, and U4, reduced the force to approximately 77%, 73%, 70%, and 58%, respectively. IPS method demonstrated a further 40-50% force reduction compare to the FP method. Using vinyl and carpet increased the values by 4-8%. All values in four tiles showed the growth of the performances up to 3% when covered by parquet and ceramic as a rigid surface.

U2>U1>U3>U4

In-shoe sensors provide a more acceptable result in terms of force received by the soles of the feet if they are active and not damaged and in confirmation of the previous test, a thin layer of soft flooring over the CF tile does not impair the performance of the system.

Results of Impact Simulation:

Since all people are different from person to person, various factors are considered when simulating a model. The CF system must provide a condition that protects people with varying measurements of body and behavior from getting injured. Accordingly, the CF system cannot be too stiff so that a light-weighted body would not be protected, but yet stiff enough to protect a heavy body. Hence, as demonstrated in Figure 5-1, the failure load among women is lower than for men. Therefore, to ensure and guarantee the performance of the CF system for a larger target group, more tests and simulations on different body measurements should be performed. When developing a new product, the simulation method has the benefit of examining diverse configurations and seeing the effects of a fall on the tile and body. Since diverse configurations can be examined before prototypes, it is valuable and affordable from an economic aspect.

[123] Coefficient of Restitution (CoR)

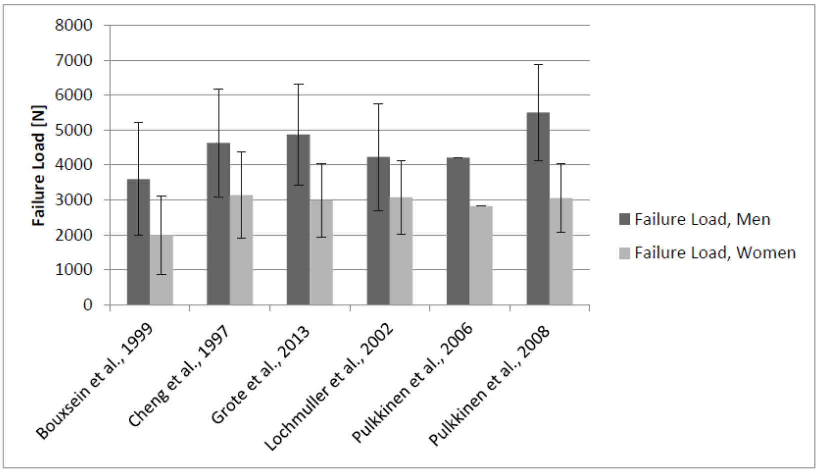


Figure 5-1 Outcomes of six reports illustrated the failure load on the proximal femur among cadavers from the elderly in a sideways fall loading configuration among men and women. The I- bars represent the standard deviation (Dahlgren, 2014).

Considering the only material offered in the CF system in the market, the desired simulation was arranged to consider *SmartCell* tile as a reference example and continued other simulations according to the proportions in this CF system. It was decided to simulate different cell geometry as a structure while preserving the same material (rubber) applied in *SmartCells*. The simulation aimed to understand the reaction and the natural phenomena of the force dissipation in each proposed tile. The vertical displacement was the second aim of this simulation while walking.

The following items were observed by analyzing the recorded animation of impact force on each of the CF tiles.

The graphical perception and analysis that can be seen from the vertical cutting of tiles is as follows:

The classification of colors in the legend from the bottom to the top indicates an increase in the amount of force from dark blue (min) to red (max).

Due to the small amount of time in the force spread in the tiles, instead of the time unit, frame counting has been used.

Due to the large number of frames, only a certain number of them are is given in this section to show the process of transmission and dissipation of force.

<u>Comparison of soil with solid rubber tile:</u>

Frame 30 for all three tiles represents the first striking impact on the tile surface. By comparing the colors, it is clear that the amount of force in the first impact on the surface of the soil tile is more than the other two tiles.

Figure 5-2 shows the force dissipation in two soil tiles and solid rubber with a thickness of 2.5 cm, on which an impactor with a mass of 64.25 kg was landed at a speed of 3 m/s.

The simulation shows that the shape of the force dissipation is quite different in and soil tile and a solid rubber tile without a structure. As the colors represent the amount of force applied and the force dissipation inside the tile, it can be seen that in the first impact on the soil, the top surface of the soil completely receives the force and transmits it vertically and almost integrated into the underlying layers. The amount of initial force received at the impactor edges is greater (red), and the more time passes, the force becomes larger and bigger. In the 56th frame, the force applied to all parts of the tile is almost uniformly distributed. The force received at the corners (edges) of the tile is maximized (red) and transmitted to the force in the form of a pyramid, which contains less force at the top of the pyramid. Up to 66 frames, the color in solid rubber tile has the same blue and turquoise spectrum. While the appearance of green color is seen from frame 38 in the soil tile. It takes about 58 frames to transfer force from the surface of the soil tile to the bottom of the tile floor. While this time for solid rubber tile is about 127 frames, which is almost twice as long.

The maximum amount of vertical displacement of the solid rubber surface with the red ruler is shown in Figure 5-2. In solid rubber tile, the vertical displacement resulting from the impact is very low ($d<3.5$).

Figure 5-3 shows the force dissipation in two solid rubber and a CF system (cylinder cells) with a thickness of 2.5 cm, on which an impactor with a mass of 64.25 kg was landed at a speed of 3 m/s.

<u>Comparison of solid rubber tile with CF tile with cylindrical cells:</u>

The first major difference is the transmission time from the surface to the bottom of the tile floor. As the frames show, the CF system reduces the time of transmission and propagation of force in the tile.

The impulse of force is equal to the change in momentum of an object:

$$\underbrace{F\Delta t}_{\text{The Impulse}} = \underbrace{m\Delta v}_{\text{The Change in Momentum}} \qquad 5.1$$

The average impact force during collisions depends on the velocity of impact, mass, and time:

$$Impulse = F_{average}\Delta t = m\,\Delta v \qquad 5.2$$

Reduce average impact force ($F_{average}$ ↓)
Extend time of collision (Δt ↑)
For a given change in momentum, the impulse stays constant.

When we jump to the ground from a height, we bend our knees upon impact, increasing the time of the collision and decreasing the impact force.

Cars are made to collapse upon impact, increasing the time of the collision and decreasing the impact force.

A volleyball player, after receiving a pass from his teammate, holds the ball between his fingers for a very short time (by bending his fingers) and then throws the ball with a controlled kick of his fingers. The same bending in the knuckles and increasing the time reduces the impact. If the ball is received with the fingers fully open and without flexibility (without increasing the impact time), the volleyball player's fingers may be injured and may even break or dislocate.

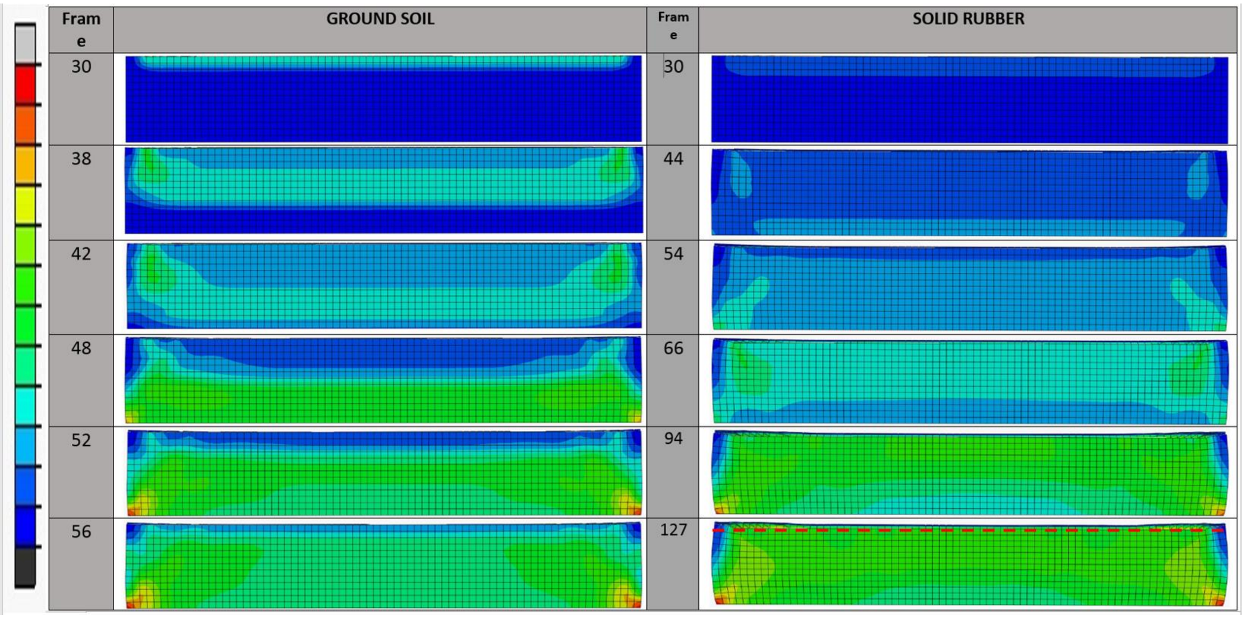


Figure 5-2 Frames of force transmission in ground soil and solid rubber material -By Author

The same springing action that the cells of the CF system structure perform to increase the time it takes to receive force. In frame 50, the applied force has reached the bottom of the solid rubber tile. This transmission happened in frame 225 for the CF tile. This means that it takes about four and a half times as long to transfer the force from the surface of the CF tile to the bottom compared to a solid rubber tile.

The second major difference is the vertical displacement of the surface. In solid rubber tile it was lower than 3 mm while in CF system it was about 6.41 mm. The following formula explains the inverse relationship between the impact force and the vertical displacement. The higher the vertical displacement, the lower the impact force, and vice versa.

The same scenario can be examined with the help of the work-energy principle:

Extend distance of collision

$$F_{avg}d = -\frac{1}{2}mv^2 \qquad (5.3)$$

Reduce average impact force

For a given change in kinetic energy, the work required stays constant.

An Impact needs to stop a moving object. The impact must do enough work to eliminate the kinetic energy of the moving object, so increasing the distance moved during the collision decreases the average impact force. CF systems use the approaches to minimizing force during a collision.

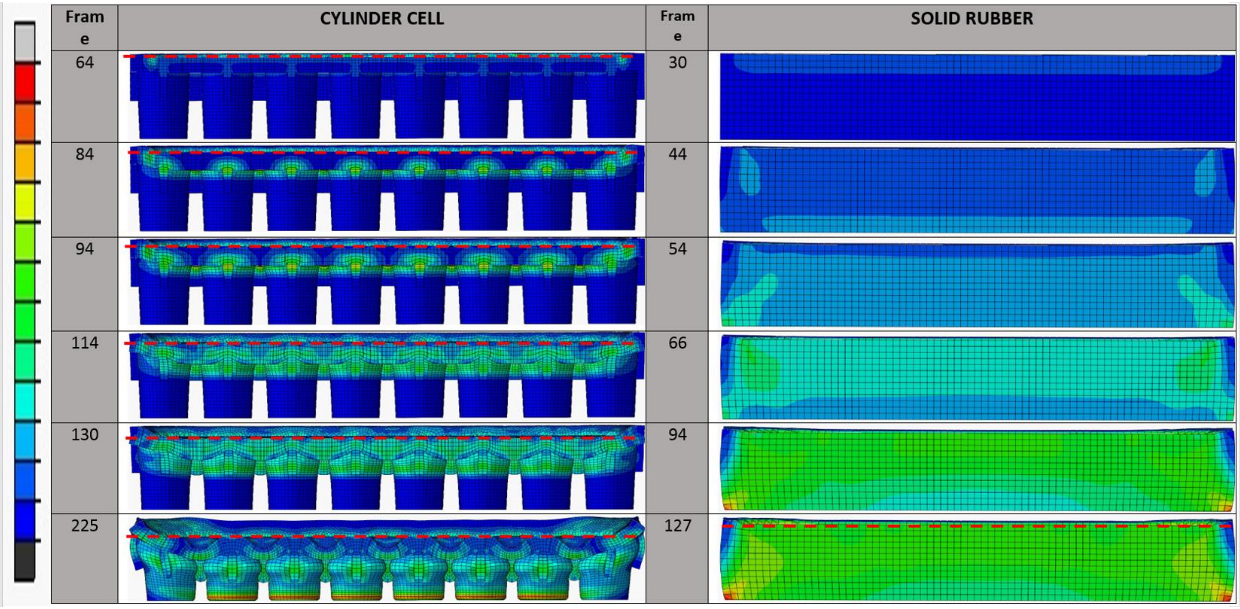


Figure 5-3 Frames of force transmission in solid rubber and CF system with cylinder cell (First)-By Author

The geometry of cell: Evaluation of the geometry and structural shape that provide an excellent impact absorption regardless of the material. This feature is used in other fields of the construction industry with different materials, even with rigid materials. Using stiffener to make an integrated surface and tile is recommended. Results showed this component can not only prevent vertical displacement during walking but also prevent fatigue. And using different geometry of cells in the structure of CF systems contributes to the variety of designs and products on the market. It helps the most appropriate geometries better display their application, and their credibility and performance are also evaluated in practice. In general, all the tested methods showed force reduction between 50-58% in CF systems depend on the material, cell structure, and thicknesses. It was implying that there is a 10% difference between various geometry of cells.

The Thickness of CF Tiles: Four different CF systems were examined in a study conducted by Laing and Robinovitch (Laing A. C., 2009) using a hip impact tissue simulator. The research showed a force attenuation of 22.5% in the CF system of SmartCell with 25 *mm* thickness and at a velocity impact of 3 *m/s*.

The thickness of the tiles was studied in the current study. Due to limitations, it is impossible to use this type of tiles with high thickness in some spaces. For this purpose, the tiles were evaluated in three different thicknesses. The floor's thickness was expected to significantly reduce impact, as shown in previous practical tests with U1, U2, and U3 CF tiles. The thicker the tile with the proper structure, the greater the ability to force reduction due to the impact of the fall. By increasing the tile height by 10 *mm* in the simulation, we saw a reduction in force of up to 12% more than the initial thickness. As previously described, 5 *mm* was added to the top layer and 5 mm to the cell height (2.5 to 3.5 *cm*). Changing in thickness for 10 *mm* reduced the impact force from 56.07% to 69.60%.

Overlays on CF Tiles: Overlay, known as the finish or coating layer, is a crucial layer fixed on the underlays (CF tiles), which should be selected according to the flooring material and the function of the architectural environment. In the simulation done on CF tile, we covered it with two thin floors of cork and marble, which was fixed entirely with a tile and was not allowed to move. It was observed that when the surface of the CF tile was covered with a soft layer (cork with thickness and mechanical specifications stated in section 4.3.5), the force reduction increased by about 20% (from 56.08% to 73.48%). The same test was performed with the BIO method and the vinyl layer, which showed a force reduction of up to 30%. In addition, using the rigid marble layer in the FE method (with the thickness and specifications announced in section 4.3.5), the force reduction decreased by 10% (from 56.078 to 49.94%). However, the BIO test with ceramics showed an increase in the force attenuation of about 22%. Figure 5-4 shows the possible layers in the CF system.

We could not use this method to confirm or reject the results of the other two techniques (DWI and VPA) since the HIC test does not test the rigid surfaces because of damage to the device's sensors. So it makes sense to say that it is preferable not to use rigid surfaces on the CF system even if it is unlikely to have not a significant effect on CF system performance.

- Due to the constitutive material of CF tiles, the main property of impact absorption does not decrease significantly using overlay. In this regard, vinyl, rubber, and carpet are the best options as a coating layer for indoor use.
- The coating layer could be provided in roll or tile. However, to avoid the least amount of seams, accumulation of germs, contamination, and better cleaning, the roll system is recommended.
- The preferred size for the CF system is 60x60cm, but due to the weights, thickness and materials, and flexibility of the tiles, they have the potential to be provided in a larger size.
- The liquid adhesive can be used to fix the coating layer (finishing layer) on the CF tiles.
- The CF tiles must be fixed to the dry and clean subsurface with or without liquid adhesive depends on the joints.

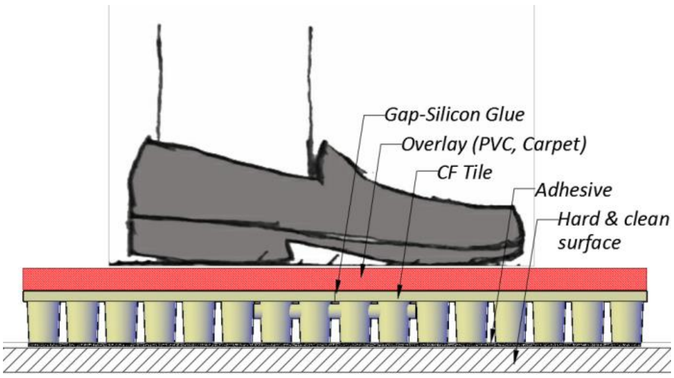


Figure 5-4 Layers of flooring with CF system-By Author

The advantage of such flooring is its quick and easy installation. There is no odor, no mortar, and no extra clutter like conventional flooring.

***Hint:** As a result, we can say that the U1 tile (as a cylinder cell with stiffener) attenuates the force about 88.20%, 73%, and 56.08% due to the results achieved by HIC, BIO, and FEM simulation, respectively. While using vinyl as an overlay, increased the force attenuation of up to 88.60%, 79%, and 73.48%, respectively, in the same tests.

Installation of CF Tile: To improve the durability and performance of the flooring product, proper installation and executive connections between the tiles and subfloor are of particular importance (for more details, see section 6.2).

Material of CF Tile: Investigate materials that able to impact force reduction. Recyclable materials that are currently widely abandoned in nature and their potential is not used correctly. Apart from recycled tires, wastes from the agricultural cycle are also highly exploitable with this theme. Finally, it can include the production of composite materials that can be an excellent alternative to commercial flooring (for more details, see section 6.3).

5.3 PRINCIPAL DISCUSSION AND RESULTS - WITH RESPECT TO HYPOTHESIS

Considering that we started our thesis with a series of questions in the hypothesis section, we will also address the answers that have been obtained.

N.	QUESTIONS	ANSWERES
1	Why there is no norms, building technologies, or safety flooring provided for the elderly environment?	Due to the research, it should be said that many national or international standards focus on shock absorption. These standards and their testing methods can be used to produce the desired products. The only point is that the physical condition of the elderly is such that in addition to the absorption of impact by the floor, other points must be considered, and these cases must also be standardized.
2	What are the essential characteristics of safety flooring with a focus on older users?	-Impact/shock absorption structure. -The CF systems need a soft surface enough to cause minimal damage to the body when hit, and in addition, it must have enough rigid surface not to interfere with walking so as not to cause a fall. (The two mentioned above need an integrated structure to consider both items in CF system design. -Acceptable durability, easy maintenance, suitable thickness, the elasticity of CF tile material, or the elasticity behavior of the CF structure have the least pores on the surface to perform proper and accurate cleaning. -The surfaces must be anti-slip du to the standard (section 4.2.2). However, the friction between the floor surface should not be such as to cause fatigue of the employees' feet or the difficulty of moving the wheels of the equipment (which, of course, has a direct relationship with the type of caster roller wheel design and wheels' width (section 3.2.3)). It may also become a reason for the elderly not to move their feet easily, which leads them to fall. * Hint: Or the ability to install a thin layer of other floorings on it to create an integrated and uniform surface. Integrated proper surface solves many related items to the top surface of the CF system, such as the anti-slip, beautiful and suitable appearance of the space, non-reflection, and glare of light, accurate and easy cleaning, etc. Products such as vinyl or carpet can be tracked and helpful. -If the tiles are presented in larger dimensions, they will overlap with each other and transmit the force vertically, and dissipate the energy horizontally at the appropriate level -Odorless and non-toxic -And other features that should be a priority for all products with flooring performance. Some of which are listed in a table in Appendix A.
3	Why are the products on the market not capable of being installed in nursing homes! Are they not adequately optimized for such spaces!	-According to research, as mentioned earlier, unfortunately, except for one product (*SmartCells*) professionally branded, there is no other product in the market that is suitable for the elderly and indoor installation. Until recently, the number of these products was 4 (*SmartCells, Kradal, PSSF, and SorbaShock*) (see section 3.2.3), which unfortunately are not available at the moment. -Other products with shock absorption properties are not suitable for the elderly and indoor. -Non-compliance of the product with the user or the interior space, including rigid surface, high thickness, surface with high porosity, and the presence of seams and gaps between the tiles after installation. Because of the texture of the surface, it is not possible to install another layer over the CF surface, which causes uneven surfaces and not to be adequately cleaned. -Use of rubber in structure and insecurity during fire and production of toxic gas.
	Given the examples of existing architectural designs, why do architects not consider the importance of this matter! Why do they not make any difference in the design of	-Honestly, many architects and stakeholders have not even looked for such products and are not even aware of the existence of the CF system. They use those CF systems in sports, industrial spaces, or children's playgrounds that have been introduced to them. Or see them daily in the mentioned places and are aware of presented products in the market. -Regardless of the lack of information and advertising, research and interviews conducted in this study show that they do not have enough confidence in such products. They believe that dealing with the elderly is a risky issue. They prefer not to use products that have not been proven the performance and validity in public with massive and pervasive use. -Cost-effectiveness and high durability are a priority for stakeholders. However, the initial installation and purchase of these products may, to some extent, be costly. Significant savings can be made by reducing damage and reducing medical costs in the long run.

4	the floor, considering the users! Are architects not aware of the existence of such products!	-It should be noted that a lot of academic research has been done on this matter, especially in medical engineering, to validate other products such as hip protectors' tissue. But except for one case of KTH conducted in the Department of Neuronic Engineering (see section 3.2.3), no other research was found that specifically focused on the material and structure of the tile with a focus on the elderly to reach the mass production stage by raising capital. And it seems to have remained at the level of academic research. -There is not enough product variety and advertising in the market. Variety in structure, materials, and beautiful appearance can persuade the designer or consumer to apply the CF system in risky indoor areas. -In other countries, carpets or rugs are more common and widespread (especially in private homes), which using such soft texture in indoor areas reduces damage. But research showed that in Spain, due to the reluctance to use this fluffy and soft flooring, using the CF products is more important.
5	How to secure the floor of the currently built spaces?	-According to the products available in the market, the simplest and least expensive method to secure the currently active spaces in centers and apartments can refer to 10 to 12 mm rubber foams used in interior spaces. It is noted that the rubber foam tile cannot be used in all areas since some changes must be made to the cover layer of the tiles. However, the initial installation is simple, and in case of any problem, they can be easily replaced. -Using a layer of vinyl on the rubber foam tiles is recommended, if possible, to provide a uniform and integrated surface. So that in addition to good flexibility for shock absorption, it also provides a sufficiently firm surface for the elderly to walk safely without disturbing their balance. -The rubber foam tiles should be installed in spaces where the staff traffic is low (not suitable for corridors) because it may cause fatigue in the lower limbs of staff. Appropriate areas for using rubber foam include bedroom, dining room, and even bathroom if the installation and sealing are done correctly. -As the test results showed in section 4.3.4, the rubber foam can reduce approximately 20-23% of the impact. However, it is worth using these floors in high-risk spaces even with this small value of force reduction to minimize possible injuries from falls.

5.4 LIMITATIONS

VPA Test: The problem in this part was related to the behavior of the floor concerning the metal ball rebound. In some cases, the metal ball rebound was so slight that it was difficult to grab the ball after the first collision. So it created points or lines on the film that were not what we wanted, so the test had to be repeated.

BIO Test: One of the limitations is related to insole sensors. Due to the high price of insoles, only one pair of insoles was dedicated to each participant. This error coefficient was considered because of no evidence or study on the durability of sensors during frequent jumps. Some of the sensors may become deactivated or show an error. The difference magnitude between the force received by the sensors in the first jump on the unprotected surface (force plate-as rigid surface) and the last jump on the unprotected surface has been added in proportion to the value of force absorption and force received by Flooring. The added value has been calculated by considering and comparing the decreasing or increasing force received by the sensors. The error coefficient in all participants made the value reasonable with the most negligible error possible.

Secondly, participants did not have the same footwear during the test. They wore their personal sneakers, which may affect the results or damping energy by the shoe sole's thickness or material. Besides that, the type of jumping is critical. Although they were asked to jump without any bending joints, however, controlling all the conditions or habits of the participant's body is almost impossible.

Despite the result, it should be noted that a conclusive assessment of the effectiveness of the interventions is not possible due to the limited number of studies and the lack of insole sensors for the study outcomes. Therefore, there is a need for more volunteers to receive accurate and precise biases.

Regarding the results, it seems the force plate method is not an accurate option for measuring the force applied to the CF system. One of the reasons for the anomalies and distortions in the results may be related to the geometric shape of these floors. It should be noted that the sensors embedded in the FP system cannot receive the applied force properly from the tiles.

The In-shoe sensors method provides a more acceptable result in terms of force received by the soles of the feet if they are active and not damaged.

FE Method: Although every effort has been made to bring the simulation results closer to reality. There are still conditions and cases in the natural state that are either impossible or very difficult to provide when it comes to the reaction and behavior of the human body.

The tensile test is a standard method for identifying materials' physical and mechanical properties and is widely used by engineers and researchers. However, there might be some human errors in measuring the dimensions of the specimen, which is due to the limitations and the lack of a standardized material test method.

Studies have stated that the thickness of the soft tissues surrounding the greater trochanter can reduce the probability risk of a hip fracture. A slimmer person with lower trochanteric soft tissue has a higher risk of hip fracture during a sideways fall (Majumder, 2013). Furthermore, Laing and Robinovitch (Laing A. C., 2008), illustrated that the stiffness of the soft tissue between different parts of the buttock, which would affect the severity of the force when falling at different angles.

Hence, one of the limitations was finding a way to model the impactor as a factor that is supposed to act similarly to the human body. The behavior of the human body is very complex. The human body comprises different materials (Volume of muscle tissue, fat tissue, joints, tendons, etc.), each with a different damping coefficient. In the face of injury, they have the ability to control and reduce a large volume of received force. Therefore, the reaction dependence on performance between members manifests itself better and more when jumping. It implies that simulating an individual weighing 64.25 kg with a weight of 64.25 kg in the software in the face of jumping is very different. For this purpose, the impactor in computer simulation should be selected as more elastic with lighter weight which may not have been chosen correctly due to computational errors. For this reason, the rate of absorption of the target tiles may be higher than the simulated one, as was observed in BIO tests. However, since the behavior (deformation, vertical displacement, reduction of force, and final overlay) of the CF system was more considered in this study, the desired and expected results were achieved with this amount of information and simple simulation.

Among the limitations of this method, the high capacity of executed files and the long time to complete the execution process was considerable. Although simulation methods open a via to contribute knowledge and better perceptions, it must be noted that simulations also have some limitations.

Since the CF system, damper and impactor were composed of a simplified mesh, the achieved values are not accurate and trustable enough, which could be concluded by overviewing the energy levels. Experiences indicate that a denser mesh is required to get more accurate results. The peak force received during the simulations might provide a value that is too small (Okan J.-S. S., 2015).

Since many simulations were to be performed during the thesis, the time limitation aspect, a more robust system to processing were of importance.

CHAPTER 6

SUGGESTIONS FOR FUTURE WORK PLAN

CHAPTER 6

6 SUGGESTIONS FOR FUTURE WORK PLAN

The current investigation indicated that despite the importance of the issue, there is no standard measurement unit to define the borders of a norm to validation. And corresponding to the findings, we hope this study creates a spark to start a generation and use of such products in industry and trade. It may open up a new argument for architects and designers, students, and manufacturers.

The evidence implies that the CF system needs more comprehensive investigation in the practice and experience field. As the research showed, most of the studied on shock absorption category are conducted on normal soft mats / foams or just few sample of CF system based on biomedical point of view. The two categories of structure or geometry of CF system requires extensive study. And the lack of this issue in the field of research and practice is quite obvious. Using different and simple test validation help researchers to rich the goal of design faster and easier with low price before entering the factory construction and mass production stage.

Elastic materials or composites composed of several natural and agro-based fiber materials and fillers with proper resilience character and the potential of appropriate reference behavior, can be a good option in this field of design and require more accurate and scientific discussion. This is not a matter that can only be studied by laboratory modeling. Although, the sound or thermal insulation properties of these materials have been widely used in products such as walls or acoustic ceilings. But, their elasticity and texture have not been discussed in any research based on being used in flooring tiles.

Here is a summary investigation to give an idea and some suggestions for future work plan which needs further review and research.

Keywords: Geometry and Structure, Material, Agro-Based Material, Green Materials/Composite, Recycled Rubber, Recycled Material, Matrix (binder), Filler (fiber), Cushioning, Installation.

6.1 STRUCTURE OF CF SYSTEM

Similar CF systems, materials, and elastic behavior were explained in section 3.2.3. Unfortunately, we could not find a sample of other products to evaluate the structures. But examining materials and structures gives the main perspective and background for dealing with the principles in system design. A strategy that provides spring behavior and leads to cushioning system.

1. Phenomena or technology used in energy dissipation of CF floorings
2. Use the right and appropriate materials (Single substance, Multi-substance, or Combination of material and elements)
3. The thickness of flooring tiles
4. Structure, the geometry of cell unit, and layers of tiles

6.2 INSTALLATION: JOINTS AND CONNECTIONS

Besides designing flooring tiles, installation methods and the connection between tiles are a considerable matter in the flooring industry. In this chapter, the ideas for installation details related to the CF tiles' type of structure and geometry are presented. This chapter also includes details associated with the connection of adjacent tiles on the horizontal surface. The end of the tile, the installation on the sloping surface or the ramp, and the final layer on the CF tiles are discussed issues. Appropriate coverage and uniformity across the floor need larger tiles to minimize the gaps between the adjacent tiles. In addition, this method provides lower stiffness between the joints. That's why most CF systems are available in sizes larger than 50 x 50cm and even 100 x 100cm. This is due to both the reduction in the boundary of the adjacent tile joints and the quick and easy installation, which varies depending on the tiles' thickness, material, and structure.

The following charts proposed the type of possible joints in adjacent tiles on a flat surface, joints, and installation on a sloping surface, and correct the difference in levels of the installed CF tile with the lower surface:

NO.	Description
A	• Similar to the Idea presented by Bryce L. Betteridge et al.[124], two or three rows of cells adjacent to the edge of each tile would be trapped in a grid of circular hollow cavities (the shape of the grids will be different due to the geometric of the cells) which is raised about 1.5 cm above the surface by bending at the end of both sides of the grid. • A very thin silicone adhesive fixes the connection edges at the top layer of the tile in order to fill the gap between the tiles. • In fact, due to the large size and strength of the tiles provided, there is no need for mesh and glue, and the tiles are very well placed next to each other;
B	• In a similar method provided by Rubber cal[125], a series of fasteners are used in the form of plastic screws. The entrance hole of the plastic screws is already embedded horizontally inside the tiles. • A very thin silicone adhesive fixes the connection edges at the top layer of the tile in order to fill the gap between the tiles.
C	• A plastic binding connector in the form of “W” locks the two adjacent tiles together like a clip from the bottom. • A very thin silicone adhesive fixes the connection edges at the top layer of the tile in order to fill the gap between the tiles.
D	• Series of fasteners in the form of plastic screws are used. The entrance hole of the plastic screws is already embedded vertically inside the tiles. • A very thin silicone adhesive fixes the connection edges at the top layer of the tile in order to fill the gap between the tiles.

[124] Scott, R. P., & Betteridge, B. L. (2009). U.S. Patent No. 7,575,795. Washington, DC: U.S. Patent and Trademark Office.” „IMPACT ABSORBING SAFETY MATTING SYSTEM WITH ELASTOMERC SUB-SURFACE STRUCTURE”
[125] https://www.rubbercal.com/rubber-flooring/building-playgrounds/eco-sport-1-inch-interlocking-rubber-flooring-tiles.html

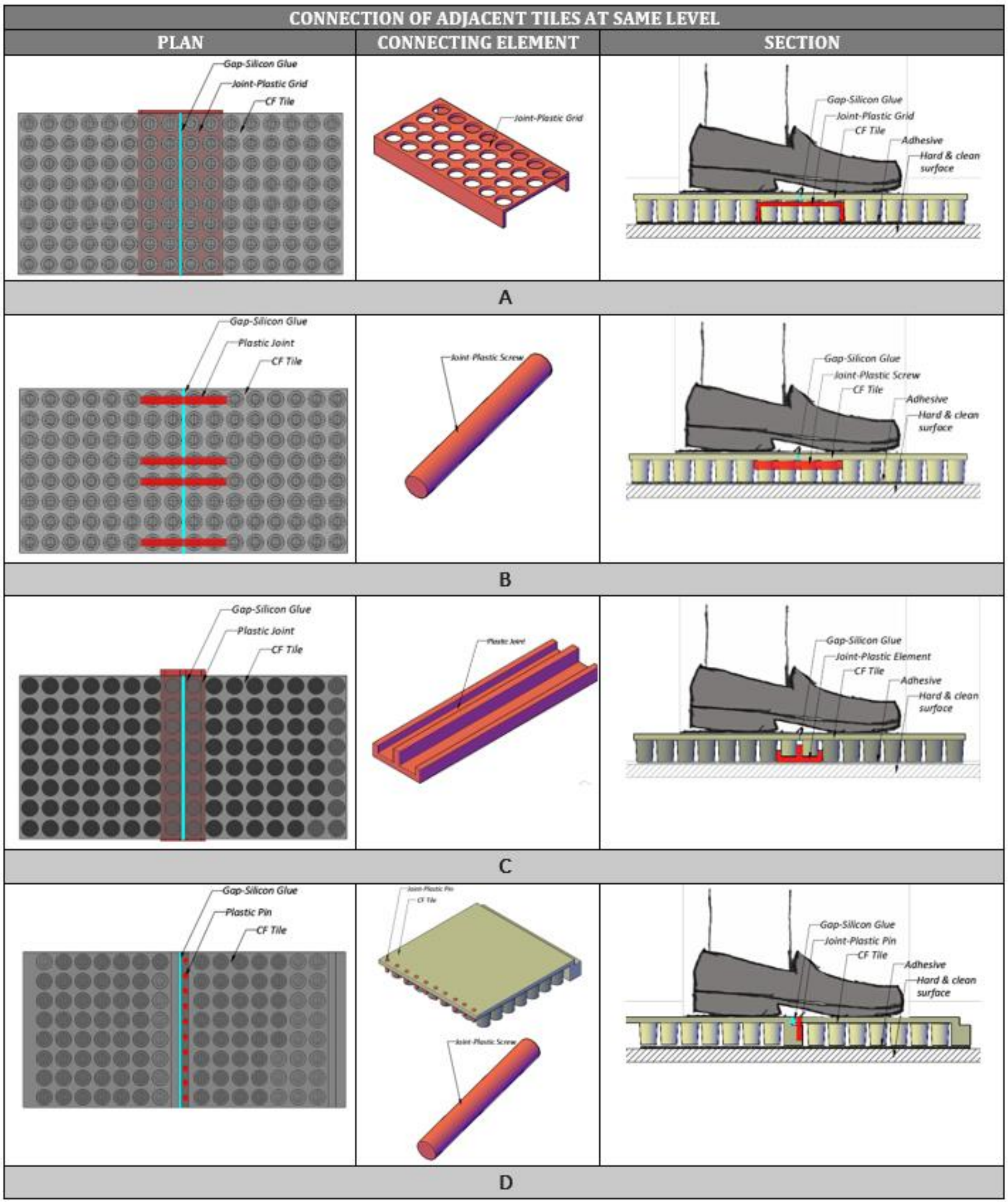


Figure 6-1 Methods in connection of adjacent CF tiles at the same level-By Author

NO.	Description
A	• The end of the tiles with an approximate thickness of 2.5cm cannot be released at the end of the tile. Because the foot gets stick to the edge of the tile, they are considered a factor in the fall. • Similar to the idea used earlier, a plastic grid of hollow holes would be used to trap the cells embedded under the last tile and the tile with a proper slope t • A very thin silicone adhesive fixes the connection edges at the top layer of the tile in order to fill the gap between the tiles.
B	• Similar to the idea used earlier, a series of fasteners in the form of plastic screws are used to link the last tile to the finishing tile. The entrance hole of the plastic screws is already embedded vertically inside the tiles. • The finishing tile with a proper slope that designed and dedicated to close work. It can be glued to the subsurface or screwed in through pre-built holes. • A very thin silicone adhesive fixes the connection edges at the top layer of the tile in order to fill the gap between the tiles.
C	• The end sloping tile locks the two adjacent tiles together like a clip from the bottom. It can be glued to the subsurface or screwed in through pre-built holes. • A very thin silicone adhesive fixes the connection edges at the top layer of the tile in order to fill the gap between the tiles.

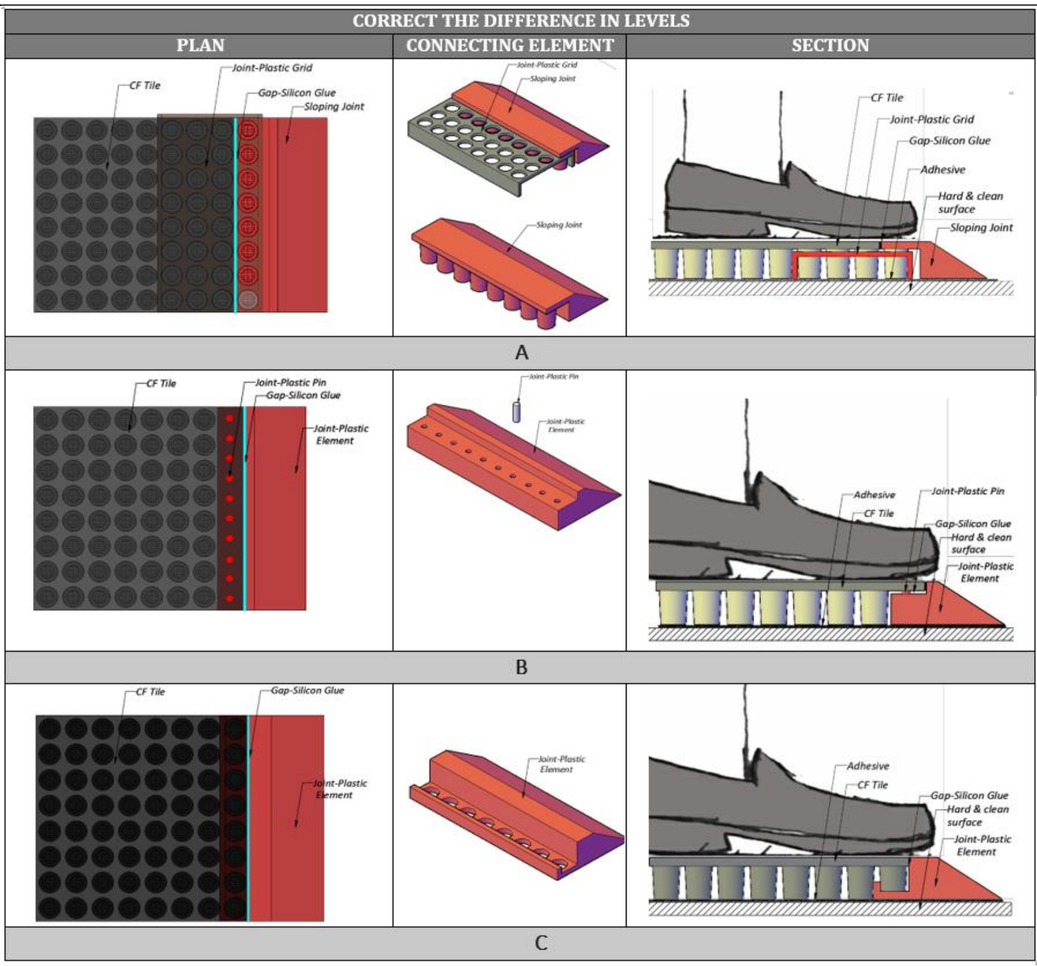


Figure 6-2 Methods to correct the difference in levels between CF tiles and subfloor-By Author

NO.	Description
	• The connection gap between two adjacent tiles on the ramp can be locked using clips with three shapes of "T, M, and W" from the top or bottom of the tiles.
	• The "T" clip can be glued or screwed to the tiles by plastic screws.
	• A very thin silicone adhesive fixes the connection edges at the top layer of the tile in order to fill the gap between the tiles.

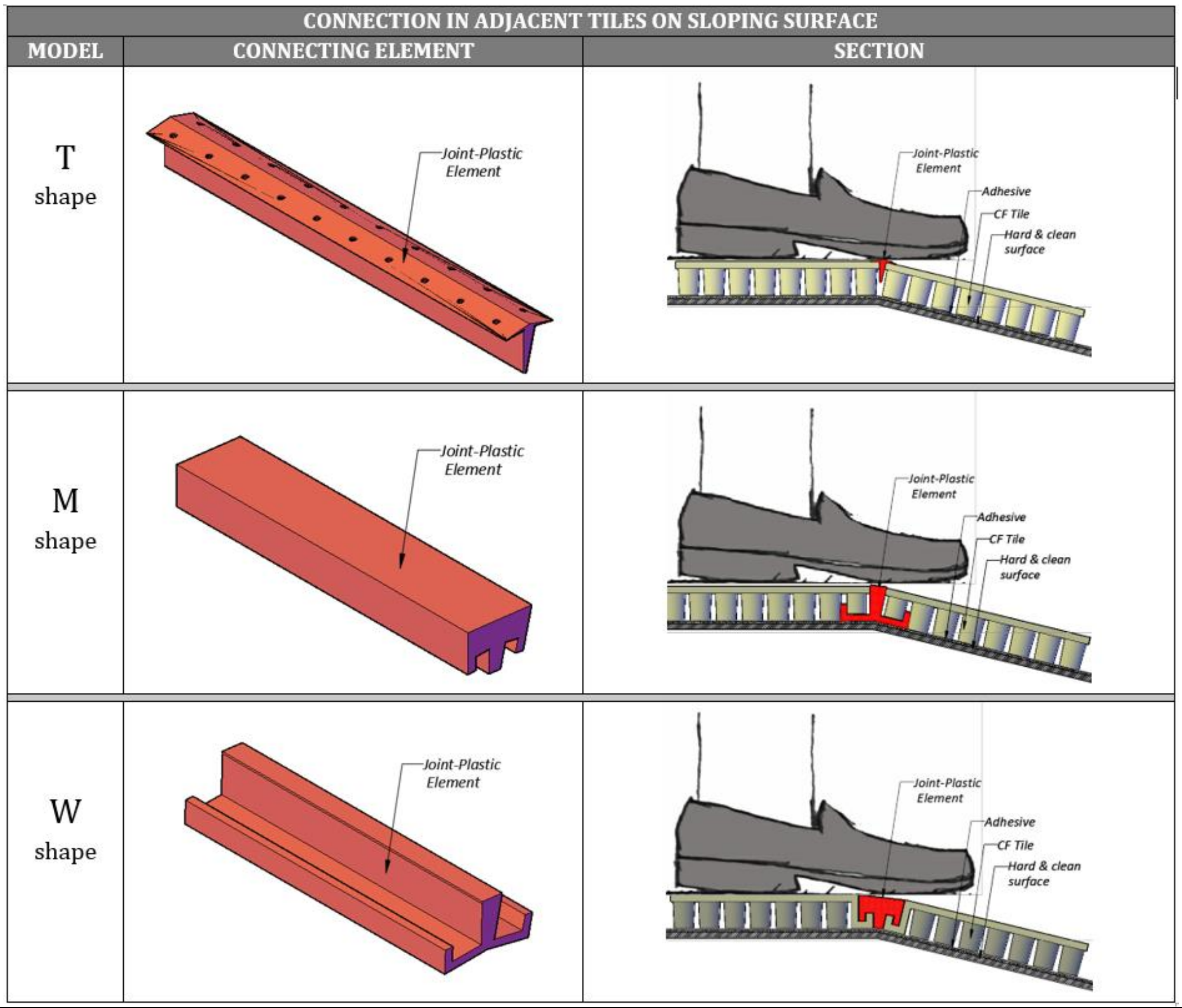


Figure 6-3 Methods in Adjacent CF tiles on slopping surface (Ramp) -By Author

6.3 MATERIAL AND STRUCTURE

Due to the unique properties of shock absorbing floors, which must be elastic, we have divided materials that have shock absorption properties into three main categories:

1. **Conventional Rubber and Foams:** It can generally be natural or synthetic rubber. Preferably use tires that are in the recycling cycle, such as worn and discarded car tires. But foams are not suitable for high load-bearing floors due to their excessive softness.

2. **Composite materials:** Composite materials and tiles generally consist of two main parts, filler, and matrix. Fillers can include plant products such as cottonseed, sawdust, bran or rice and wheat stalks, hemp, or animal products such as animal wool. And matrices can also use polymeric materials such as PLA, PP, or PE.
3. **Integration of multiple systems:** For example, the integration of elastic materials (foam, rubber) in a system with elastic behavior like spring

6.3.1 CONVENTIONAL RUBBER AND FOAM

RECYCLED RUBBER

Worldwide, the magnitudes of utilized polymer and rubber products are growing fast by the year, particularly those used in the automobile industry, mainly in the form of used and waste tires. Reports show, the annual global generation of tires is about 1.4 billion units, which causes an estimated 17 million tons of utilized tires each year (RMA.org, 2009) (JATMA, 2018) (WBCSD, 2010). This imposes a high cost for disposing of them in EU countries at nearly 600 million euros (Maciej Sienkiewicz, 2012). The scale of the problem is enlarged by the environmentally dangerous buried tires already. These dumps are seriously threatening both the natural environment and human health. There is always the possibility of fire because, over time, the proper degradation of this material causes safety problems. On the other hand, burning causes the emission of toxic gases harmful to the environment and suitable habitat for rodents, snakes, and mosquitoes (Lebreton, 2006). The reproduction of certain mosquitoes that transmit diseases such as fevers and encephalitis through bites leads to 4000 times more than in the stagnant water (Esteve, 2012).

Since 2006 the European Directive 1999/31 prohibits landfilling of both complete and crushed used tires. This regulatory framework has favored new uses of end-of-life tires (EOLs), such as retreaded tires that are recycled for other industrial uses or, ultimately, their use as an energy source (Aimplas, 2013). End of Life Vehicle Directive 2000/53/EC, passed in 2000 and Directive 2008/98/EC published in 2008 by (Figure 6-4, and Figure 6-5) the European Union expresses an effective movement forward in all related aspects of waste management. Under the already released, extended-produced responsibility (EPR) norm, new policies have been declared to continuously gain better environmental performance of main products throughout their life phases (Angel Uruburu, 2013). This directive controls processes for treatment with vehicles withdrawn from service. According to this law, in order to recycle the tires, they must be removed from vehicles before they become scrap and unusable. Because of the properties of the used tires, they are now a source of valuable raw materials with the potential of effective conversion to energy or materials, which can be used to produce new goods with high performance and value. The prohibit stockpiling rule was the big step in levels of recycling to rise. At present, rubber regeneration has a significant role in the rubber industry, which is used as additive materials to new rubber mixtures (Maciej. Sienkiewicz, 2012) (Aisien, 2006).

Year	Code	Topic
2011	Law 22/2011	Spanish law of wastes and polluted soils
2008	2008/98/EC	On waste management
2006	2006/12/EC	On waste management
2005	RD 1619/2005	Management of EOL tyres
2000	2000/53/CE	Management of EOL Vehicles

Figure 6-4 European and Spanish EOL tire regulations (Ange. Uruburu, 2013)

The main Spanish integrated management system (IMS) model for end-of-life (EOL) tires has consolidated its status as a benchmark, not only in Spain but also in other states. During a few years, the IMS has successfully and targeted handled approximately a million tons of used and waste tires, more than 100% of the tires placed into the market (Ange. Uruburu, 2013).

Directive	Main relevant aspect
2008/98/EC	Waste hierarchy: prevention, preparation for reuse, recycling, other recovery, and disposal End-of-waste status for several wastes, such as paper, glass, metal, tyres and textiles Need for prevention of waste Encouraging the design of products to reduce their environmental impacts Cost of the WM share by the producer of the product that created the waste and the distributors of the product
2006/12/EC	Cost of WM by the original waste producer or by the current or previous waste holders

Figure 6-5 Main relevant aspects in a comparison of Directive 2008/98/EC and Directive 2006/12/EC (Ange. Uruburu, 2013)

Norm 22/2011, 28 July, Spanish law of Wastes and Contaminated soils

According to the Spanish Law 22/2011 of the 28th of July, Waste and Soil Contamination by-products are any materials or products or objects caused by a manufacturing process whose primary purpose was not producing this material or object (EuropeanCommission-FOREMATIS, 2020). In Spain, 250,000 tons of used tires are generated each year from machinery and means of transportation (Esteve, 2012). The Spanish Federation of Recovery and Recycling (Federación Española de la Recuperación y el Reciclaje-FER) ensures that, besides, a large part of recycled rubber is used as an alternative fuel for energy purposes (Figure 6-6).

NEUPRO project: new applications for recycled rubber AIMPLAS ends the first phase of the NEUPROD project. The main objective of this project is the development of new applications of recycled rubber through new recycling processes, product design, and shaping that allow its incorporation in new sectors such as construction, furniture, etc. The NEUPRO project is part of the IMPIVA Strategic Development call and has been co-financed by the FEDER Funds within the FEDER Operational Program of the Valencian Community 2007-2013. The project aims to ensure that a product that is generally intended for uses with little added value (road filling, athletics tracks, rubber pavement for playgrounds ...) is used as a raw material in environmentally sustainable and economically viable products (furniture, systems insulators, non-slip rubber floors ...).

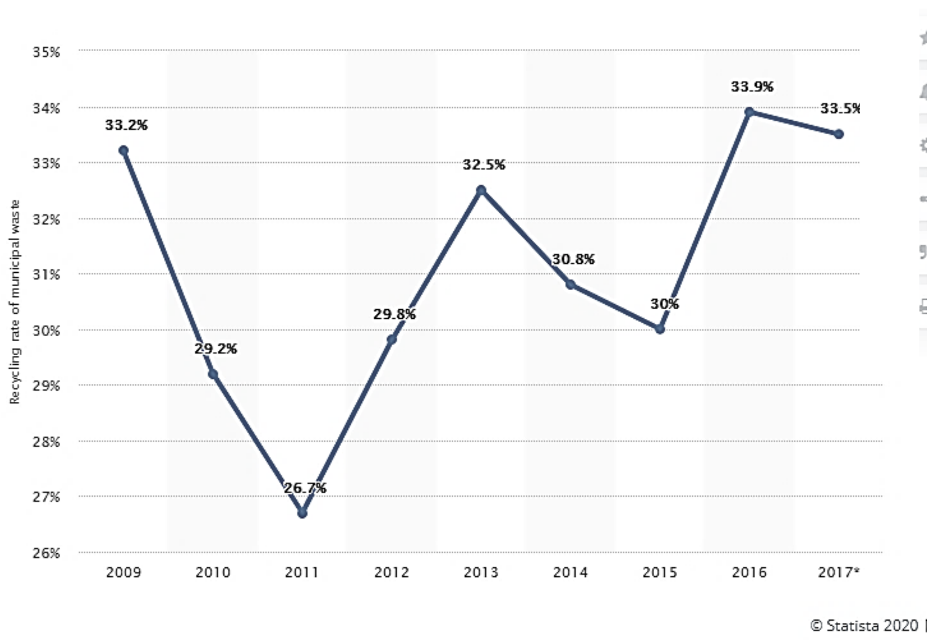


Figure 6-6 Recycling of municipal waste in Spain 2009-2017 (Statistica, 2019)

The plastics sector is increasingly seeking greater sustainability and solutions to increase the new applications of plastic and its useful life and minimize the environmental impact through recycling and bioplastics (Aimplas, 2013).

Rubber Shredding

Shredding is the most typical format in the transformation of material recycling in Spain. This method facilitates rubber transport, decreases mass, and homogenizes the waste for new applications. The shredding process involves the considerable wear of the blades of machines and the high cost of their following renewal. Shredding and grinding technologies are purely mechanical; there are no chemical agents or heat addition. It consists of passing the initial tire through a series of successive crushing until its volume reduced to a very small output size, which will regarding the the subsequent use of the product (most applications is used between 2 and 4 mm), pulverization (between 0.8 and 2.5 mm for artificial turf or a basis layer) and micronization (less than 0.8 mm for bitumen applications) (Ange. Uruburu, 2013).

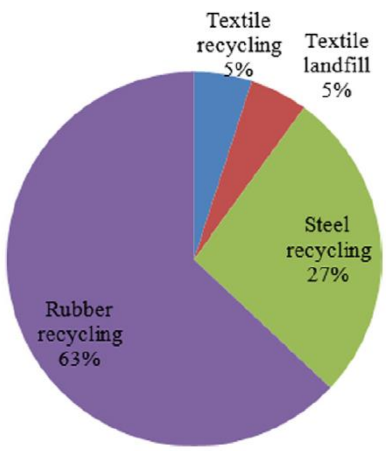


Figure 6-7 Recycling market by material (Ange. Uruburu, 2013).

After crushing the tires, the metal that exists in an achieved mixture of rubber and metal that includes the original tire is removed using magnetic separators (magnets), so the final product would be a pure and clean rubber to be used in different sectors of industry (Esteve, 2012).

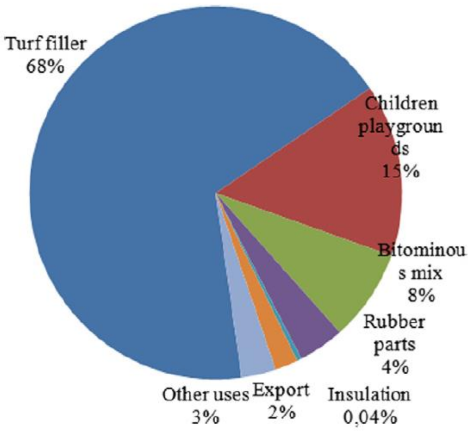


Figure 6-8 Rubber granulates market (Ange. Uruburu, 2013).

In case of need, shredded rubber is placed below the freezing point of -200 C with liquid nitrogen. It is lost the elasticity property and becomes fragile, enabling its easy decomposition. Shredding is the most typical format in the transformation of material recycling in Spain. This method facilitates rubber transport, decreases their mass, and homogenizes the waste for new applications. The process of shredding involves the considerable wear of the blades of machines and the high cost of their subsequent renewal. In 2010, the products obtained from this production method showed a significant demand in the market. Still, rubber granulate continues to be the most important and popular product concerning the recycling material market. In some cases, the rubber granulate market slightly changed in its profile (Figure 6-7, and Figure 6-8).

<u>Conversion of tires into electrical energy</u>

Besides, once prepared, tire waste can be converted into electrical energy that can be used in the recycling plant itself or to other distribution facilities. The residues are introduced into a boiler, where the combustion is carried out. The heat that is released in it is converted into the steam of high temperature and pressure that is conducted to a turbine (Esteve, 2012). Recycling used tires and rubber is a sustainable alternative that prolongs the useful life of this material. Due to its malleability and versatility, rubber offers many opportunities for reuse. They can be used for the manufacture of prefabricated elastic floors in the form of tiles, plates, or rolls, for sports floors, gyms, rubber mats, game rooms, or playgrounds.

Particles of intermediate size can be used to fill artificial grass pitches and the finest as an additive to improve the quality of asphalt mixes and as a component for manufacturing parts in the rubber industry. Waste tires are a significant concern among waste materials because of their rapid increase. Most countries' policies are based on encouraging industries to use waste tires in construction in order to prevent environmental pollution. Also, this material is an excellent insulator, both thermal and acoustic; they are applied in the production of:

- Insulating systems, e.g., vehicles, washers,
- cable housings,
- rubber roofs
- Road pavement and components of the asphalt layers used on the roads. Resilient asphalt is a particular type of flexible pavement applied in sports fields and recreation areas to help decrease

the pain of feet insole and joints while walking. Resilient asphalt has a mixture of asphalt, vulcanized rubber fibers, and rubber latex. Resilient asphalt involves a remarkably higher resilient modulus than generic asphalt concrete and resists under different environmental humidity or temperature.

- footwear
- Particles to fill artificial grass pitches
- solid fuels for cement kiln and paper mill
- Construction materials

6.3.2 COMPOSITE TILES

COMPOSITE AND BIO-COMPOSITE TLES

Reducing energy consumption is one of the most important issues of future building construction, which is a challenge for all their life phases, from construction to destruction (F. Asdrubali, 2012). The rush towards environmentally friendly structures in recent decades predetermines increasing opportunities for new sustainable and recycled materials. For this reason, Natural materials individually or combined with other materials as composites are used in various industries, especially construction. The availability of Agro-based materials and low cost have made it possible to replace common synthetic materials based on petroleum materials. Due to the research, natural and recycled materials are widely exploited in the acoustic and thermal insulation, shock absorption, and packaging sectors. In this section, we have a review of a number of studies about the capabilities and potentials of natural or recycled materials in various applications, especially construction. We will compare and evaluate the ability to use agricultural-based materials as another option and recycled shredded tires, which are currently used as shock absorbing flooring in many places. Verification of this claim is fulfilled through simulation in the software.

Sound and Thermal Insolation

Acoustical sustainable materials, made of natural or recycled materials, have less environmental effects than synthetic materials and generally require less energy for their production than conventional materials (Nations, 1988). The sound insulation of natural materials such as flax or recycled cellulose fibers is often a valid alternative to rock or glass wool. Many natural materials (bamboo, rice straw, kenaf, cork, coco fibers) demonstrate worthy thermal insulation and sound-absorbing performances. All these materials are often light and are not harmful to health also; natural fibers contain very low toxicity (Zabalza Bribian, 2011) (Joshi, 2004) (Figure 6-9)

N	Material	Thermal conductivity (W/mK)	Absorption coefficient a_S at 500 Hz (-)	Index of reduction of impact noise DLW (dB)
1	Hemp	0.04	0.6 (30 cm)	-
2	Kenaf	0.044	0.74 (5 cm)	-
3	Coco fiber	0.043	0.42	23
4	Sheep wool	0.044	0.38 (6 cm)	18
5	Wood wool	0.065	0.32	21
6	Cork	0.039	0.39	17
7	Cellulose	0.037	1 (6 cm)	22
8	Flax	0.040	-	-
9	Glass wool	0.04	1 (5 cm)	-
10	Rock wool	0.045	0.9 (5 cm)	-
11	Expanded polystyrene	0.031	0.5	30

Figure 6-9 Acoustic and thermal properties of some natural (1-8) and traditional (9-11) insulating materials (V. Desarnaulds, 2005)

In recent decades, combined recycled waste and green material as composite materials have been welcomed as affordable options in construction. On the other hand, some materials such as melamine and polyurethane foams used in sound insolation are relatively expensive and dependent on petrochemicals. In particular, natural fibers are the most popular that have been considered reliable raw materials for producing sound-insolating panels at a scrimped cost. Moreover, these fibers mostly have significant thermal insulation characters, do not threaten health, and are available as a waste material of other output cycles (Umberto Berardi, 2015).

Shock Absorption and Packaging (Cushioning materials)

Packaging materials for logistical goals are used to protect any type of product from damages due to shock and/or extreme vibrations during handling and transportation. Some packing materials are used just as empty space-filler to avoid content moving inside the package (David, 2015). In the current market, expanded polystyrene (EPS) and polyethylene materials are used to meet this purpose which is not expensive when produced in massive amounts. Still, such materials are non-biodegradable and bring environmental and health concerns. Research has shown that packing foams like EPS distribute ten times the volume of carbon dioxide and uses up a lot of energy during the production cycle to packaging (Di, 2005). From the same baseline, 1-inch thick rice hulls reduced impact acceleration by 25% compared with 39% and 42% of bubble wrap and anti-vibration pad with the same thickness, respectively. When wet, rice hulls became denser. Thus, the impact increased at the rate of 0.054% per 1% increase of water per hull weight. Sealed bags containing rice hulls reduced impact acceleration by 41%, comparable with the bubble wrap case due to trapped air inside the sealed plastic bag. Using bubble wraps would be more economical and practical. However, bubble wraps could burst, and cushioning property would be lost (Figure 6-10). A sealed plastic bag with rice hulls inside could burst, but the rice hulls would provide another line of protection. Also, the rice hull is an excellent thermal insulating material. It would help protect some temperature-sensitive products during the distribution by placing bagged rice hulls on all sides of a tote or box.

Figure 6-10 8cm Bubble Wrap (left), 0.33cm thick Anti-Vibration Pad (center); and Rice Hulls (right) (Malasri, 2014)

Agricultural waste products, such as cotton and rice hulls are sustainable and compostable. Rice hulls have been used as cushioning materials in mushroom packaging. Some other natural products, such as coconut fiber and wood straw, have been used to prevent damages to papayas and mangoes during the distribution (Castro, 2014). Banana leaves and Teak leaves were used as wrapping materials for guava, while Neem leaves, rice straw, and bamboo leaves were used as cushioning materials for guava fruits during storage (Chandra, 2012). Fibers obtained from natural and agro-based products are often used as fillers or support in a non-biodegradable polymer matrix (Ng, 2011). They are sustainable eco-bio-composite materials that are used for shock cushioning applications such as packing and packaging materials. In this case, they need to be lightweight materials. Other groups of natural fibers include crop wastes such as coir, sunflower stalk, and rice husk, which are inedible and lower in density and price, are safer to handle, and can be processed using available polymer manufacturing technologies.

Cellulose is the main structural component of Natural Fibers (NF), one of the hard and toughest constituents in NF, and provides strength and structural stability properties. It should be noted that NFs generally contain high failure strain and partly poor strength due to their lower densities. The superiority of NFs includes accessibility, cheap, friendly environment, low density, resilience, low abrasive, manufacturability, and energy-efficient production. These benefits cause NFs to be used as reinforcement or filling applications in composites. Numbers of NF fibers include flax, hemp, coir, bamboo, kenaf, and oil palm empty fruit bunch (EFB) fibers (Ishak, 2010). It is mentioned in a study (Du, 2008) that the tensile feature of NFs generally increases with the growth of cellulose content of the fibers. In kenaf, for example, the cellulose content of the core (center pith-to-bast) fiber and the bast (epidermis skin-to-outer core) fiber is about 50.6 % and 60.8%, respectively (Ismawati, 2006) (Wan Daud, 2011). The following diagram shows the comparison of the mechanical properties of the numbers of natural and conventional synthetic fibers (Figure 6-11).

Type	Fiber	Density (g/cm^3)	Tensile Strength (MPa)	Elastic Modulus (GPa)	Elongation at Break (%)
GRASS	Bagasse	1.2-1.25	20-290	17-27.1	1.1
	Bamboo	0.6-11	140-230	11-17	-
WOOD	Hard Wood	0.3-0.88	51-210.7	5.2-15.6	-
	Soft Wood	0.3-1.5	45.5-1000	3.6-40.0	4.4
FRUIT	Coir	1.15-1.45	106-593	1.27-6.0	15.0-59.9
	Oil palm	0.7-1.55	100-400	1.0-9.0	8-25
BAST (STEM)	Jute	1.3-1.46	393-800	10-30	1.5-10.0
	Flax	1.4-1.5	345-1500	27.6-80	1.2-3.2
	Hemp	1.47-1.48	550-900	70	1.6-4.0
	Kenaf	1.2-1.45	295-930	53	1.6-6.9
	Kudzu	-	130-418	-	-
	Nettle		650	38	1.7
	Ramie	1.45-1.5	220-938	24.5-128	1.2-3.8
LEAF	Abaca	1.5	400-980	3-12	3-10
	Banana	1.35-	355-500	12-33.8	5.9-53
	Henequen	1.2-1.4	430-580	10.1-16.3	3.0-4.7
	Pineapple	0.8-1.6	170-1672	82	1.0-3.0
	Sisal	1.33-1.5	400-700	9.0-38.0	2.0-14
SEED	Cotton	1.5-1.6	287-597	5.5-12.6	3.0-10.0
	Kapok	0.38	93.3	-	-
SYNTHETIC	Carbon	1.4	4000	23-240	1.4-1.8
	E-glass	2.5	2000-3500	70.0	0.5-3.0
	S-glass	2.5	4570	86.0	2.8
	Aramide	1.4	3000-3150	63-70	2.5-3.7

Figure 6-11 Mechanical properties of some natural fiber types (Şafak Yıldızhan, 2018)

In addition to natural fibers, cellular tissues and materials such as luffa sponge are commonly used as packaging and cladding materials to protect products and personnel during collision and impact events (Lorna J. Gibson, 2010). The mechanical characterization of those cellular materials at varying strain rates is essential for their efficient use in dynamic loading applications. In recent research (Shen J, 2012) the luffa sponge has the potential to be used as an alternative sustainable material for various practical applications such as acoustic isolation, packaging, vibration, and impact energy absorption. The luffa sponge material can be derived from the fruit of the LC plant and has the recycling capability and triggered biodegradability (Oboh IO, 2009).
Due to the high strength-to-weight ratio of cellular materials and favorable enhanced energy absorption capacity at a high strain rate, the luffa sponge can be used as a good packaging material and an excellent energy dissipation material. This particular feature provides an opportunity to widen the applications of natural cellular materials, especially when lightweight is a crucial design requirement (Jianhu Shen, 2013). It is notable to mention that at the same time, when the density of the cellular materials decreases to a certain range, other interesting functional properties will emerge, such as good damping and reversible properties.
It is also worth noting that human beings have discovered and developed many materials, notably various metals. When lightweight material is considered, different metallic/ ceramic/polymeric foams, honeycombs, and micro lattice structures are considered designed and fabricated using those materials as base materials. However, most man-made materials are not environmentally friendly and have not been designed with genuine concerns over their long-term sustainability (Zhang Z, 2011). The results confirm that cellular material such as luffa sponge as a sustainable material is an alternative material for man-made designs.

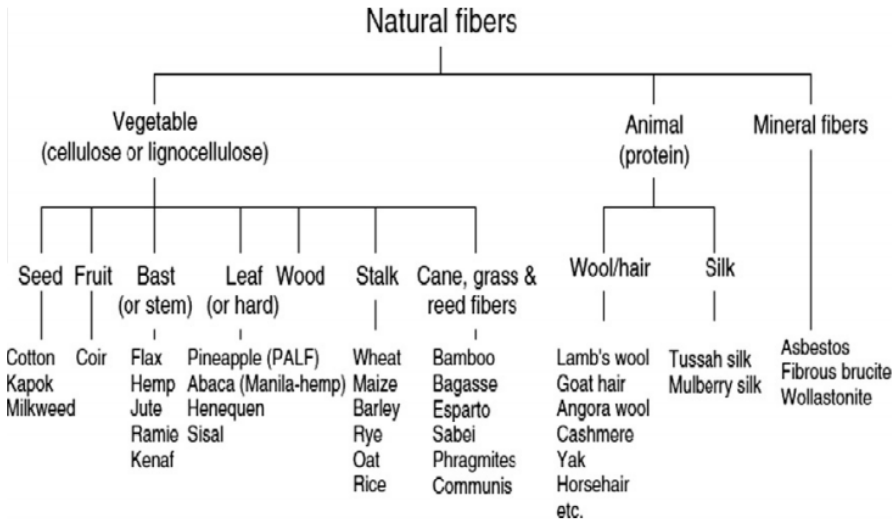


Figure 6-12 Classification of natural fibers (H.M. Akil M. O., 2011)

Another study aimed at testing shock absorption on different natural material and various grain size of the crumb rubber. It shows that among the five materials examined in this study (Waleed Alnashwan, 2014) (bubble wrap, anti-vibration pad, rice hull, crumb rubber, and coconut fiber), the coconut fiber provided the best performance in shock reduction. Besides, coconut fiber is light and clean (compared to crumb rubber). The results show the grain size and crumb rubber decreases the impact acceleration from about 15% to almost 40%. The study noted that the crumb rubber with a smaller particle size reduced shock better than crumb rubber with bigger particle size. In the same study, the test executed on the same thickness and acceleration of coconut fiber showed more impact absorption than crumb rubber. It should be noted that coconut fiber is more advantageous in impact absorption when it contains less water. The dried coconut fiber decreased the impact acceleration by approximately 50% from the base value. Coconut fiber is a great agricultural waste product in many tropical countries. It has been used to produce more environmentally friendly products, such as rope, brushes, tapestry, automotive parts, gardening products, reinforcing composite, acoustic, thermal insulation, and fruit injury prevention (Clívia Danúbia Pinho da Costa Castro, 2014). In a study, the rice hull was studied as a cushioning material placed in sealed plastic bags. A 1-inch thick layer of dried rice hulls absorbs a significant number of shock acceleration by 41% compared with a 3/16” bubble wrap, or another pad of the same thickness and impact reduction has a reverse Ratio Bulk Density crumb rubber and rice hulls. In addition, rice hulls are a natural waste product, which is more environmentally friendly and is an excellent thermal insulating material (Siripong Malasri, 2014). If we want a kind of composite flooring from agricultural waste that has the ability to reduce impact, its elasticity and flexibility must be considered (Figure 6-12).

Flexible Composite

The types of flexible composites examined are cord/rubber composites, coated fabrics, and composites containing wavy fibers. The advancement in the predictability of analytical models enhances the utilization of flexible composites as load-bearing structural composites. The versatility of flexible composites in engineering applications lies in the fact that their load-deformation behavior can be tailored by a suitable selection of fiber/matrix systems and the design of fiber geometric configuration (Tsu-Wei Chou, 1989). The term 'flexible composites' is used to describe composites based on polymers with elastomer properties. Deformation in flexible composites is greater than that the conventional composites based on thermosetting or thermoplastic polymers. Flexible composites are capable of enduring fatigue loading (tension-compression) as well as provide high load. The performance of increased extensibility could be gained without losing stiffness and strength properties through the specific geometric shape of fibers or ductile matrixes. Unique properties of the flexible composites are: (1) low Young's modulus in the range of low applied stress and high modulus in the range of high applied stress; (2) increased elongation; and (3) high load associated with deformation (T.-W. Chou & Takahashi, 1987).

Generally, deformation in flexible composites emanates from two factors of matrix and fiber. In order to maintain the performance of the above two factors, the fibers must be able to deform proportionally with the elastomeric matrix:

• Using short–length fibers;

• The orientation of the continuous fibers should be following the direction and magnitude of the load;

• Using reinforcements in the forms of weave, knit, or braid.

The 'flexible' behavior has not been successful enough in advanced composites because of the low extensibility of fibers and the low elongation of the matrix resin. In a study (James H. a., 1943) (Treloar, 1973) a Linear elastic stress/strain relations of glass and Kevlar fibers, and Rubber elasticity were assumed for polybutylene terephthalate (PBT) matrix and the other elastomeric polymers in their numerical calculations. The aims of developing a flexible composite that presents low stiffness under low stress, and high stiffness and strength under high stress.

Composite and Bio-Composite Material

Each year, millions of scrap tires are generated globally, which has a negative effect on environmental and public health. About 3.3 million tons of expired or used tires were created just in Europe in 2010. Stored Scrap tire causes many different viruses, fungus, and diseases. The typical application of scrap tires includes athletic and playground surfaces, molded or extruded rubber grains, rubber-based asphalt, etc. (Tires, 2010). The managing of rubber tires is one of the significant issues of waste treatment. Recycled materials, specifically crumb rubber, can be utilized as an option since they decrease waste production. Several such materials include textile fibers, scrap rubber, plastics, and solid wastes. On the other hand, because of the availability and other properties mentioned about natural and agro-based material, both groups of recycled rubber and agro-based have the potential to be used in composite materials as shock absorption flooring tile. Figure 6-13 shows the industrial application of several fiber types.

Fibers	Application
Hemp fibers	Construction products, textiles, cordage, geotextiles, paper and packaging, furniture, electrical, manufacture of bank notes, and manufacture of pipes
Oil palm fibers	Building materials such as windows, door frames, structural insulated panel building systems, siding, fencing, roofing, decking, and other building materials
Wood fibers	Window frames, panels, door shutters, decking, railing systems, and fencing
Flax fibers	Window frames, panels, decking, railing systems, fencing, tennis rackets, bicycle frames, forks, seat posts, snowboards, and laptop cases
Rice husk fibers	Building materials such as building panels, bricks, window frames, panels, decking, railing systems, and fencing
Bagasse fibers	Window frames, panels, decking, railing systems, and fencing
Sisal fibers	In construction industry, such as panels, doors, shutting plate, and roofing sheets; also, manufacturing of paper and pulp
Stalk fibers	Building panels, furniture panels, bricks, and constructing drains and pipelines
Kenaf fibers	Packing materials, mobile cases, bags, insulation, clothing-grade cloth, soil-less potting mixes, animal bedding, and materials that absorb oil and liquids
Cotton fibers	Furniture industry, textile and yarn, goods, and cordage
Coir fibers	Building panels, flush door shutters, roofing sheets, storage tanks, packing materials, helmets, postboxes, mirror casings, paper weights, projector covers, voltage stabilizer covers, as a filling material for seat upholstery, brushes and brooms, ropes and yarn for nets, bags, and mats, as well as padding for mattresses and seat cushions
Ramie fibers	Use in products as industrial sewing thread, packing materials, fishing nets, and filter cloths. It is also made into fabrics for household furnishings (upholstery, canvas) and clothing, paper manufacture
Jute fibers	Building panels, roofing sheets, door frames, door shutters, transport, packaging, geotextiles, and chipboard

Figure 6-13 application of natural fibers in industry and construction (L.Mohammad, 2015)

Consumption of composite materials (CM) in the construction industry is growing. The most important uses of CM include roofing, walls, and flooring for sound insulation, heat insulation, and shock absorption. At present, most of the components of CM are synthetic or petroleum-based materials. The composite material is a compound of two different materials with separate features and generally is a combination of the reinforcement (known as fiber) of a matrix structure[126]. Composite materials provide a lighter and safer compared to its similar traditional samples. Mechanical properties of different matrixes and fibers were summarized in (Figure 6-13). The main advantage of composite materials is the ability to modification of the properties according to design necessities. Due to the study executed on mechanical and chemical properties and application of bio-composites, specifically plant fibers[127] , it is noted that in recent years the popularity of Bio-composite materials (known as green composites) has notably developed due to the potential of being a replacement for conventional materials used in industries. Bio-composites' benefits availability, being renewable, and sustainable (Şafak Yıldızhan1, 2018).

[126] While the fibers endure and support the structural loads of the composite parts matrix material holds and retains the structure in solid phase that craetes the shape and the exterior form of the product.
[127] plant fibers (Lignocellulosic fibers) are formed from three chemical particles (cellulose, hemicelluloses and lignin).

Fiber	Fiber Treatment	Matrix	Fibre/Matrix-Ratio (%-wt – Fiber/Matrix)	Tensile Strength (MPa)	Elastic Modulus (GPa)	Elongation at Break (%)	Production Method
Bagasse	Untreated	Cardanol-formaldehyde	15	24.4	1.8	-	Compression Moulding
Bagasse powder	Untreated	Polypropylene	3	35	2.0	-	Injection Molding
	ChOAc		3	40	2.6		
Bagasse	Untreated	Polyethylene	5	36±5.1	330±8.4	8.7±5.1	Melt Compounding
	Mechanical			129±1.1	440±6.1	10.6±5.1	
Bamboo	Untreated	Polypropylene	80/20	37	4.34	-	Compression Molding
	Alkali			40-51	4.38-5.57		
Corn	Untreated	Polylactic Acid	-	46	-	-	Injection Molding
	Alkali			58-64			
	Alkali+Silane			62-72			
Kapok	Untreated	Cassava Starch	5	3	25	30	Compression Molding
			10	4	40	20	
			15	4.5	40	19	
Jute	NaOH	Polyethylene	30	10.9±0.1	0.25±0.02	12.8±0.9	Injection Moulding
	Stearic Acid			12.8±0.3	0.26±0.01	11.8±0.8	
Flax	-	Polypropylene	30	29±1.5	5±0.4	2.7±1.5	Compression Moulding
			40	29±0.8	7.6±0.9	1.5±0.8	
		Polylactic Acid	30	53±0.2	8.3±0.6	1.0±0.2	
			40	44±0.2	7.3±0.5	0.9±0.2	
Kenaf	-	Polylactic Acid	10	61.1±1.3	3.8±0.1	-	Injection Molding
			20	74.5±0.9	5.3±0.2		
Sisal	-	Thermoplastic Starch and Polycaprolactone.	5	3.8	0.205	5.3	Twin Screw Extrusion
			10	3.6	0.255	2.9	
Cotton	Untreated	Epoxy	-	35	-	-	Hand Lay-Up
	Alkali			45			

Figure 6-14 Mechanical properties of some natural fiber-reinforced composite material (Şafak Yıldızhan, 2018)

Fibers are often categorized into two main groups of natural or synthetic. Natural fibers involve

- plant fiber (kenaf hemp, wood);
- animal (wool, fur felt); or
- mineral (asbestos);

While artificial fibers involve minerals (carbon, fiberglass, mineral wool, glass wool) or polymer (polyester) (D. Chandramohan, 2011) (H.M. Akil M. O., 2011). Plant-based fibers include cellulose and leaf, seed, bast, fruit, wood, grass, and stalk. Animal fibers are composed of proteins (hair, silk, wool, etc.) (Figure 6-16, Figure 6-15, and Figure 6-17)

This research aims to compare recycled (crumb rubber) and natural materials (agro-based) as an alternative to the shock absorption floors. For this purpose, with regard to some properties such as density, tensile strength, and young's modulus, we have used many of these materials to simulate materials and apply impact in Abacus software. This simulation will compare the recycled rubber and agro-based composite tiles, in which the tiles would cover the three performances of heat, sound insulation, and shock absorption. In summary, a comparative study of the mechanical properties of numbers of fiber-reinforced composites is collected together and shown in (Figure 6-10, Figure 6-11, and Figure 6-12).

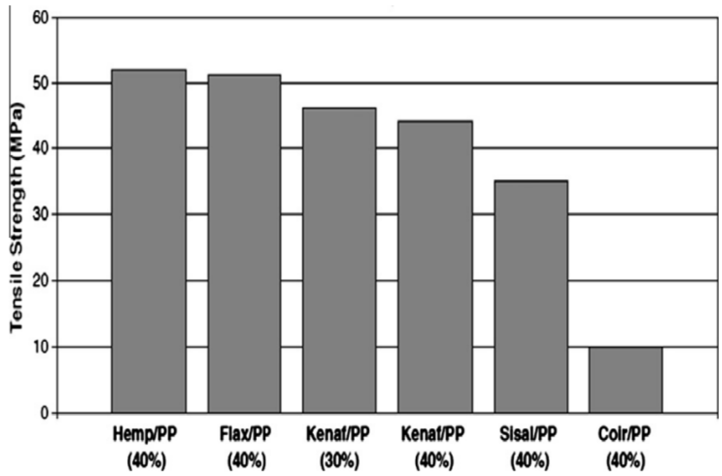


Figure 6-15 Comparison of tensile strength of a number of the natural fiber composites (H.M. Akil M. O., 2011).

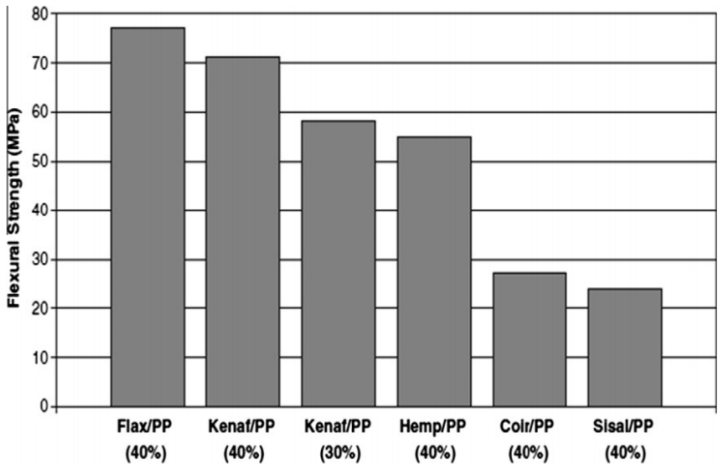


Figure 6-16 Comparison of flexural strength of a number of the natural fiber composites (H.M. Akil M. O., 2011).

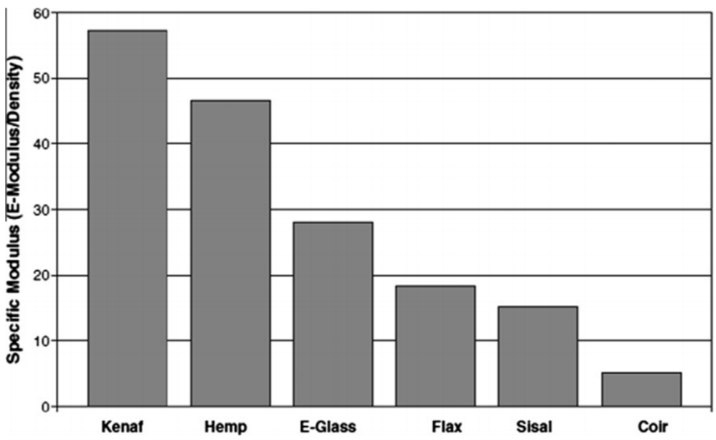


Figure 6-17 Comparison of specific modulus of different fiber (H.M. Akil M. O., 2011).

Some other natural materials, crumb cork, sawdust, and stalks or straw of rice and wheat, are items obtained from the waste of related factories and can be mentioned as a potential for the desired CF system.

MATRIX (BINDER) AND FILLER (FIBER) IN COMPOSITE MATERIALS

In the last decade, natural fiber composites have reached a constantly progressing place in the automotive sector. Some companies such as *ECOSHELL* propose using renewable and environmentally safe materials and bio-based resins to achieve a new high-performance bio-composite. Achieving a composite made of agro-fibers (natural fiber) (Figure 6-18) will provide novel solutions regarding lightweight, low cost, low energy consumption, and environmental impact using ISO 9001 standards in structural transportation applications such as a vehicle body structure, aircraft, heavy vehicles, ships, trains, etc. The aims are to minimize vehicle mass means reducing the weight of the traditional vehicles by 20% to reducing petrol consumption and consequently reducing the price by 15% and CO2 emissions by 22% (Mueller, 2004).

Composites include mixing more than two chemically and physically dissimilar components together (Krishnan KA, 2015). The two main components are a 1-continuous component known as the matrix (binder) and 2- a separate or discontinuous component called the fillers (fiber) that create a new material. In some cases, there is a need for some other additive materials regarding the composite's performance (Shekar HS, 2018).

There are different types of composites. These include:

1. ceramics matrix composites (CMC- lightweight, high stiffness, high strength, and ease of manufacture) The ceramic matrix needs enough understanding of all the factors that manage the connection between all components inside the composite (La Mantia F, 2011)
2. polymer matrix composites (PMC-eco- friendly natural fibers from vegetable sources) and
3. metal matrix composites (MMC) (Tao Y, 2009). (Figure 6-19)

An investigation has studied the possibility of using waste tires and rice straws as composite materials. The manufacturing parameters used in this research were: specific gravity of 0.8 (Yang, 2003) and by mixing different content proportions of rice straw and waste tire particle. Rice straw was cut in two different length sizes. Waste tire particles consisted of two different diameters less than 5 mm, and a commercial polyurethane adhesive for rubber was used as the composite binder with 97 wt.% of solid content. The straw–waste tire particle composite boards, with random cut rice straws, without size screening, and waste tires were shown suitable sound-absorbing insulation as flexural materials in construction in the middle and high-frequency range than those of commercial wood-based materials, such as fiberboard, rice straw–wood particle board, or plywood.

Moreover, the results showed higher sound absorption coefficients than the wooden floor, ceramic tiles, and concrete over the entire frequency range. The bending MOE128 diagram showed the same pattern as the bending MOR129 results. Composites with longer and broader rice straw particles resulted in better bending MOR values (Han-Seung Yang, 2004).

[128] Modulus Of Elasticity-MOE- is the slope of the tangent line at the stress point of proportional limit.
[129] Modulus Of Rupture

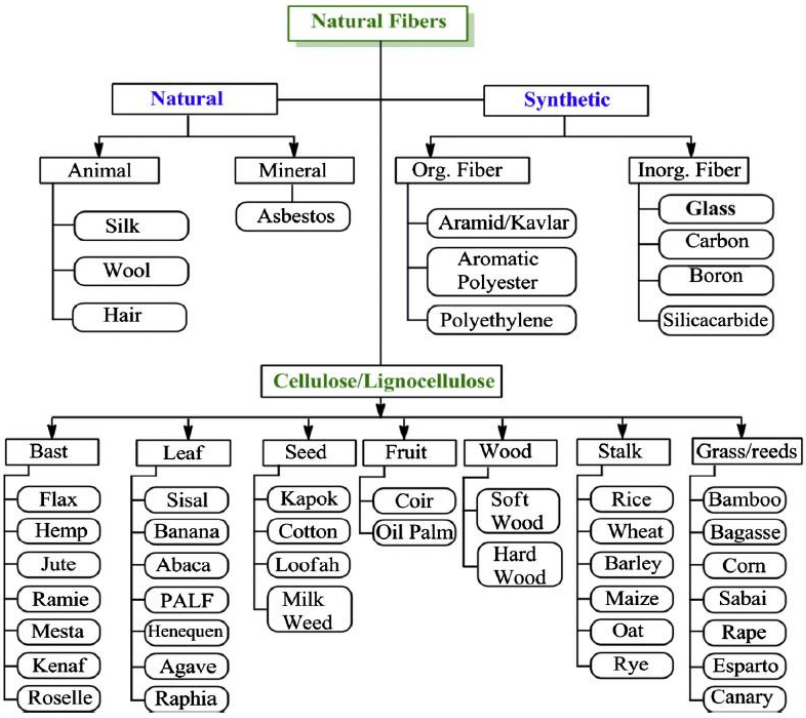


Figure 6-18 Classification of natural and synthetic fibers. (Saba, 2014) (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

The composite board mixed of rice straw and waste tire particles (Ductile) in a randomized size had a lower MOE value than the wood particleboard (Brittle). It showed a better flexural property, which can be used for specific applications, such as manufacturing flexural materials for curved walls, etc. These boards, including random-cut rice straws, had a similar strength to the other boards; consequently, there is no charge for screening straw and agricultural fibers sizes. Because of rubber's hardness and elasticity properties, good resistance to weathering and low specific gravity can be used for preventing impact damage and construction materials. Moreover, they are able to be used in any climate, both hot and cold. Finally, tires are easily modifiable, anti-caustic, and anti-rot properties, and inexpensive. It is possible to be used as electrical insulation and use in areas that need low heat conductivity (Han-Seung Yang, 2004). Most of the natural fibers have several disadvantages, such as high water absorption by the fiber, which can be solved with the proper matrix. The level of interfacial adhesion between the reinforcement (fiber) and the matrix determines the overall properties of the composite.

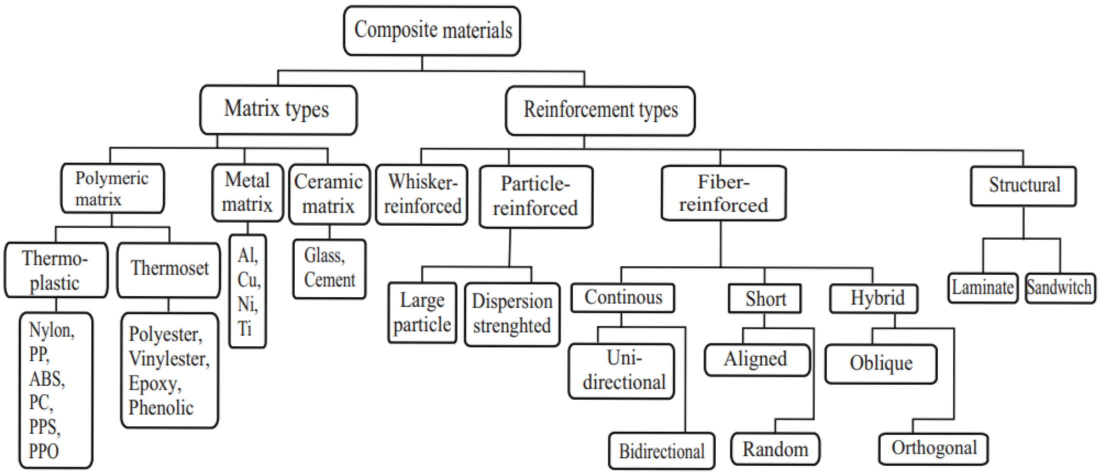


Figure 6-19 Classification of composite materials based on reinforcement and matrix types (P. Priyanka, 2017).

Different composite materials are used regarding the reinforcement type, and the matrix is used in the composite (Idowu D Ibrahim, 2015) (Figure 6-19). Besides, the properties would be different depends on the layout and how the fibers fit together (Figure 6-20). The performance of the matrix is modified depending upon the volume fraction, as well as its geometry and orientation relative to applied stress. In some cases, it should comment on the fact that using long fibers may be incompatible with the matrix and cause a weak connection or conducive to diffusive phenomena at the fiber/matrix interface. This can affect the performance of the fiber, matrix, and consequently especially composite over time (Murr, 2015).

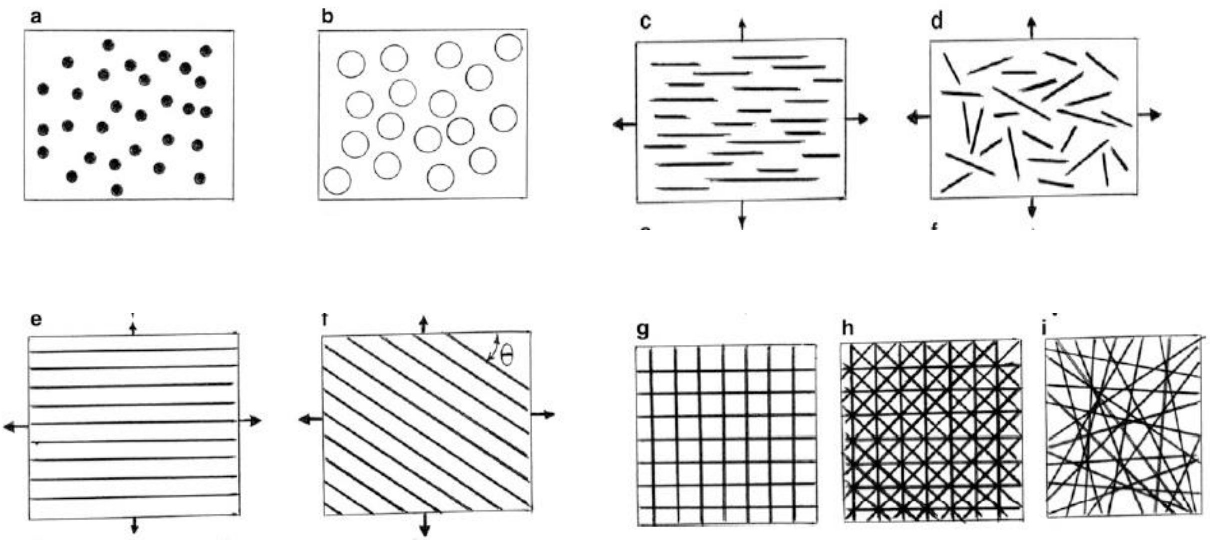


Figure 6-20 composite material classification examples. (a) and (b) show homogeneous particle distribution in a matrix. (c) and (d) show aligned (anisotropic) and random (quasi-isotropic) discontinuous fibers. (e) and (f) show aligned (unidirectional) continuous fibers: θ=0, θ=90; 0 < θ < 90. (g) bidirectional or cross-ply continuous fibers. (h) multidirectional fibers. (i) continuous, random (Lucas Barcelos Otani, 2014)

Filler (Fiber):

The filler is the reinforcing and load-bearing component of the composites, while the matrix binds the fillers together. The length of the fibers must be both long enough and aligned with the direction of the applied force. In addition, the interfacial adhesion (such as barrier properties, mechanical and thermal properties) must be strong enough (da Luz FS, 2018). The strength and stiffness of any polymer composite are a direct result of the fiber properties and arrangement (Sen T, 2011) (Figure 6-18) The effects of moisture and temperature of composites on several performance parameters, such as tensile and shear strengths, elastic moduli, fatigue behavior, creep, rupture stress, response to dynamic impact, and electrical resistance must be considered (Agarval, 2006) in order to evaluate the performance of the composites in real area, which is not our matter in this research.

Matrix (Binder):

The polymer matrix serves as the cohesive material (binder). It helps to hold the fillers/fibers in position and also helps to transmit stress and load within the material (Besson F, 2012). Polymers are categorized based on their chemical behavior (i.e., thermoplastic or thermosetting) or the basis of their source (i.e., synthetic or natural). Thermoplastic is polymers that, once processed and are challenging to form but can be reprocessed several times as demanded. Polyethylene (PE), polypropylene (PP), poly (caprolactone) (PCL), poly (lactic acid) (PLA) are such materials. Thermosetting is a polymer that, once processed and its shape is stabilized and cannot be reprocessed again. Polyesters, epoxies are such examples (John MJ, 2008). It must be mentioned that different ratios of using binder and fiber in a composite lead to varying results in mechanical properties. The study shows that the higher the binder loading in kenaf-polypropylene (KF/PP) composites, the better are mechanical properties for both tensile and modulus strength. A study discussed using a binder (polypropylene) to formulate typical asphalt as a modifier to produce a surface that resists the action of temperature changes, air, water, and the movement of traffic. A paper reviewed the mechanical properties of Polypropylene (PP) matrixes with bamboo fibers to produce a bamboo fiber reinforced polypropylene (BFRP) composite (A.I. Al-Hadidy, 2009) (Ibrahim, 2015). In appendix F a brief overview of the three matrixes mentioned earlier has been explained.

Compatibilizers

Compatibilizers or additives are used to increase interfacial interactions amongst polymer-polymer in blends and polymer-fibers in composites (Yatigala NS, 2018). In a series of projects (Karmaker A, 1994), the tensile strength and bending strength increased dramatically when three wt% maleic anhydrides grafted polypropylene (MAHgPP) was added Jute/PP composites as coupling agents. The flexural and dynamic strength of Jute/PP composites was enhanced by approximately 50% in related work. In summary, adding other components and additives to NFPCs has directed to a diminution in some of the problems associated with their fiber-matrix interface. Compatibilization helps attenuate fiber agglomeration, water absorption, and improved disparity in the matrix (Karmaker A, 1994).

In summary, Fiber-matrix interfacial interactions are fundamental properties of all-polymer composites. The physical (interlocking between the matrix and the fibers) or chemical (formation of bonds from the weak Van der Waal force to a solid covalent bond) kind of fiber-matrix interfacial bonds defines the composite property. Furthermore, using various additives and hybrid fibers (natural/natural or natural/synthetic) of polymer blends is another way of improving the interaction in natural fiber polymer composites (NFPCs) and enhancing the polymer matrix's stiffness physical interlocking. Such additives can enhance thermal stability and mechanical properties.

6.3.3 INTEGRATION OF MULTIPLE SYSTEM

This section of suggestion needs to evaluate other similar systems. “*Sorbashock*” (see section 3.2.3) and “*Revolution* and *Boundceback*[130]” are good examples to be analyzed and can be considered as a comprehensive program in the future which is not included in this dissertation.

[130] https://www.snapsports.com/athletic-surface-outdoor-revolution.php

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LIST OF FIGURE

LIST OF TABLE

LIST OF ACRONYMS & ABBREVIATION

Acronyms	Definition	Acronyms	Definition
WHO	World Health Organization	EPA	Environmental Protection Agency
NCF	Novel Compliant Flooring	PVC	Polyvinyl Chloride
CF	Compliant Flooring	NIOSH	National Institute for Occupational Safety and Health
SHAF	Shock Absorbing Flooring	EN	European Standard
GRF	Ground Reaction Force	ASTM	American Society for Testing and Materials (international standards organization)
DWI	Drop Weight Impact	TPEs	Thermoplastic Elastomers
VPA	Visual Pressure Area	SEF	Strain Energy Function
CoR	Coeficient of Restitution	MOE	Modulus of Elasticity
CoF	Coeficient of Friction	EC	Arruda-Boyce model
HIC	Head Injury Criteria	NH	Neo-Hookean model
FEM	Finite Element Method	MR	Mooney-Rivlin Model
MSA	Matrix Structural Analysis	*PE*	Potential Energy
BIO	Biomechanical test	FPRE	Fall Prevention
CFH	Critical Fall Height	FDT	Fall Detection
G-Max	Maximum Gravity	FPRO	Fall Protection
FP	Force Platform	IADLs	Instrumental Activities of Daily Living
SLR	Slip-Resistance	PPT	Physical Performance Test
UN	United Nations	ToF	Time of Flight
TBI	Traumatic Brain Injuries	SVM	Support Vector Machine
LTC	Laong-Term Care	DSP	Digital Signal Processing
IMSERSO	Instituto de Mayores y Servicios Sociales	EPDM	Ethylene Propylene Diene Monomer
GDP	Gross Domestic Product	BAA	Berlin Artificial Athlete
MSSSI	Ministerio de Sanidad, Servicios Sociales e Igualdad de España	CoP	Center of Pressure
IED	Instituto Europeo de Diseño	CoF	Center of Force
DJT	Drop Jumping Test	HAI	Healthcare-Associated Infections
CG	Center of Gravity	IPS	Insole Pressure Sensor
QALY	Quality-Adjusted Life Years	PSRV	Polished Slip/Skid Resistance *Value*

ABS	Acrylonitrile Butadiene Styrene	SF	Smart Flooring
PC	Polycarbonate	MBS	Model-Based Simulation
GRF	Glass Reinforced Fiber	THUM	Total Human Model for Safety
EPS	Expanded Polystyrene	CAE	Complete Abaqus Environment
CAE	Center for Accessible Environments	CCP	Center Català del Plàstic
IEQ	Indoor environmental quality	CIM UPC	Center for Innovation and Technology in Digital Manufacturing –Polytechniq University of Catalonia
VOC	Volatile Organic Compounds	ENAC	Entidad Nacional de Acreditación- National Accreditation Entity
SVOC	Semi-Volatile Organic Compounds	FRF	Floor Reaction Force
VCT	Vinyl Composition Tile	FR	Force Reduction
MTS	Material Testing System	FA	Force Applied
SD	Standard Deviation	CTE[131]	Codigo Tecnico de la Edificación de España
USB	Universal Serial Bus	SLR-T	Slip Resistance Pendulum Test
PMF	Pressure Measurement Films	Rd	Slip Resistance
CTIOA	Ceramic Tile Institute of America	DCOF	Dynamic Coefficients Of Friction
HRV	Heart Rate Variability	ECG	Electrocardiogram
SPO2	Pulse Oximetry		

[131] https://www.codigotecnico.org/DocumentosCTE/DocumentosCTE.html

Abbreviations	Definition	Abbreviations	Definition
σ	Stress	Po, μ or ν	Poisson's ratio
$\mathcal{E}$	Strain	Iij	Strain invariants of the Cauchy-Green tensor
L	length	λ	Lame's constant
F	Force	W	Strain tensor invariants or principal stretches
E	Young´s modulus (Modulus of Elasticity)	μ	Shear modulus
E_d	Dynamic Young´s moduli	Cij	Material constants
E_{st}	Static Young´s moduli	N	Number of terms
m	Mass	J	Jacobin for volume changes and total volume ratio
ft	Fundamental frequency of the bar in flexure	Dk	Constants parameter
d	Defluxion corresponding to load F	μi and, αi	Material parameters
v	Poisson ratio	ET	Extended Tube Model
H	Hardness	g	Gravity constant
Ψ	Strain Energy Density	KE	Kinetic Energy
K	Constant factor characteristic of the spring in Hooke's law	d	Distance traveled
k	Bulk modulus	C_R , (e)	Coefficient of Restitution

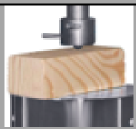
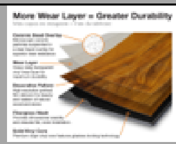
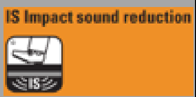
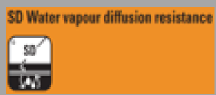
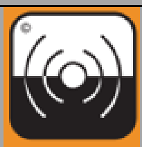
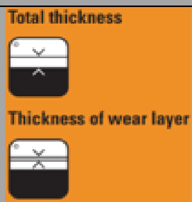
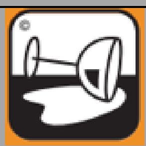
APPENDIX

APPENDIX A – NORMS AND TECHNICAL (PHYSICAL & MECHANICAL) INFORMATION

Appendix A present number of norms important in CF system floorings:

Related Norms	Definition
EN (European standards)	
EN 397:2012+A1:2012	safety include helmets, Motorcyclists'
UNE-EN 1621-1:2013	protective clothing against mechanical impact
UNE-EN 12503-4:2017	sport mat-Determination of shock absorption
UNE-EN 12503-7:2017	sport mat-of static deformation
UNE-EN 1177:2018+AC:2019-HIC	Impact attenuating playground surfacing - Methods of test for determination of impact attenuation- Shock-absorbing surface coatings for play areas
UNE-EN 14808:2006	Surfaces for sports areas - Determination of shock absorption
UNE-EN 14809:2006/AC:2008	Surfaces for sports areas - Determination of vertical deformation
EN 20105 - B02	Colorfastness
UNE-EN 12633: 2003	Method to determine the rate of slip resistance of polished and unpolished floors' surfaces.
EN 434	Dimensional stability
EN 423	Chemical resistance
EN 13501-1	Behavior to fire
EN 14904	Mechanical, safety, and biomechanical sport surface performance -Sports Parquet Floors Shock absorption and Vertical Deformation- surface finish effect (also called "friction"), and ball rebound
EN 12503	the determination as to the characteristics of absorption of impacts and deformation in gymnastic mats
EN 12665	a subjective condition of visual well-being induced by the visual environment
PN–EN 14808	Shock absorption
(American Society for Testing and Materials)	
ASTM F1976 - 13	Impact Attenuation of Athletic Shoe Cushioning Systems and Materials
ASTM F355-01-A	Test Method for Shock Absorption Properties
ASTM D2240-05	Hardness Test Method
ASTM F1292 and ASTM 1936	Test Method for Impact Attenuation of Playgrounds-HIC
ASTM F2772	Shock absorption, surface finish effect (also called "friction"), ball rebound, and vertical deformation
ASTM F2157	include force reduction, surface finish effect (also called "friction"), ball rebound, and vertical deformation
ASTM E-648	fire behavior
ASTM D412	Test Methods for Vulcanized Rubber and Thermoplastic Elastomers— Tension. Active Standard
(Australian Standards)	
AS / NZS 2111.2	Determination of the loss of thickness under the dynamic load of textile floor coverings.
(Methicillin-Resistant Staphylococcus aureus)	
MRSA A129 (Staphylococcus Aureus)	A wide range of microorganisms, including bacteria, molds, yeasts, and algae.
(German Institute for Standardization e. V.)	
DIN 18032	include force reduction, surface finish effect (also called "friction"), ball rebound, and vertical deformation
DIN 18032-2	shock absorption. Sports halls. Rooms for gymnastics, games, and multiple uses. Part 2: Flooring for sports activities. Requirements, tests (Pre-standard).
(International Organization for Standardization)	
ISO 9073-3-1989	Determination of the breaking and extension force
ISO 10545-5: 1998	the standard establishes a method for determining the impact resistance of ceramic tiles by measuring the coefficient of restitution
ISO 37	A test method for the determination of the tensile stress-strain properties of vulcanized and thermoplastic rubbers.

Technical information on flooring that should be standardized:

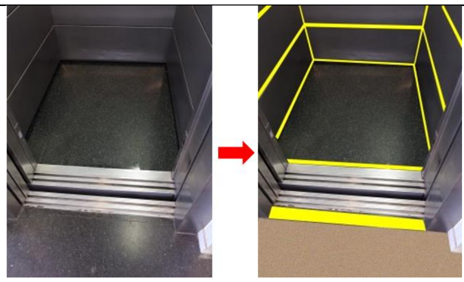
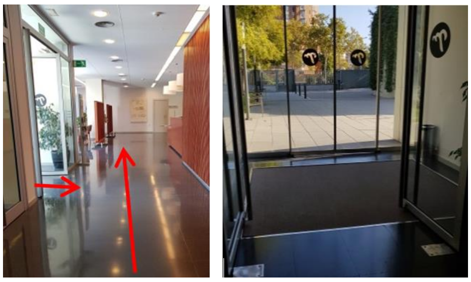
Standard feature	Symbol	Standard feature	Symbol	Standard feature	Symbol
Shock absorption /Force reduction /Impact resistance		Suitable for wheeled Access		Effect of Castor Chair	
Residual Indentation depth		Effect of a Furniture Leg		Light Reflectance Values (LRVs): Glare luminance	
Hardness		Bottom-out (Thickness loss under dynamic loading (The load applied is in a cyclic petM BGV tern to assimilate a walking action))		Wear layer (vinyl)	
Acoustical - Impact noise reduction	 	Water resistance (Suitability for use in incidental humid conditions)	 	Colorfastness to Light - UV test	
Acoustical - Walking noise (footfall sound)	 	Anti-fatigue		Cleaning/ Maintenance - detergent	
Slip Resistance		Thickness			
Abrasion/Scratch and Wear Resistance	 	Mark and stain resistance (Anti-Stain)			

APPENDIX B - SUGGESTION FOR SOLVING VISUAL PROBLEMS AND BETTER DIAGNOSIS

Appendix B provides suggestions to solve other problems of the center of Collserola that may cause disorders in diagnosing the elderly and causing problems for them.

Problem	Photo of Problem-Collserola center	Proposed solution
Entrance of the lift, metal thresholds or expansion **joints** in some spaces may cause older falls. In addition, because older adults usually walk with short steps and pull their feet on the ground while walking, this bulge can disturb their balance.		Uneven surfaces should be avoided in the places where seniors travel there.
The color of the **walls**, **doors**, **handles,** and **handrails** are very close, and it is difficult to distinguish them from each other.		The color of the seat cover of the toilet, bath chairs, handrails, handles, and other disability aid instruments should be in contrast to the walls and flooring.
Natural or artificial **light reflection (glare)** hurts eyesight: Glossy and polished surfaces should be avoided.		Using Anti-Reflective Coatings and Anti-Glare Coatings or PVC sheets can be beneficial. It should be noted that the coating Has good resistance to UV rays and detergents. Matte pavements reduce the reflection.
Reflection of objects on flooring can disturb visual recognition.		The texture of the flooring should be in a way that prevents the reflection of light and objects. Polished flooring is not suitable for such areas. Matte pavements reduce the reflection.
1-The **similarity** of the **color of the floor and the wall**, or even at some angles of vision and light, may make the mistake of vision and disrupt the clearance. 2-Or in another case, despite the difference in the color of the **flooring and the wall**, the **color** of these two surfaces can become similar in dealing with		1- To solve this problem, the color of these two faces or the frame of the walls or windows can be changed into different colors. 2-Using of a different color at the junction and the boundary of the two surfaces can be a suitable solution for such cases

light reflection or viewing angles which will disrupt the diagnosis and vision.		or using Anti-reflection light overlay can be beneficial.
Stains for any reason (Food, Medicine, Detergents, Hand disinfectant, Water deposits on the floor ...) affect the appearance of the flooring. Or, even over time, it may cause decay.		Using anti-stain coating
Protruding walls, columns, edges, and **corners** of the walls should be marked with a contrasting color. Using the same color for all of them makes it difficult for the elderly to diagnose.		A different boundary (opposite color) must be defined in the connection border of the wall to the floor.
90% of areas have the **same flooring** type regardless of different zone functions and users. The same flooring type is used inside of the apartments, rooms, kitchen, and corridors	 Corridor and restroom	The color or pattern of the flooring in access paths (corridor) should be different from the lobby bath, dining room, or rooms.
The color of the **ceiling tiles** and tiles in the bathroom are different. Therefore, to prevent visual distortion, they must be ordered.		Tile sealing grout can be the same tile color or different color, but they should all be uniform and continuously stained.
No **pre-space** (In terms of the type of flooring) has been defined for changing the type of space function (specifically in areas with a high risk of fall). Pre-space for staircase, Lift, Ramp, from the entrance to reception ...	 Ramp	The change must be announced when the floor approaches the level difference, stairs, ramps, and elevators with the help of a changing of flooring type, color, and pattern or material texture.

	 Lift  Stair	
One area with the **same function** has a different risk of fall, which should be controlled more than other parts. For instance the area from the main entrance to the lobby or reception, from the pool to the locker room.	 Entrance to lobby	-The main lobby receives different users and different functions. -It must be considered that the flooring of the entrance must be secured from the danger of collapse and use anti-slip flooring type at least about 15 steps. Especially on rainy days using carpet at the entrance is not enough. The smooth coating of the terrazzo or marble which combined with residual moisture, can cause serious injuries. -Entrance to the reception counter -Start of the stairs -In front of the lift -Waiting area with sofa -**Epoxy Resin:** allows traffic of rolling objects -PVC checker rolls/plate
Changing in position, for example, from sitting to the standing state or vice versa. (start walking, Stand up from the chair (toilets) and willing to walk, willing to sit, willing to get out of bed…) is a condition that causes older people to fall.		Such movements more happen in D.C, residential dining rooms, rental apartments, lift, baths…

Physical problems (Foot and shape of the walking), environment condition, **shoes,** and flooring are the main factors involve in falls.		In this case, the types of flooring must be analyzed and their shoes (elderly and staff) and walking styles must be considered (Requires expert or physiotherapist counseling).
It must be avoided **sharp edges** (wall, furniture…) and made them curved and gentle.		
Lack of adequate **light** for the elderly in their navigation can be confusing.		1-Using luminescent, phosphorescent bands to find a path and distinguishing the walls or doors. 2-Using smart bedside-mat in order to show the path automatically once the foot touches it
In order to **intuitive navigation** and safety, the color, pattern, and flooring type of the access paths (corridor) lobby, bath, stairs, rooms, and … should be different from each other.	 Main Lobby – Waiting area	The function of the area and users would define the types, texture, and color of the floorings.

APPENDIX C1 - INTERVIEW QUESTIONNAIRE (current flooring and statistical information)

Architects
1- Do you think the flooring type is effective in reducing post-fall injury in older people?
2-In your opinion as an architect what should be considered in design and selection of suitable flooring for the elderly (Apartment or nursing home)? What features is significance? (About the flooring layers, About Function of the flooring, About Safety & Healthy, About Comfort of flooring, Cost, Durability …
3-What type of flooring do you use in different units of hospitals or nursing homes?
4-If older people prefer to stay barefoot in their room or their accommodation what type of flooring you recommend?
5-Have you ever think of -Shock/Impact absorbing surface for elderly? (Why?) - Do you know any shock absorbing flooring material which is suitable for elderly?
6- What actions and arrangements have been taken to protect and prevent the risk of fall?
Elderlies
1- Do you think it is important to use flooring with impact absorption to protect you from falling and reduce injuries after falling?
2-Have you ever fall in your apartment, gym, pool or any other parts of this center? In which position? Did any part of your body hurt? What was the reason of your fall? on stomach on left or right side from back sitting position on the floor Other side: ……………..
3-According to your experiences, what kind of indoor factors usually causes fall in the elderly? (rate them with: 3=Most possibility, 2=Medium possibility, 1= Least possibility) Stairs Ramps Carpet Different level Home Appliances (wire, chair leg…) Medicine Slippery floor (wet, oil, flooring …) Physical problem (eyesight, weakness, taking…) Light reflection Lack of light Other reason like…………………..
4- Which parts of your body do you think are most vulnerable if you fall? (rate them with: 3=Most possibility, 2=Medium possibility, 1= Least possibility) Head hip hand shoulder wrist ankle Knee Elbow Arm ……………..
5-Which area do you think is dangerous for old people and there is a risk of fall for them? In dining room Bathroom kitchen Gym salon Club pool Corridor Yard Stair Ramp Physiotherapy saloon Neurological unit Occupation therapy In the street Terrace
6-Have you ever lost your balance after using medicine-FALL? At what time of day? Morning After lunch Afternoon Night Midnight
7-Have you ever fallen at midnight when you wake up to go to bath or drink water?
8- In general what time (when) do you feel low energy and sleepy? (High-Risk Hours)? (rate them with: 3=Most possibility, 2=Medium possibility, 1= Least possibility) For example: In the Morning In the Afternoon At Night When they want to get out of bed during the day… During the night when they wake up to go to the bathroom… After each meal Any time they may fall
9-Do you use a hip protector? Why?
10-What kind of facilities you have or your family offers you to reduce the risk of fall or protect yourself from falling?
11- What colors do you think could be the best colors for walls or pavements in order to better distinguishing?
12-do you prefer walk with or without shoes in your apartment or room? Do you like carpet for your flat? Why?
13-What types of problems have the current pavements in your apartment or the center? Give them rate from 3-1) Color Slippery Light reflection Hard surface and cold Sound Hard to clean

14-What types of pavements do you like for your apartment or room? (In terms of walking style, comfort and safety) PVC (vinyl) wood (parquets) ceramic stone terrazzo carpet
15-Do you prefer natural light or artificial and controlled light in your room?
16- What type of shoes do you normally wear? Do you change them for different activities such as going to the gym or pool?
Repairman
1-In general how often does the flooring of the center need to be repaired or replaced? (Exp: Every 10 years, more than every 10 years, never) Room or apartment Toilet of their room Dining room Bathroom Gym Club Corridor Yard Stair Ramp Day center Physiotherapy saloon Terrace or open space Any other places: ………………………………..
2- What are the common factors that cause the flooring to be damaged or its appearance altered? Room or apartment Toilet of their room Dining room Bathroom Gym Club Corridor Yard Stair Ramp Day center Physiotherapy saloon Terrace or open space Any other places: ………………………………
3-What spaces and parts of flooring need to be maintained and repaired more than other parts (in general flooring)?
4-In what **areas** have you seen more damage on the flooring or needs constant follow-up to replace or fix the problem. why? (rate them with: 3=Most possibility, 2=Medium possibility, 1= Least possibility) Rooms Toilet of their room Bathroom Dining room Corridors Stair and ram Day center Physiotherapy saloon Gym salon Terrace
5- What factors make maintenance and repair of flooring difficult?
6-What arrangements are considered to reduce the risk of falling in the elderly? (to make a safe floor)
7- Do you have any experiences about the installation of other flooring types? What are their weakness and strength? **Weakness and strength:** 1-wood (parquet) 2-vinyl- PVC 3-Rubber flooring ....
Cleaners
1- Do you think the flooring type is effective in reducing post-fall injury in older people?
2-How often do you clean the flooring per week? Once a day More than once a day 3 times per week More than 3 times per week
3- Due to the types of flooring, what kind of detergents (substances or liquids) do you use? (Name them) Bathroom and toilet:…….Rooms and corridors:……Physiotherapy room:…..Gym salon:……Dining room :……Kitchen:……Club:……Store:………………
4-Do you currently have problems with the movement of the distribution trolleys, wheelchairs and other elements? Any explanation: ……………….
5-Has it ever occurred that the detergent causes any damage to the surface of the flooring? Or has affected its appearance? - What kind of change? ………………………
6-What kind of problems would appear if the floor of the rooms (individual or duplex) was covered with carpet? For example: Moving the wheelchair, handcart or trolley is hard It's hard to clean Absorbs contamination Over time, they smell bad (due to urine absorption) lead to a fall It is illegal Older people are unwilling
7-What are the problems of the current pavement? (What characteristics of flooring cause staff /elderly discomfort?) For example:

Reflection of light Color Very smooth and slippery surface Fatigue of the ankle muscles Temperature Problems related to mobility over time Stain on the floors Other reason: ……………………
8-Do older people prefer to stay barefoot in their room? If the pavement of the room is covered by carpet or a warm material, they would prefer to walk on barefoot? Why?
9-In what areas have you find more damage on the flooring and why? Rating them from 3 to 1. Rooms Toilet of their room Bathroom Dining room Corridors Stair and ram Day center Physiotherapy saloon Gym/game salon Terrace Any explanation: ………………
10- Which zones have hard surface to clean in this center and contamination or stains may remain? And why it is hard to clean them? Bathroom Corner of the wall Junction of the floor to the wall Connecting metal profiles between flooring…………………
11-Do you have any experiences about the cleaning of other flooring types? What are their weakness and strength? **Weakness and strength:** 1-wood (parquet): 2-vinyl- PVC: 3-Rubber flooring: 4-………………
Physiotherapists and assistance
1- Do you think the flooring type is effective in reducing post-fall injury in older people?
2-In which position normally old people tend to fall? (rate them with: 3=Most possibility, 2=Medium possibility, 1= Least possibility) For example: on stomach on left or right side from back sitting position on the floor Other side: ………………
3-Do older people prefer to stay barefoot in their room? If the pavement of the room is covered by carpet or a warm material, they would prefer to walk on barefoot? why?
4- According to the reports, in what places do fall normally occur (Risky Zones)? (Or which places are more dangerous to them?) (rate them with: 3=Most possibility, 2=Medium possibility, 1= Least possibility) For example: Residence-Day center: In their bedroom In the toilet or bathroom In dining room (public) Corridor Yard Stair Ramp Day center Physiotherapy saloon Terrace Apartment: In their bedroom or sitting room In the toilet or bathroom Kitchen Gym salon Club Corridor Swimming pool or Jacuzzi Yard Stair Ramp Physiotherapy saloon Terrace
5-Do the elderly take medications that reduce their balance or alertness during the day? What time of day usually?
6- According to the reports, what time (when) is the most likely risk of falling for elderly people within 24 hours? (High-Risk Hours)? (rate them with: 3=Most possibility, 2=Medium possibility, 1= Least possibility) For example: In the Morning (7h-14h) In the Afternoon (14h-21h) At Night (21h-7h) When they want to get out of bed during the day… During the night when they wake up to go to the bathroom… After each meal The probability of fall is the same at any time, and there is no specific time
7- What gender/sex tends more to fall? In your opinion what is the reason for this? ……………………………

8-Could older adults walk better and easier with shoes or without shoes? (Walking style and comfortable)
9- Do you classify seniors (patients and users) in this center? Why (reason)? Which group is more likely to fall?
10- In which section do you see and receive more the possibility of fall? (Rate from 4 till 1) Apartment(AP) Residence (RES)
11- What parts of their bodies are most vulnerable when they fall? (rate them with: 3=Most possibility, 2=Medium possibility, 1= Least possibility) Head Hip Hand Shoulder Wrist Ankle ……………………..
12-In physiotherapy, which parts of their bodies, are most vulnerable when they fall? rate them from 3 to 1. Head Hip Hand Shoulder Wrist Ankle ………………………..
13- According to the reports, what kind of indoor factors normally causes fall in the elderly? (rate them with: 3=Most possibility, 2=Medium possibility, 1= Least possibility) Stairs Ramps Carpet Different level Home Appliances (wire, chair leg…) Pets Slippery floor (wet, oil, flooring …) Other reason …………………..
Geriatric, Psychologist, Neurology
1- Do you think the flooring type is effective in reducing post-fall injury in older people?
2-In which position normally old people tend to fall? (rate them with: 3=Most possibility, 2=Medium possibility, 1= Least possibility) For example: on stomach on left or right side from back sitting position on the floor Other side: ………………
3-According to the reports, what kind of indoor factors normally causes fall in the elderly? (rate them with: 3=Most possibility, 2=Medium possibility, 1= Least possibility) Stairs Ramps Carpet Different level Home Appliances (wire, chair leg…) Pets Slippery floor (wet, oil, flooring …) Physical problem (eyesight, weakness, taking medicine…) Other reason like…………………..
4- Which parts of their bodies are most vulnerable when they fall? (rate them with: 3=Most possibility, 2=Medium possibility, 1= Least possibility) Head Hip Hand Shoulder Wrist Ankle ………………………
5-Are mental and neurological disorders in the elderly a factor that increases the likelihood of falling?
6-Do the elderly take medications that reduce their balance or alertness during the day? What time of day usually they must take such medicines?
7-Approximately how many accidents are recorded here by falling people to the ground per month? (for various reasons) less than 10 10-20 more than20
8- According to the reports, in what places do fall normally occur in this center (Risky Zones)? (Or which places are more dangerous to them?) (Give them numbers: 3=Most possibility, 2=Medium possibility, 1= Least possibility) For example: In their room or apartment In the toilet of their room In dining room in Residence section Bathroom Gym salon Club Corridor Yard Stair Ramp Day center Physiotherapy saloon Neurological unit Occupation therapy In the street Terrace
9- In general what time (when) is the most likely risk of falling for elderly people within 24 hours? (High-Risk Hours)? (rate them with: 3=Most possibility, 2=Medium possibility, 1= Least possibility) For example: In the Morning In the Afternoon At Night When they want to get out of bed during the day…

During the night when they wake up to go to the bathroom… After each meal Any time they may fall
10-What gender/sex tends more to fall? - In your opinion what is the reason for this?
11- According to the elderly's vision problems colors do you think could be the best colors for walls or pavements in order to better distinguishing? Do you have any reference to suggest?
12-Do elderly like to stay in an area with so much light or they prefer few light or dark place?
13-Could older adults walk better and easier with shoes or without shoes? (Walking style and comfortable)
14- Do you classify seniors (patients and users) in this center? Why (reason of classification)? -Which group is more likely to fall?
15- In which section do you see or receive the report of fall or the possibility of fall? (Rate from 4 till 1) Apartment(AP) Residence (RES)
16-What types of pavements do you recommend it for elderly? Why? (In terms of walking style, comfort and safety) PVC (vinyl) wood (parquets) ceramic stone terrazzo carpet
17-Do elderly prefer natural light or artificial and controlled light?

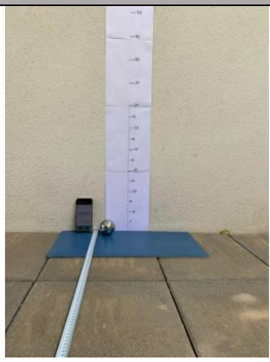
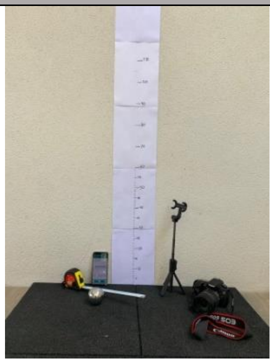
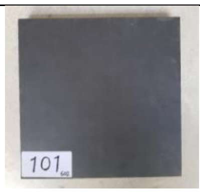
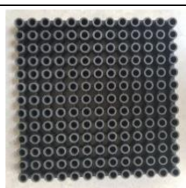
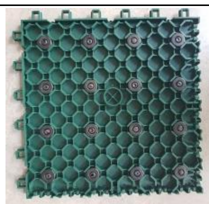
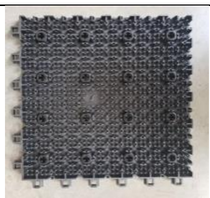
APPENDIX C2 - INTERVIEW QUESTIONNAIRE (collected floorings)

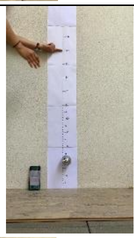
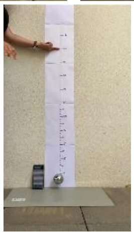
Architects, Elderlies, Repairman, Cleaners, Physiotherapists and assistance, Director of Unit, Geriatric, Psychologist, Neurology
1-Do you think elderlies living environment really need such pavements or it is not necessary?
2- Do feel the difference between changing the pavements when you walk on then?
3- On what pavement do you prefer to walk?
4- In your opinion, which one gives you more comfortable and more secure feeling?
5- What do you think about the difference between these pavements and the current internal pavement that is terrazzo. And which of them do you prefer? Terrazzo is fine? Or prefer any of the proposed pavements?
6- In your opinion which of them is more comfortable and safe for older adults to walk?
7- Which areas do you think needs more using of shock absorbent flooring? Apartment as a private area: kitchen, bath, living room, bed room, pool, club, gym, corridor Residence section as a public area: dining room corridor rooms baths lobby …

APPENDIX D – DEFINITION OF TESTS

Appendix D shows an explanation of the condition of the DWI test with photos of some of the floorings.

FIRST TEST – DWI-T

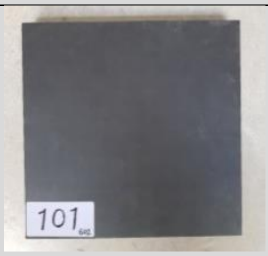
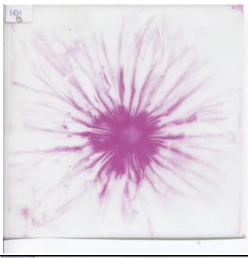
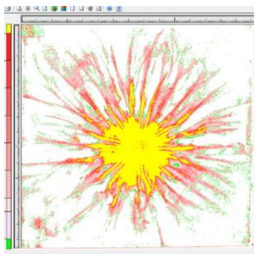
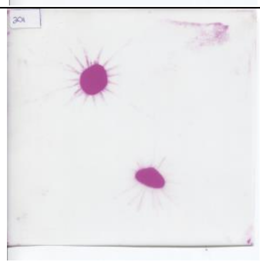
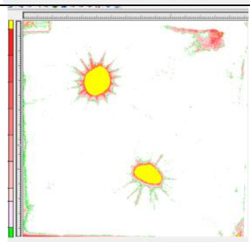
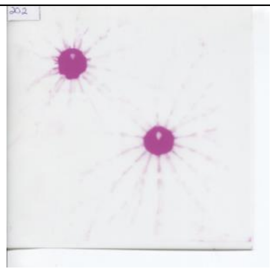
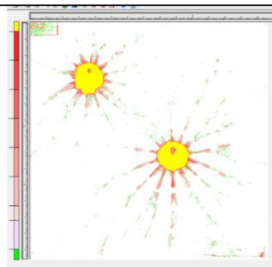
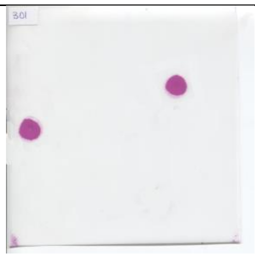
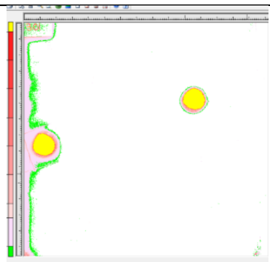
Num	Name	Photo	Description
	Slow-motion video technique: -Camera -Metal ball: Weight: 55gr Radius: 3.5cm -Measurement -Tonometer -Floorings	 	**Date:** 30.07.2019 **Time:** 13:30 **Temperature:** 29 centigrade degree **Humidity:** 56% **Height of fall:** 100cm **Height of Camera:** 52cm **Distance of Camera from wall:** 130cm
1.	101 **Smartcells:** 4 tile 24x24x 2.54cm (0.230 m^2)	  	
2.	201 **Revolution**: 1 tile 30.48x30.48x15.9mm (0.0930 m^2)	  	
3.	202 **Boundceback:** 1 tile 30.5x30.5cmx19mm (0.0930 m^2)	  	
4.	301 **Taralay premium comfort**: 2 tile 48x 48cmx 3.00-3.30mm (0.460 m^2) 302 **Taralay impression comfort:** 2 tile 48x48cmx 3.00-3.30mm (0.460 m^2)	 	 

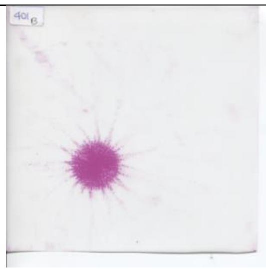
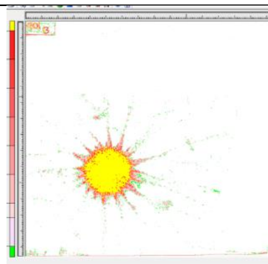
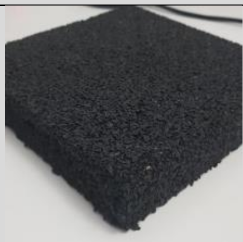
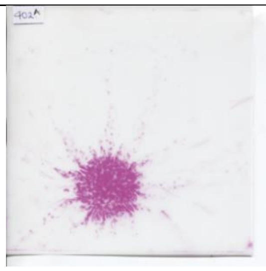
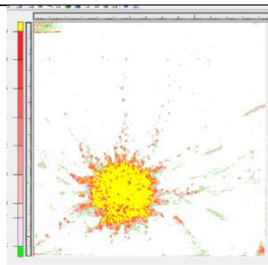
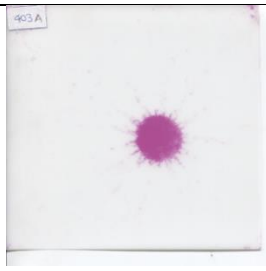
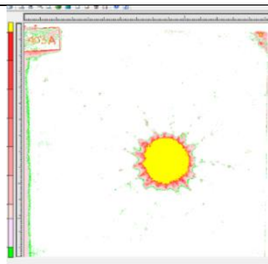
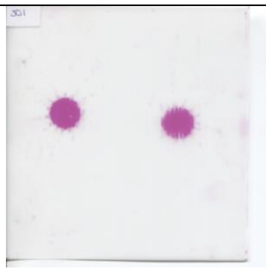
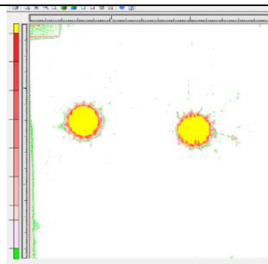
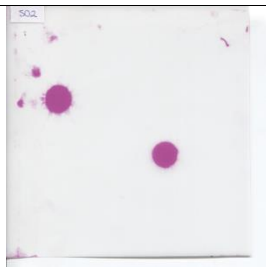
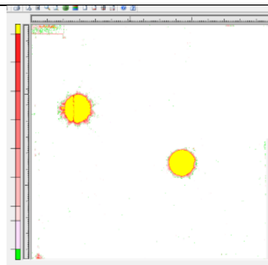
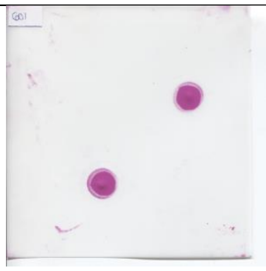
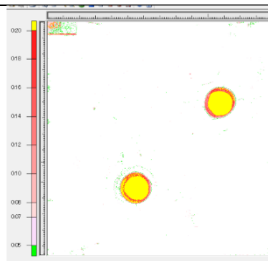
5.	401 **SportEX 6.7**: Rolle 2mx2mx6.7mm (4 m^2) 402 **Energy CF 20mm:** 2 tiles of 100×100 cmx 20mm (2 m^2) 403 **Energy storm 8mm:** 4 tiles of 50×50 cmx8mm (1 m^2)	  	  
6.	501 **Resist + wood Traces spice:** 8 tile 1.28mx18.50cmx 10.5mm (1.90 m^2) 502 **Resist + Cork Traces spice:** 8 tile 1.22mx14cmx10.5mm (1.36 m^2) 603 **Sentica Acoustic:** Rolle 5mx1.22mx3m (6.10 m^2)	  	  
7.	601 **Sentica:**10 tile 60x60cmx3mm (3.60 m^2) 602 **Valua:** 16 tile 60x30cmx3mm (2.88 m^2)	 	 
8.	701 **5.08 cm. DuraSafe:** 4 tile ~ 61x61x5.08cm (1.50 m^2)	  	

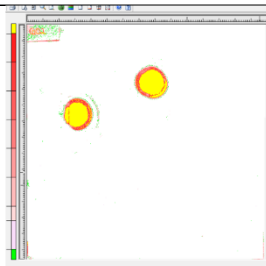
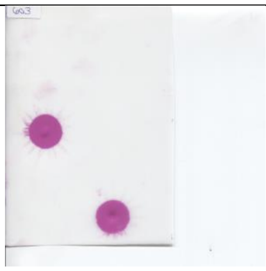
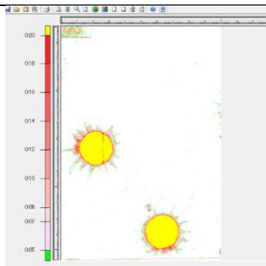
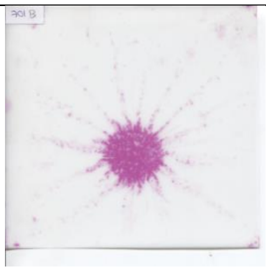
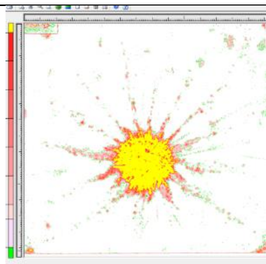
SECOND TEST – VPA-T

Photos of graphical results of VPA test on site:

Test condition	
Date: 18.07.2019 Prescale sheet model: 4LW Size of the metal Ball: Radius of 3.5cm Weight of the metal Ball: 55gr	Hight of fall of the metal Ball:100cm The temperature of area: 28°c The humidity of area: 54%
Specifications and Operational Environment by Fujifilm	
Recommended service temperature	20°C~35°C(68 °F~ 95°F)*
Recommended service humidity	35% RH ~ 80% RH**
*Extreme low pressure (4LW), Super high pressure * (HHS): 15 °C~30° **Extreme low pressure (4LW): 20% RH ~ 75% RH	

	Photo	Scanned sheets	Analyzed sheet by software
101	 		
201	 		
202	 		
301			

401			
402	 		
403			
501			
502			
601			

602			
603			
701	 		

THIRD TEST – HIC-T

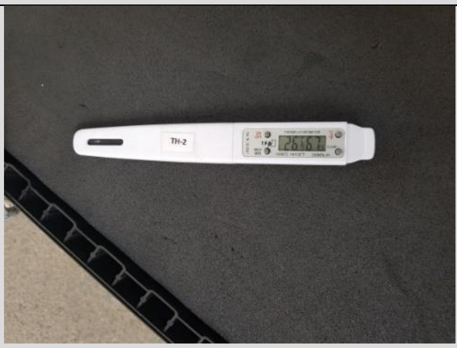
Photos during HIC test and analyzing data on site:

HIC-meter - Wireless Value

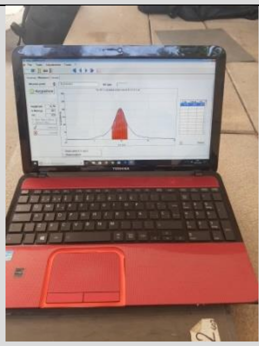
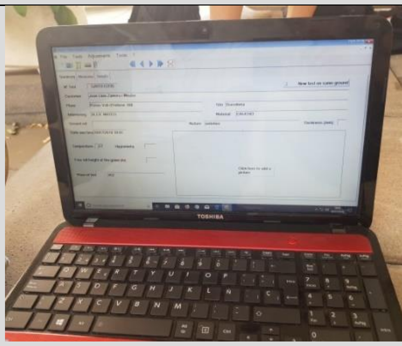


INFORMATION RELATING TO THE TEST

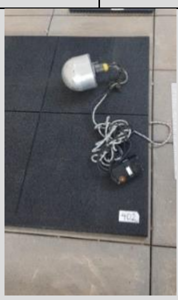
Location: PASEO VALL D´HEBRON, 169, BARCELONA



Temperature:26, Humidity:67%, Hour: 10:00-11:30

Ludometer Software


All pavements

INFORMATION REGARDING THE SAFETY FLOOR
Test without vinyl

Flooring cod 402

Floor reference: 402 and 402-301
Material: RUBBER
Assay position: TEST
Nature of the soil: SYNTHETIC-CONCRETE TILE
Thickness: 20mm

Weight: UNKNOWN
Density: UNKNOWN
Mass per unit: UNKNOWN
Other properties: UNKNOWN
Temperature: 26 ° C
Humidity: 72%

402

402-301

TEST DETAILS (402)

Point N 1		
HEIGHT	G-max	HIC
0,31	89	183
0,46	130	429
0,66	174	758
0,74	218	1156

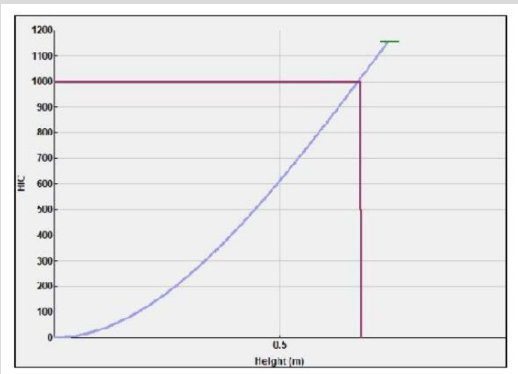
$$\frac{218}{X} = \frac{1156}{1000} \rightarrow X = 188.6 \text{ Gmax}$$

Critical Fall Height (CFH): 0.68 m ± 7% uncertainty

CONCLUSION

According to the UNE EN 1177: 2018 standard, Method 1 for determining the critical fall height, the critical fall height for the tested coating must be expressed rounded to one decimal place.

0.6



HIC curve as a function of fall height

TEST DETAILS (402-301)

Point N 1		
HEIGHT	G-max	HIC
0,26	79	153
0,57	155	591
0.86	198	1030
0.93	213	1161

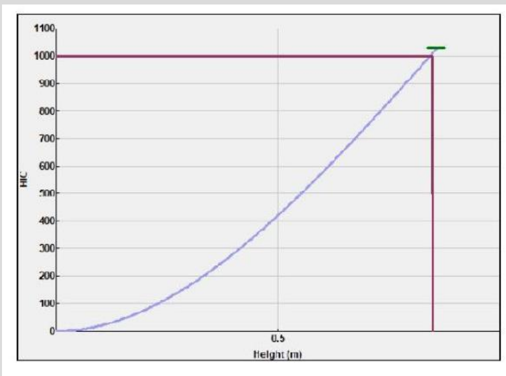
$$\frac{213}{X} = \frac{1161}{1000} \rightarrow X = 183.5 \text{ Gmax}$$

Critical drop height: 0.85 m ± 7% uncertainty

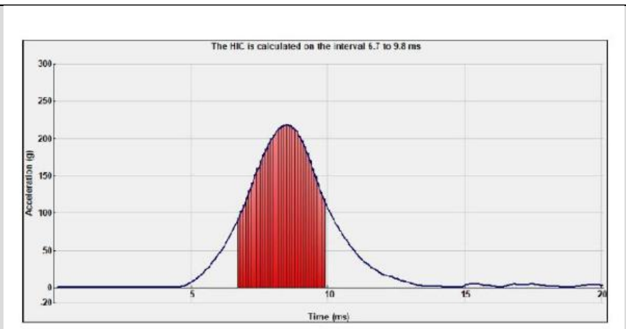
CONCLUSION

According to the UNE EN 1177: 2018 standard, Method 1 for determining the critical fall height, the critical fall height for the tested coating must be expressed rounded to one decimal place.

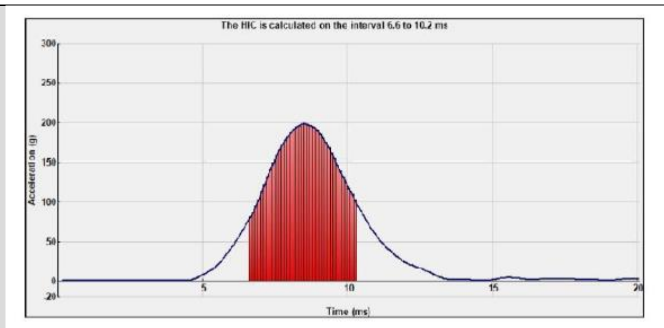
0.8



HIC curve as a function of fall height



Deceleration curve as a function of time for the height of fall



Deceleration curve as a function of time for the height of fall

Flooring cod: 101

Land reference: 101 and 101-301
Material: RUBBER
Assay position: TEST
Nature of the soil: SYNTHETIC-CONCRETE TILE
Thickness: 20mm

Weight: UNKNOWN
Density: UNKNOWN
Mass per unit: UNKNOWN
Other properties: UNKNOWN
Temperature: 26 ° C
Humidity: 72%

101

101-301

<u>TEST DETAILS</u>

Point N 1		
HEIGHT	G-max	HIC
0,36	72	133
0,79	207	833
1.01	251	1278

$\frac{251}{X} = \frac{1278}{1000}$ → X = 196.4 Gmax

Critical fall height: 0.87 m ± 7% uncertainty
A wooden frame of interior measures 1.00X1.00 m has been used.

<u>CONCLUSION</u>
According to the UNE EN 1177: 2018 standard, Method 1 for determining the critical fall height, the critical fall height for the tested coating must be expressed rounded to one decimal place.
0.8

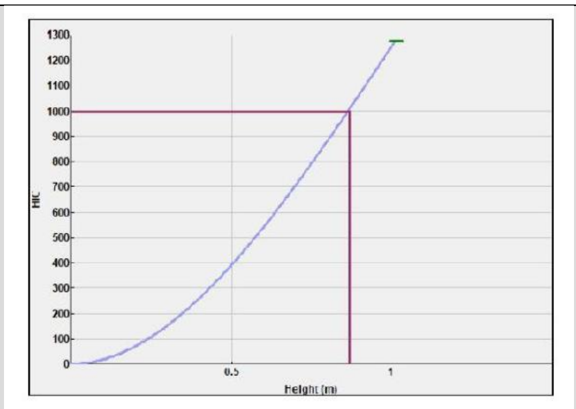
<u>TEST DETAILS</u>

Point N 1		
HEIGHT	G-max	HIC
0,79	171	632
0,84	190	768
1.05	248	1305

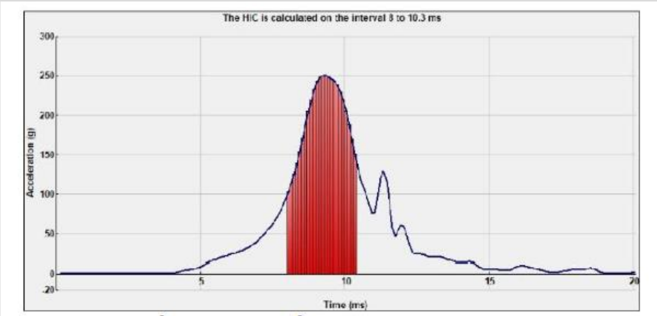
$\frac{248}{X} = \frac{1305}{1000}$ → X = 190 Gmax

Critical fall height: 0.89 m ± 7% uncertainty

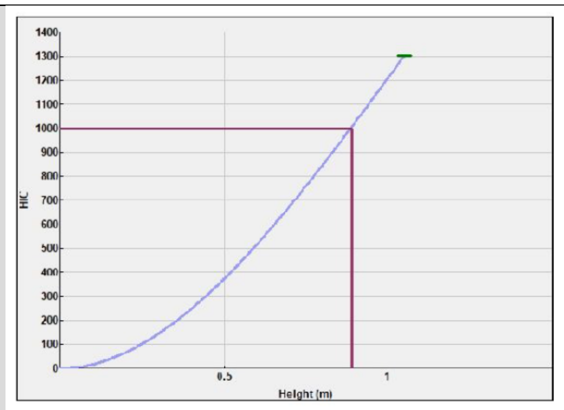
<u>CONCLUSION</u>
According to the UNE EN 1177: 2018 standard, Method 1 for determining the critical fall height, the critical fall height for the tested coating must be expressed rounded to one decimal place.
0.8



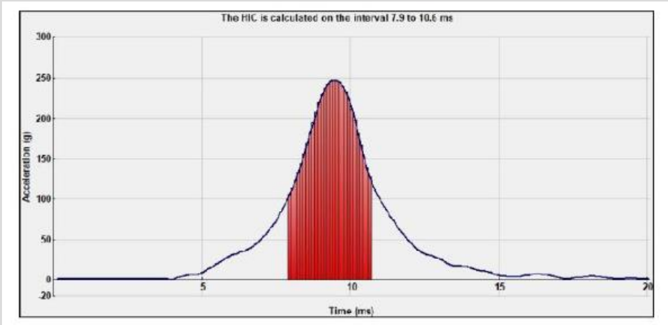
HIC curve as a function of fall height



Deceleration curve as a function of time for the height of fall



HIC curve as a function of fall height



Deceleration curve as a function of time for the height of fall

Flooring cod: 701

Land reference: 701
Material: RUBBER
Assay position: TEST
Nature of the soil: SYNTHETIC -CONCRETE TILE
Thickness: 50mm

Density: UNKNOWN
Mass per unit: UNKNOWN
Other properties: UNKNOWN
Temperature: 26 ° C
Humidity: 72%
Weight: UNKNOWN

701

701-301

TEST DETAILS

Point N 1		
HEIGHT	G-max	HIC
0,89	97	375
1.23	118	576
1.57	138	815
1.91	156	1042

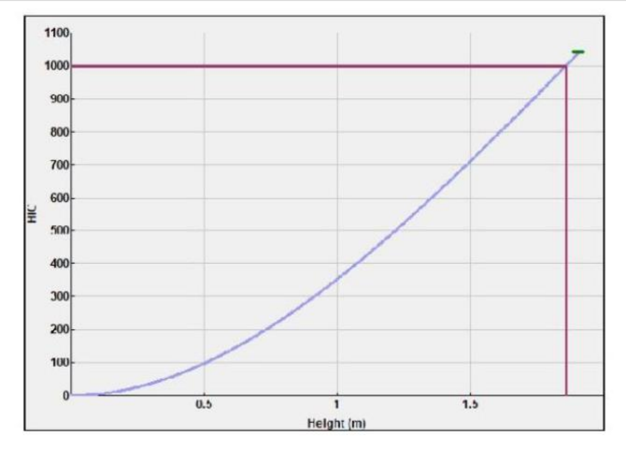
$\frac{156}{X} = \frac{1042}{1000}$ → X = 149.7 Gmax

Critical fall height: 1.86 m ± 7% uncertainty

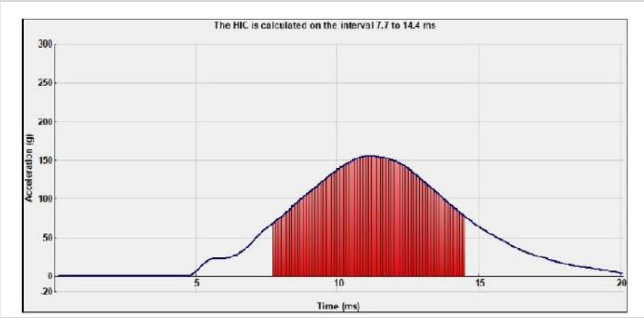
CONCLUSION

According to the UNE EN 1177: 2018 standard, Method 1 for determining the critical fall height, the critical fall height for the tested coating must be expressed rounded to one decimal place.

1.8



HIC curve as a function of fall height



Deceleration curve as a function of time for the height of fall

TEST DETAILS

Point N 1		
HEIGHT	G-max	HIC
0,71	89	301
1.02	111	487
1.41	140	796
1.77	162	1089

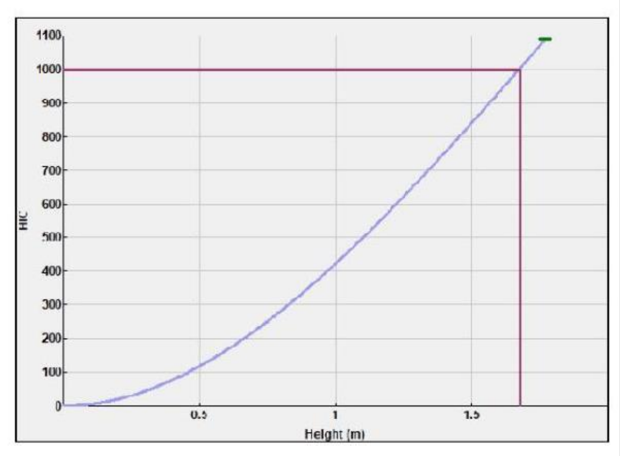
$\frac{162}{X} = \frac{1089}{1000}$ → X = 148.7 Gmax

Critical fall height: 1.68 m ± 7% uncertainty

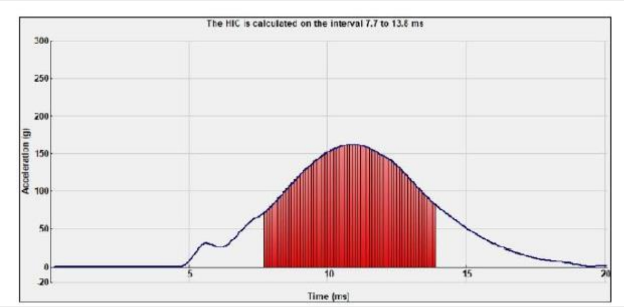
CONCLUSION

According to the UNE EN 1177: 2018 standard, Method 1 for determining the critical fall height, the critical fall height for the tested coating must be expressed rounded to one decimal place.

1,6



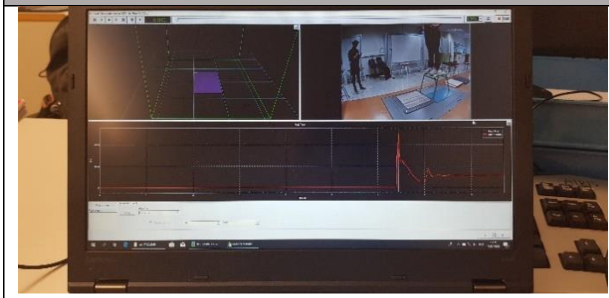
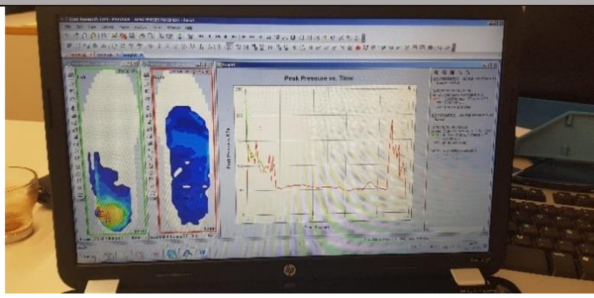
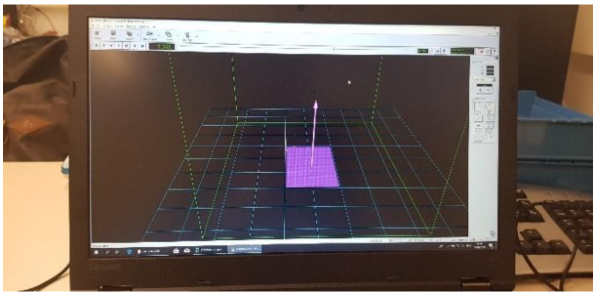
HIC curve as a function of fall height



Deceleration curve as a function of time for the height of fall

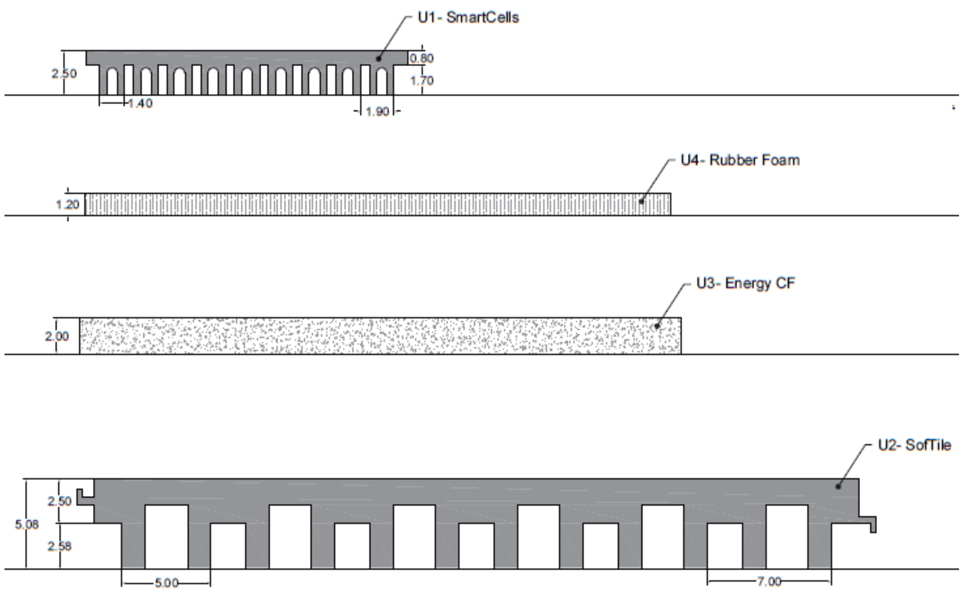
FOURTH TEST – BIO-T

Photos during BIO test and analyzing data in laboratory:

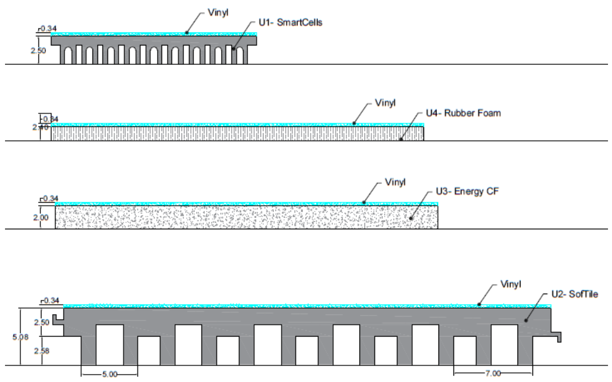
FORCE PLATE TOOLS	INSOLE PREASSURE SENSORS
	
	
 	
PHOTOS DURING TEST	
    	

Graphical shape of four types of overlay (vinyl, parquet, ceramic and carpet) fixed on four types of CF system:

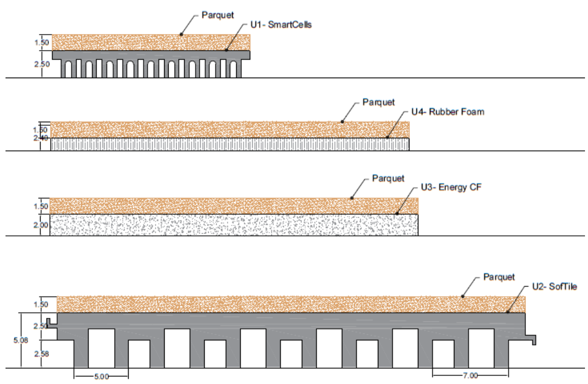
Compliant Floorings without overlay



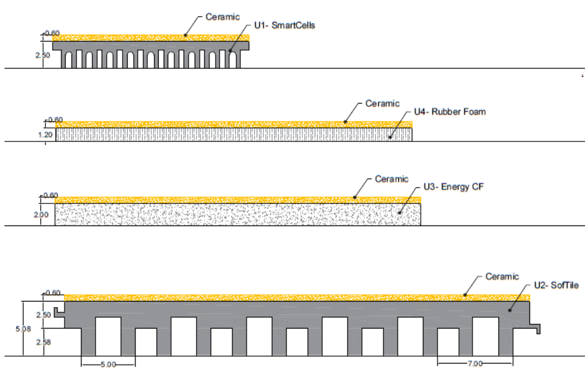
CF flooring with Vinyl overlay



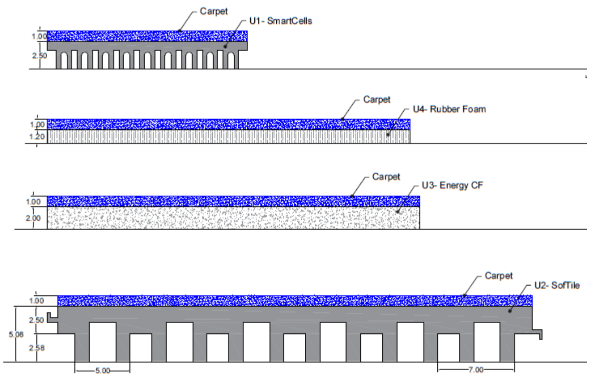
CF flooring with Parquet overlay



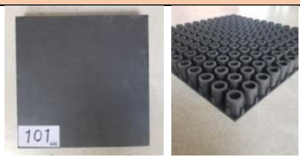
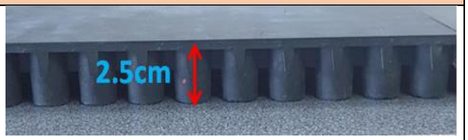
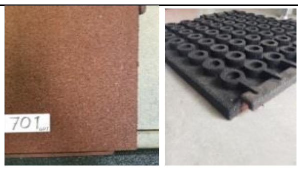
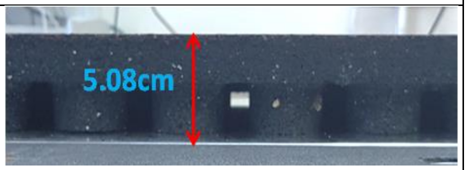
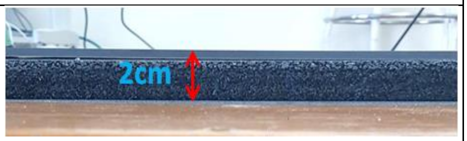
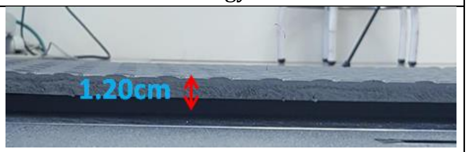
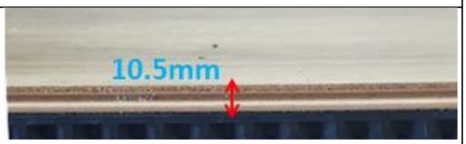
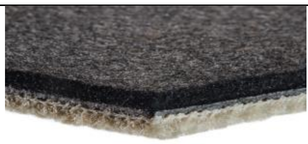
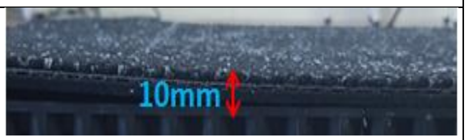
CF flooring with Ceramic overlay



CF flooring with Carpet overlay



Thickness of Four types of overlay (vinyl, parquet, ceramic and carpet) fixed on four types of CF system (Smartcells, Softile, Energy CF, and Rubber foam):

Underlay-CF		
U1		SmartCells
U2		Softile
U3		Energy CF
U4		Rubber Foam
OVERLAY		
O1		Vinyl
O2		Parquet
O3		Ceramic
O4		Carpet

FIFTH TEST – FEM-S

MECHANICAL TEST DATA OF HYPERELASTIC MATERIALS

The material constants in the strain-energy function determine the mechanical response of the selected hyperelastic model. To gain accurate analysis results, it is needed to evaluate material constants from the tested samples. These constant numbers are normally gained from the curve-fitting on the experimental strain-stress data. This test information is normally derived from various deformation modes over a wide range of strains. The material constants could be appropriate using test data in deformation states as will be experienced in the finite element analysis (FEM). Since elastomers show nearly incompressible behavior and frequently experience high strains in service, their strain conditions are usually complex. In hyperelastic materials the Poisson's ratio = 0.5, then the bulk modulus = Infinity and, *K* (constant factor characteristic of the spring) is very high, therefore the material cannot be compressed. Thus, hyperelastic materials are incompressible. This implying that under huge loads, hyperelastic material changes its shape but the whole volume remains almost constant (Deviatoric stress).

For hyperelastic materials, some deformation tests are normally used to determine the material constants. There are six main different deformation modes shown in (Figure 0-1). The combination of multiple tests will increase the characterization of the hyperelastic behavior of a material. Although there are six different deformation modes, after applying hydrostatic pressure, the following modes become identical: uniaxial tension and equibiaxial compression, uniaxial compression and equibiaxial tension, planar tension, and planar compression (Genovese, 2006).

<u>Uniaxial tension (Equibiaxial compression)</u>

This is a simple tensile test stress-strain data with no lateral restrictions. Such test data must be provided to assess the tension deformation. Uniaxial compression data can be taken from equibiaxial data.

For uniaxial tension:

$$I_1 = \lambda_1^2 + 2\lambda_1^{-1}$$
$$I_2 = 2\lambda_1 + \lambda_1^{-2} \qquad 0.1$$

I1 and *I2* are the first and second strain invariants and λ Lame's constant.

<u>Equibiaxial tension</u>

Stress-strain data in a biaxial tension test conducted by stretching uniformly in two opposite directions, the strain condition is equivalent to pure compression. Equibiaxial compression data normally taken from uniaxial tension data.

For equibiaxial tension:

$$I_1 = 2\lambda_1^2 + \lambda_1^{-4}$$
$$I_2 = \lambda_1^4 + 2\lambda_1^{-2} \qquad 0.2$$

I1 and *I2* are the first and second strain invariants and λ Lame's constant.

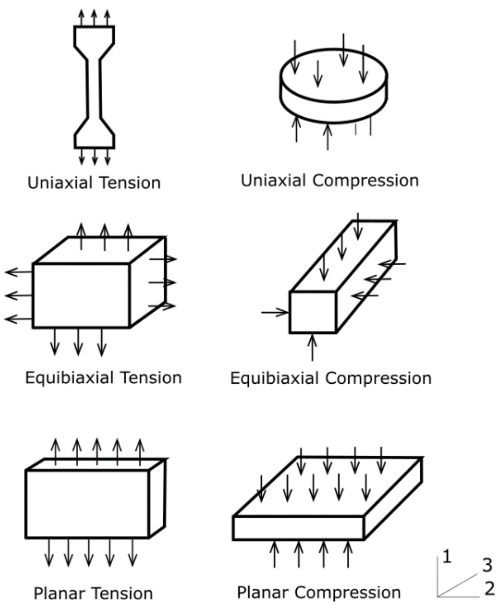


Figure 0-1 six deformation model test (Shahzad, 2015)

Pure shear deformation

Shear deformation for hyperelastic materials refers to a sample that is hardly stretched, but since the material is almost incompressible, a pure shear condition will occur (Shahzad, 2015).

The first and second strain invariants are:

$$I_1 = I_2 = \lambda_1^2 + \lambda_1^{-2} + 1 \quad 0.3$$

For an isotropic and incompressible material, W can be stated as a function of the strain tensor invariants or principal stretches:

$$W = W(\bar{I_1}, \bar{I_2}, \bar{I_3}) = W(\lambda_1, \lambda_2, \lambda_3) \quad 0.4$$

where, the three invariants ($\bar{I1}, \bar{I2}, \bar{I3}$) of the Green strain tensor are given in terms of the principle extension ratios $\lambda 1$, $\lambda 2$ and $\lambda 3$ by:

$$\bar{I_1} = {\lambda_1}^2 + {\lambda_2}^2 + {\lambda_3}^2 \quad 0.5$$

$$\bar{I_2} = {\lambda_1}^2.{\lambda_2}^2 + {\lambda_2}^2.{\lambda_3}^2 + {\lambda_3}^2.{\lambda_1}^2$$

$$\bar{I_3} = {\lambda_1}^2.{\lambda_2}^2.{\lambda_3}^2$$

HYPERELASTIC MODEL AND CURVE FITTING

Several mathematical fundamental theories of hyperelastic have been extensively researched since the works of Mooney (1940) and Rivlin (1948) which were based on the strain invariants and in the concept of the material to be isotropic and incompressible. The hyperelastic constitutive models can explain the reaction of almost incompressible materials that display immediate elastic reactions up to large strains. They are represented in terms of a strain energy density function (W) which determines the strain energy stored in the material per unit of the reference volume. This behavior depends on the material's stress-strain proportion, which connects on a series of parameters (material constants). To achieve these constants, the nominal stress versus nominal strain data is required which are gained from experimental trials to coordinate most model's theoretical behavior available (Bortoli, Wrubleski, Marczak, & Gheller Jr., 2011). The number of material constants and physical meanings are different between hyperelastic models, A list of strain energy of each hyperelastic model is classified in Appendix D (Bergström J. , 2015).

In order to understand the stress-strain relationship of hyperelastic materials, FE software packages like Abaqus ® provide some SEFs to accommodate the nonlinear behavior of rubber or other hyperelastic materials. They change greatly in computational speed and accuracy. In general, to have a more accurate hyperelastic material model, more time is required to simulate the model. And the larger strain and more material parameters lead to higher accuracy of the material model. All those material properties make it very hard to specify a model that can define their complete behavior. Over the years, various theoretical models have been suggested, and more are being proposed currently. The extensively available rules include the Mooney–Rivlin, Yeoh, neo-Hookean, Arruda–Boyce, polynomial, and Ogden rules, for which the strain energy potentials and stress–stretch ratio correlations are considered. The initial shear modulus "$\mu 0$" and bulk modulus "$K0$" are given by:

$$\mu_0 = 2.(C_{10} + C_{01})\ ; \qquad K_0 = 2/D_1 \qquad 0.6$$

For large strain elasticity, two hyperelastic models are offered: a general polynomial SEF (includes Mooney-Rivlin) and Ogden's model, both of which can be utilized for a fully incompressible or semi-incompressible response. Following Table 0-1 shows the general hyperelastic models.

Table 0-1 General hyperelastic models offered by RecurDyn

	Neo-Hooke	Mooney-Rivlin	Arruda-Boyce	Ogden
Computational speed	fastest	Slower than Neo-Hooke	Slower than Mooney-Rivlin	Slowest
Range of strain	Strains up to 100%	Strains up to 200%	Strains up to 300%	Strains up to 700%
benefit	Most accurate for Uniaxial strain	often the most popular because it has reasonable accuracy at a low computational cost.	A special-purpose hyperelastic material for certain rubbery materials such as silicon and neoprene.	A very general purpose hyperelastic material model.

Among available models for the simulation of hyperelastic rubber-like materials, the Ogden constitutive model (Gwinner, 1988) (R.W. Ogden, 1986) with a strain energy density formulated in terms of the principal stretches is certainly the most considerable and successful one. It permits the consideration of an arbitrary number of material constants, shows an excellent agreement with experimental results at large strains, and finally includes the above-cited models as exceptional cases so that its numerical simulation provides a unified treatment of various material model types. However, the Ogden model is the most complicated constitutive law concerning the numerical realization as it requires the determination of the principal stretches through strongly nonlinear equations and applies to arbitrary isotropic rubber-like materials. Its main characteristic is a strain energy ¼ (per unit volume of the undeformed state) expressed in terms of the principal stretches λi, the eigenvalues of the correct stretch tensor U (Başar, 1998).

For items where we have small nominal strains or a bit large (less than 100%), the first conditions in the polynomial series usually present an adequately accurate model. In addition, sSome specific material models (Mooney-Rivlin, neo-Hookean, and Yeoh forms) are gained for particular choices of Cij (Simulia, 2016).

In addition to the coefficients mentioned above, the second method is to define and extract the free energy directly from the experimental data in uniaxial loading (T. Sussman, 2009). One advantage of this method is that there is no adjustable parameter that needs to be detected, instead of the energy function, and finally, the stress calculations, are directly gained from the dedicated experimental uniaxial test data.

Table of Hyperelastic models and formulas:

MODEL	FORMULA-STRAIN ENERGY STORED IN THE MATERIAL
Polynomial model	$W = \sum_{i+j=1}^{N} C_{ij}.(\bar{I}_1 - 3)^i.(\bar{I}_2 - 3)^j + \sum_{k=1}^{N} \frac{1}{D_k}(J-1)^{2k}$
Eight-Chain (EC) or Arruda-Boyce model	$W = \mu\left[\frac{1}{2}(\bar{I}_1 - 3) + \frac{1}{20\lambda_m^2}(\bar{I}_1^2 - 9) + \frac{11}{1050\lambda_m^4}(\bar{I}_1^3 - 27) + \frac{19}{7000\lambda_m^6}(\bar{I}_1^4 - 81) + \frac{519}{673750\lambda_m^8}(\bar{I}_1^5 - 243)\right] + \frac{1}{D}\left(\frac{J^2-1}{2} - \ln J\right)$ $C_1 = \frac{1}{2}; \quad C_2 = \frac{1}{20}; \quad C_3 = \frac{11}{1050}; \quad C_4 = \frac{19}{7000}; \quad C_5 = \frac{519}{673750}$
Blatz-Ko model	$W = \frac{\mu}{2}\left(\frac{I_2}{I_3} + 2\sqrt{I_3} - 5\right)$
Gent model	$W = -\frac{\mu J_m}{2}\ln\left(1 - \frac{\bar{I}_1 - 3}{J_m}\right) + \frac{1}{D_1}\left(\frac{J^2-1}{2} - \ln J\right)$ $J_m = I_m - 3.$
Mooney-Rivlin 2-parameter model	$W = C_{10}(\bar{I}_1 - 3) + C_{01}(\bar{I}_2 - 3) + \frac{1}{D_1}(J-1)^2$
Mooney-Rivlin 3-parameter model	$W = C_{10}(\bar{I}_1 - 3) + C_{01}(\bar{I}_2 - 3) + C_{11}(\bar{I}_1 - 3)(\bar{I}_2 - 3) + \frac{1}{D_1}(J-1)^2$
Mooney-Rivlin 5-parameter model	$W = C_{10}(\bar{I}_1 - 3) + C_{01}(\bar{I}_2 - 3) + C_{20}(\bar{I}_1 - 3)^2 + C_{11}(\bar{I}_1 - 3)(\bar{I}_2 - 3) + C_{02}(\bar{I}_2 - 3)^2 + \frac{1}{D_1}(J-1)^2$
Neo-Hookean model	$W = \frac{\mu}{2}(\bar{I}_1 - 3) + \frac{1}{D_1}(J-1)^2$ $\mu_0 = 2.C_{10}; \quad K_0 = 2/D_1$
Ogden model	$W = \sum_{i=1}^{N} \frac{\mu_i}{\alpha_i}\left(\bar{\lambda}_1^{\alpha_i} + \bar{\lambda}_2^{\alpha_i} + \bar{\lambda}_3^{\alpha_i} - 3\right) + \sum_{k=1}^{N} \frac{1}{D_k}(J-1)^{2k}$ $\mu_0 = \frac{1}{2}\sum_{i=1}^{N} \mu_i.\alpha_i; \quad K_0 = 2/D_1$
Polynomial model	$W = \sum_{i+j=1}^{N} c_{ij}(\bar{I}_1 - 3)^i(\bar{I}_2 - 3)^j + \sum_{k=1}^{N} \frac{1}{D_k}(J-1)^{2k}$
Yeoh model	$W = \sum_{i=1}^{N} c_{i0}(\bar{I}_1 - 3)^i + \sum_{k=1}^{N} \frac{1}{D_k}(J-1)^{2k}$ $\mu_0 = 2.(C_{10}); \quad K_0 = 2/D_1$

*where μ is the shear modulus, lambda is the limiting network stretch, *Cij* are the material constants for a "N" number of terms, *J* is the Jacobin for volume changes and total volume ratio (Mathematically it is the determinant of the deformation gradient) and *Dk* is constants parameter relates the material incompressibility parameters and to the volumetric response.
*I, is the invariant of the Cauchy-Green tensor
*μi and, αi are material parameters.
*λlambda is the limiting network stretch(the deviatoric principal stretch), Jm is the limit value of I1−3.
*D1=k/2 where k is the bulk modulus.
*If the rubber is compressible, a dependence on J=det(F)= λ1λ2λ3 can be introduced into the strain energy density F(deformation gradient)

- Arruda-Boyce model (EC)

The eight-chain (EC) model by Arruda and Boyce is a hyperelastic fundamental model used to explain the deformation and mechanical behavior of the microstructure of elastomers and rubber-like. (Arruda, 1993) The essential intention of the EC model is that the macromolecules (also known as chain molecules), on average, are placed along the diagonals of a unit cell placed in the main stretch space. The Arruda-Boyce EC model is an effective micromechanism-inspired model that has been illustrated to precisely receive the equivalence response of plenty of isotropic elastomers (Bergström J. S., 1999). The basic framework of this model is that the eight chain unit cell is stretched also its initial unloaded configuration.

- Neo-Hookean model (NH)

The NH model is a simple hypoplastic model based on two material parameters: 1-the shear modulus μ and 2-the bulk modulus κ. Here, as is often done, the NH model theory is proposed for both compressible and incompressible deformations. The NH model is usually applied for solids and rubber-like materials. These materials are specified by an approximately incompressible response and the actual amount of bulk modulus, so they normally have very little effect on the response of the rubber-like component. Similar to all models of hyperelastic materials, the NH model is characterized by the expression of Helmholtz free energy per unit volume of reference (Bergström J. , 2015).

- Mooney-Rivlin Model (MR)

The Mooney-Rivlin model is a development of the NH model that intends to modify and complete the accuracy by including a linear dependence on $I*2$ in the Helmholtz free energy per unit reference volume. As demonstrated in the equation, the compressible version of the MR model needs three material parameters: $C10$, $C01$, and k (Bergström J. , 2015). Mooney-Rivlin model is widely used to model the large strain nonlinear behavior of incompressible materials. It works well for moderately large stains in uniaxial elongation and shear deformation (Shahzad, 2015).

- Yeoh Model

The Yeoh model is based on a Helmholtz free energy that is a third-order polynomial in $I*1$ and does not have any dependency on $I*2$. According to the higher-order $I*1$ term, this model able to predict more accurately than the NH model, and meantime potentially prevent some of the stability matters of the Mooney-Rivlin model.

- Polynomial Model

An extension of the NH, Mooney-Rivlin, and the Yeoh models can be gained by taking the Helmholtz free energy to be a polynomial development in terms of $I*1$ and $I*2$. This polynomial demonstration is not as generally used as the simpler models with a fixed number of terms (Bergström J. , 2015).

- Ogden Model

The Ogden model is a very general hyperelasticity model with a Helmholtz free energy per reference volume that is represented in terms of the applied principal stretches. The Helmholtz free energy for the Ogden model can be presented in different methods. One general compressible representation is shown in Equation. The volumetric response is written in terms of Di parameters instead of the bulk modulus terms. Ogden Model makes the model potent but can also complicate the choice of a proper set of material parameters that give stable predictions of general deformation conditions. The Ogden model is more accurate than the NH and the MR models, but not as accurate as the Yeoh model. The experiences show that the Ogden (3-term) model and the Extended Tube Model (ET) model are the most accurate (Yeoh., 1993).

- Gent Model

The Gent model (Gent A. N., 1996) is a development of the NH model that intends to better characterize the response of elastomer-like materials at great deformations. The Helmholtz free energy per unit reference by volume for the Gent model is given. This statement contains three material parameters: the shear modulus μ, the Jm parameter that is dimensionless and controls the confined chain extensibility at greatly applied strains, and the bulk modulus k.

ABAQUS SOFTWARE

ABAQUS software (English: *ABAQUS*) is one of the most powerful computer-aided engineering software in the field of finite element analysis (FEM) in the market. The software's name is derived from the English word abacus meaning abacus and abax (ἄβαξ) in Greek meaning sand-covered board. This software is a product of the French company “Dassault Systems”.

Abacus able to solve problems from simple linear analysis to the most complex nonlinear modeling. This software has a very wide range of elements with which any type of geometry can be modeled. It also has many behavioral models that make it possible to model a variety of materials with different properties and behaviors such as metals, rubbers, polymers, composites, reinforced concrete, spring, and brittle foams, as well as geotechnical materials such as soil and rock. Since Abacus is a general and extensive modeling tool, its use is not limited to the analysis of solids mechanics problems (ie, stress-strain problems). Using this software, various issues such as heat transfer, mass transfer, thermal analysis of electrical, acoustic, seepage, and piezoelectric components can be studied (SIMULIA website, 2020).

Abacus software consists of 4 parts:

- Abaqus / Standard is a general analyzer based on the finite element method and uses the implicit integration approach.
- Abaqus / Explicit is a finite element analyzer that uses an explicit approach to integration and is used to solve nonlinear systems including contact problems in transient loading mode.
- Abaqus / CFD, a fluid dynamics analysis software, was added to this suite of software from version 6.0 onwards.
- Abaqus / Electromagnetic which is electromagnetic analysis software.

It also supports Python's open-source programming language for programming within the software. The ability to write scripts within the software doubles its modeling capabilities. One of the most important features of Abacus software compared to other existing finite element software is the ability to modify and add to software features and libraries[1].

A complete analysis of an Abacus program usually consists of three steps:

- Pre-processing stage
- Processing stage
- Post-processing stage

[1] /https://www.3ds.com/products-services/simulia/products

The types of processing in Abaqus are related to each other in three steps according to what is stated by a number of files.

1. Pre-processing stage (Abaqus / CAE)

In this step, you have to create the problem model and create an Abacus input file. The model can usually be graphically created using ABAQUS / CAE or other preprocessors, or the Abacus input file that can be created using a text editor such as Notepad.

2. Processing step (Abaqus Standard / Explicit)

Processing, usually performed as a background process, is the stage at which a standard or explicit abacus solves the numerical problem defined in the model. Examples of stress analysis output are displacements and stresses that are stored in binary files and used for the post-processing phase. Depending on the complexity of the problem to be analyzed and the power of the computer performing the analysis, the analysis time can take anywhere from a few seconds to several days.

3. Post-processing step (Abaqus / Viewer)

The evaluation of the results can be done after the completion of the processing stage, ie when the stresses of displacement and other basic variables have been calculated. Evaluation is usually done using visual modules or other post-processors. The visual module reads the data of the binary output file and has various options such as color contours, animation, modified form, or graphical data to display the results.

Abaqus / CAE software

This software is the main software of the Abaqus collection. "Cae" stands for "Complete Abaqus Environment". This software is the Abacus graphical interface that allows the user to model in a "visual" environment. Having a graphical environment speeds up the modeling process and makes working with Abacus easier. This software has 9 environments (**Error! Reference source not found.**) each of which is called a “module”. When the user moves from one module to another, the menu bar at the top of the software screen changes, which means that some settings can only be done in a specific module. The following is the name of each of these modules along with a brief description of the function of each.

- Part module

In this module, the user can design the parts you want to analyze. Of course, the tools in this module for designing parts are not as wide as the tools available in Katia and SolidWorks software, and if the user cannot design the desired part in the *Abacus* part module, he must use *Katia* or *SolidWorks* or even *AutoCAD* to do so. And then import the assembly file that it wants to analyze into Abacus.

- Property module

In this module, the user can define the materials from which the analyzed parts are made. Abacus does not have a library of materials, so the user must enter the physical constants of the materials. Also in this module, the user must create a section from the defined material and then assign it to the relevant part. Defining a profile for beam elements and defining a local coordinate system for non-isotopic materials should also be done in this module.

- Assembly module

In this module, the user can assemble the parts designed in the part module. To do this, tools are embedded in this module. In fact, in this module, the user determines the initial state of the system before loading or before applying the initial conditions.

- Step module

In this module, the user determines the type of analysis or analyzes that should be performed on the assembly set. This is done by defining steps or steps. The steppes in Abacus are divided into two general categories: steppes that perform linear analysis and steppes that perform nonlinear analysis. By selecting the step, the user determines the solver of his model. The solver of all linear steppes is "abaqus / standard" and the number of steppers whose solver is "abaqus / standard" is far more than the number of steps whose solver is "abaqus / explicit". An analysis can contain one step or more. The type of problem and the modeling strategy determine the number of steps. Also in this module, you have to specify the model outputs. In Abacus, two types of output can be defined: "field output" and "history output". In this module, the user can change the settings related to Abacus nonlinear solvents or enable the feature related to the "sequential analysis" or "ALE" technique.

In *Abaqus*, unlike physics (which is reached from force to stress and then to strain), by calculating the acceleration of nodes and derivation, we reach speed and displacement from speed and from displacement to strain and from strain to stress and force. The difference between "explicit" and "implicit" analysis is in how the nodes accelerate.

- Interaction module

In this module, the user can define interactions (such as contact), the physics governing interactions (such as with or without friction), and constraints on the problem (some parts are rigid). Also, the definition of initial crack, seam, or point mass in this module must be done.

- Load module

In this module, the user must define boundary conditions, loads, and initial conditions (such as initial velocity or initial temperature).

- Mesh module

In this module, the user must mesh all the parts in the assembly set (except for the analytically rigid parts that do not need the mesh). In addition, you must determine the formulation and physics that the related elements solve.

- Optimization module

This module is used for optimization issues. Of course, the capabilities of this module are not extensive, and if you need to optimize the problem that Abacus uses to solve its finite element model, other methods will be used.

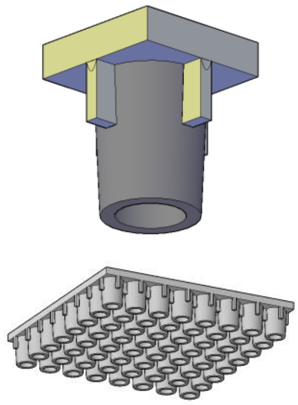
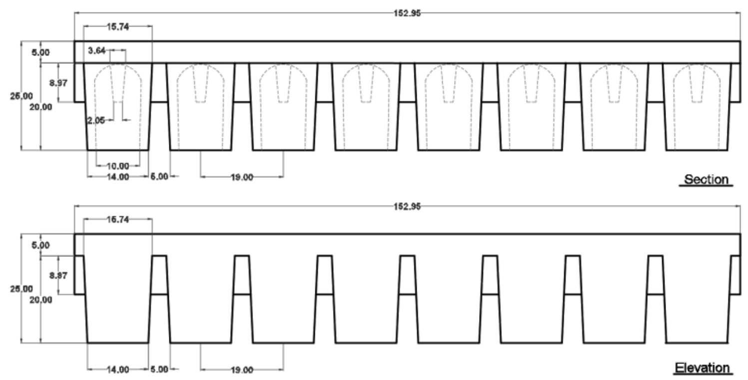
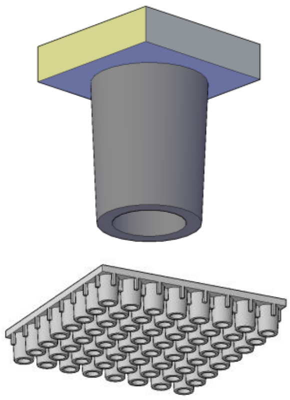
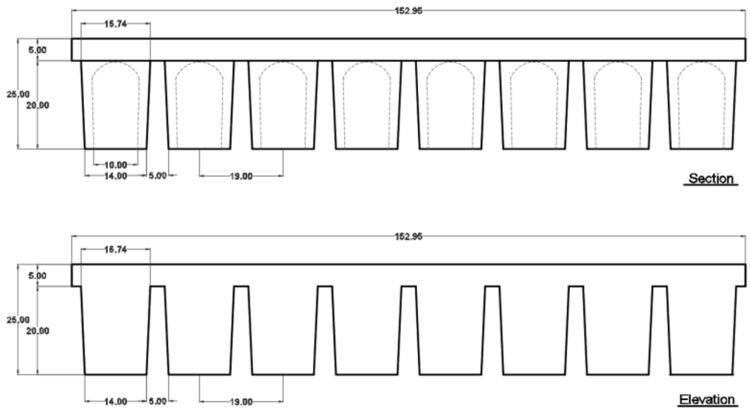
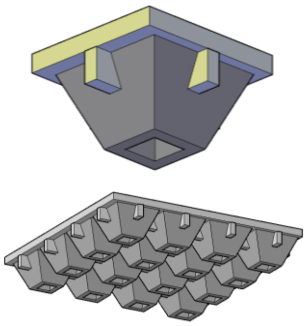
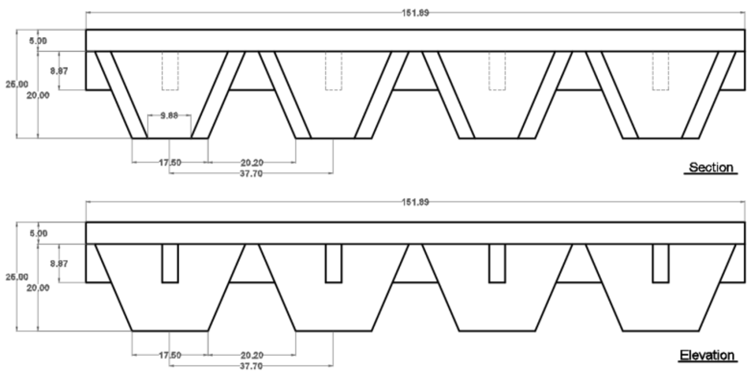
- Job module

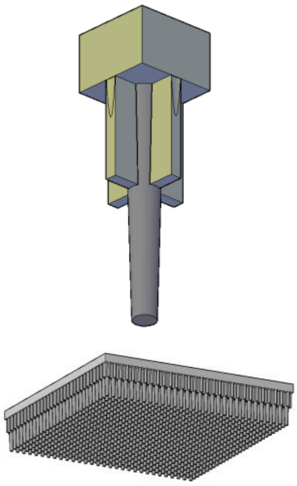
In this module, the user must define the created model, a so-called job or task for Abacus. The user can then instruct Abacus to start the solution by issuing a solution command (so-called "submitting the defined job"). This module can determine how much hardware power of the system used (laptop, pc or supercomputer) including "RAM" and "CPU" is involved in solving the model.

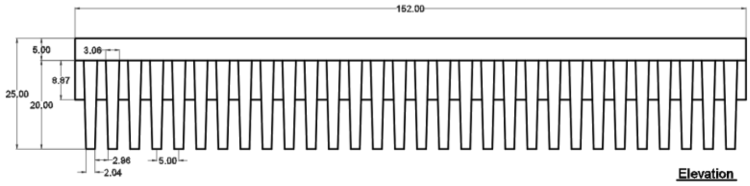
- Visualization module

This module is for viewing results. Regarding the output settings in the Step module, the user can view the recorded results at any time during the analysis. This module is also installed independently in the Abacus software suite and is the "abauqs / viewer".

3D display and detail about the geometry of the cells and structure of the proposed CF tiles with accurate dimension and 3D used in FE method:

3D of Cell use in CF tile	Section and Elevation of CF tile
	
	
	

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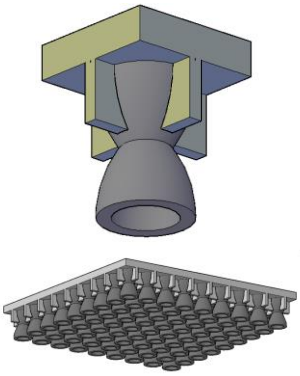
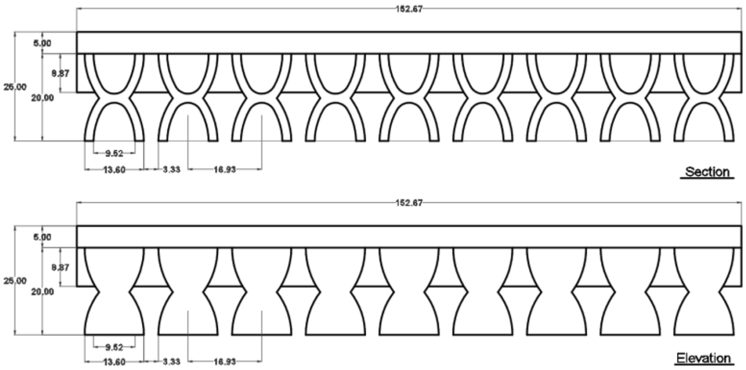
5.00
3.06
8.87
25.00
20.00
2.96
5.00
2.04
Elevation




152.67
5.00
8.87
25.00
20.00
9.52
13.60
3.33
16.93
Section
152.67
5.00
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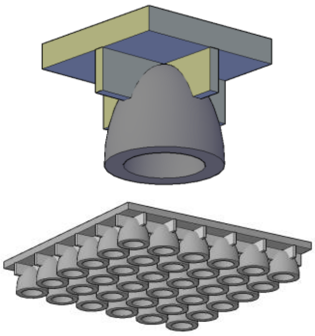
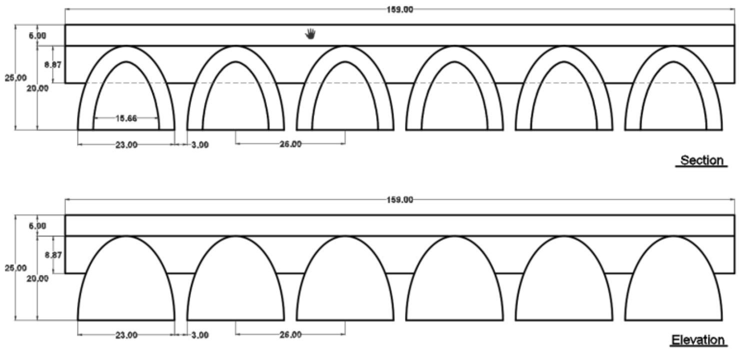
3.33
16.93
Elevation

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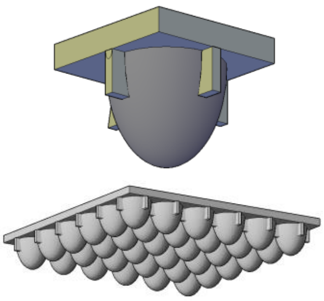

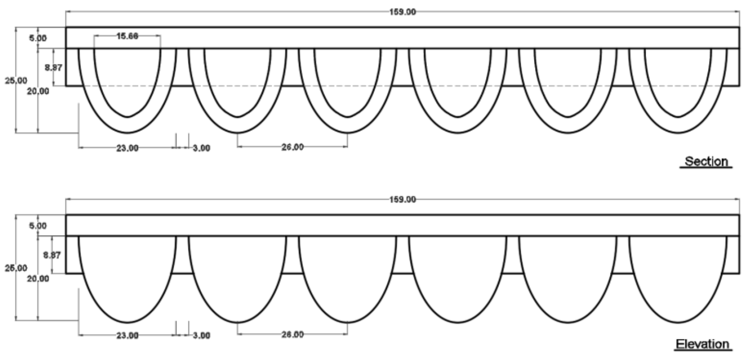
159.00
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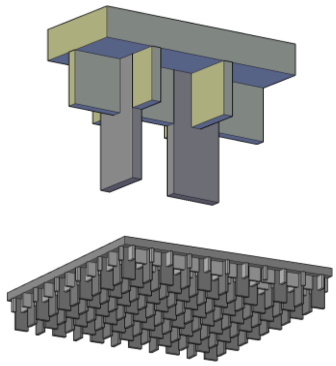
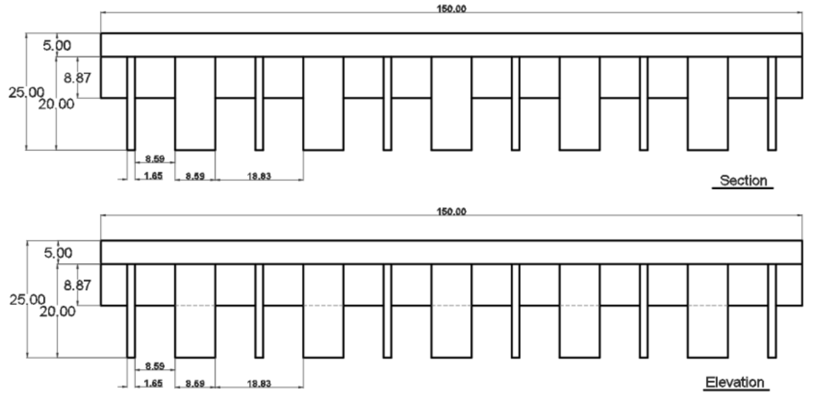
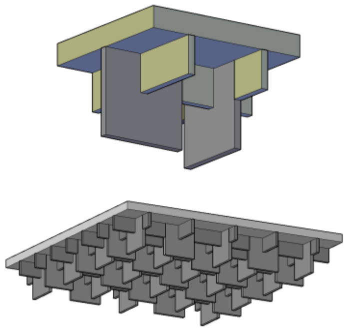
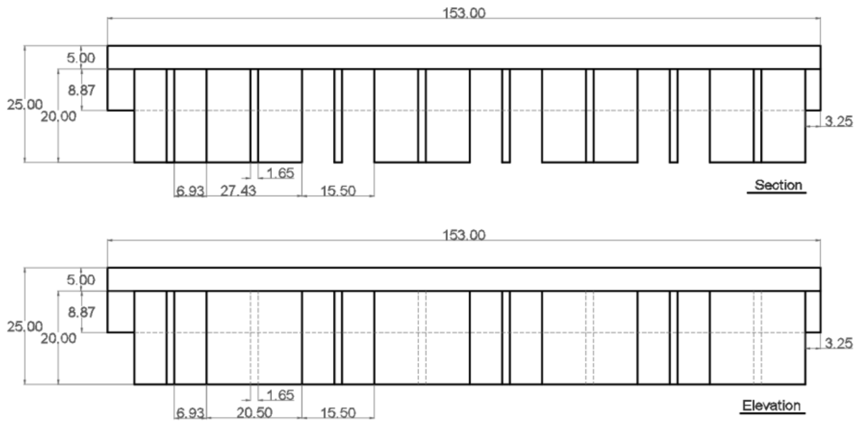
Elevation

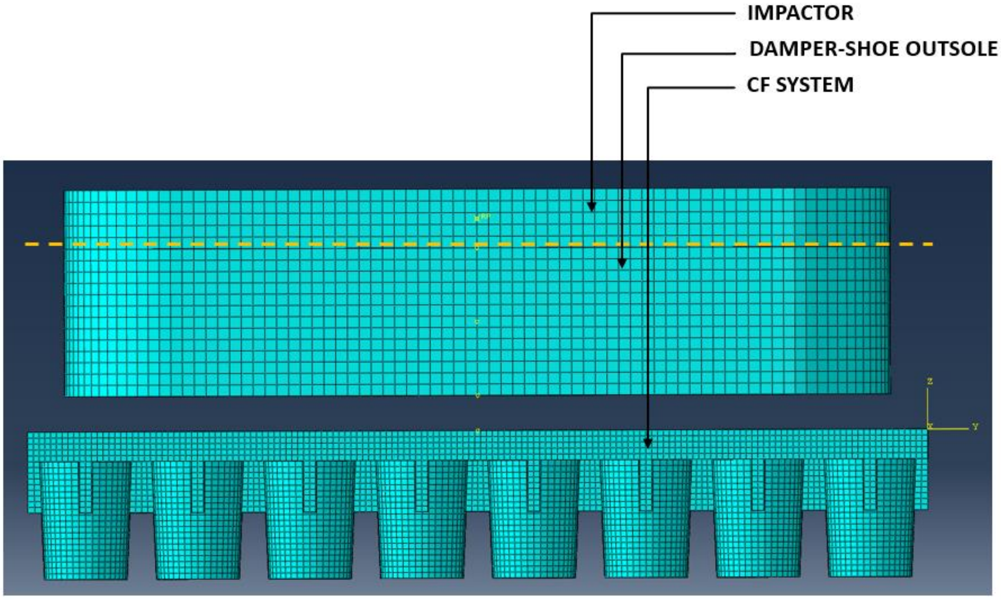




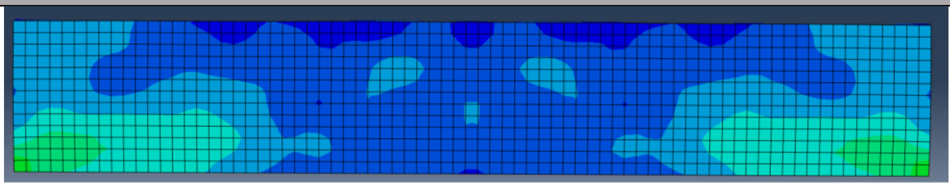
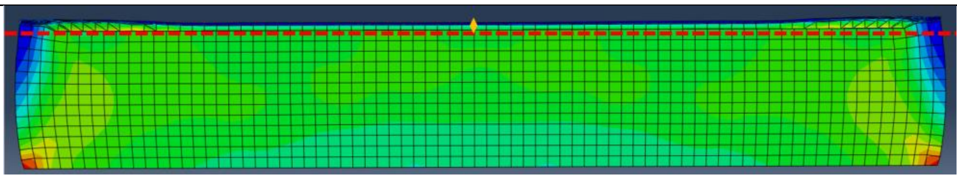
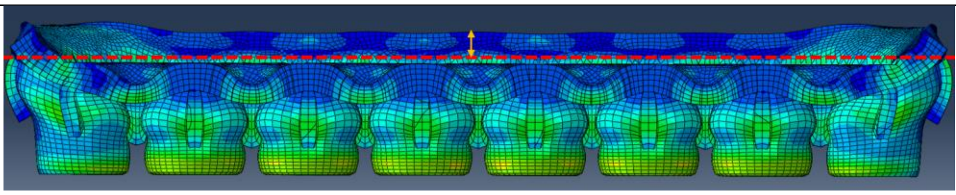
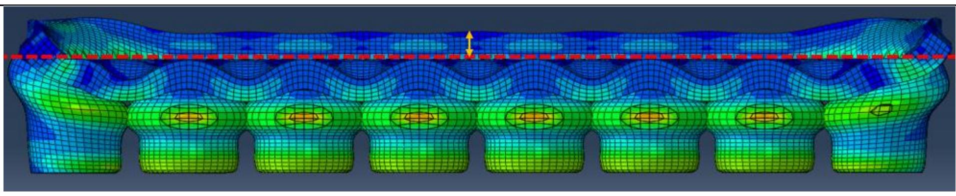
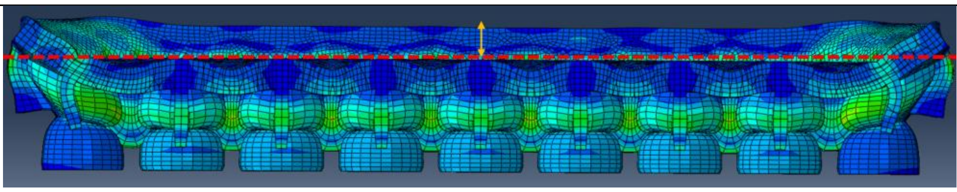


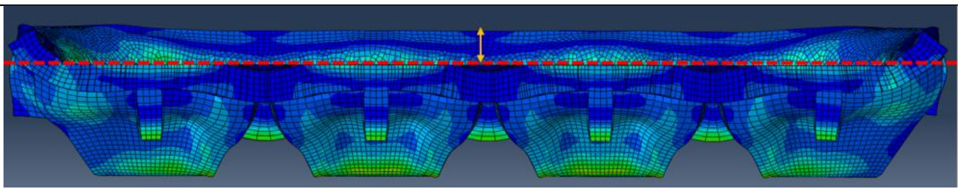
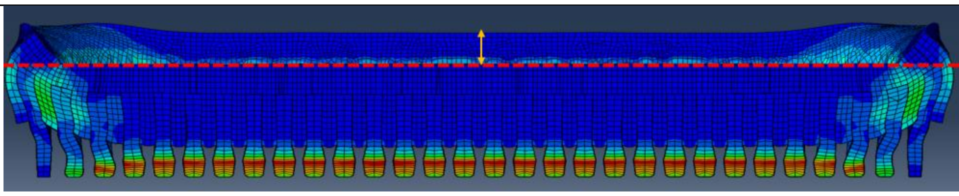
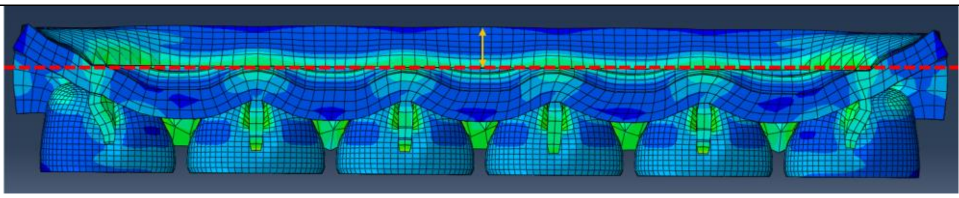
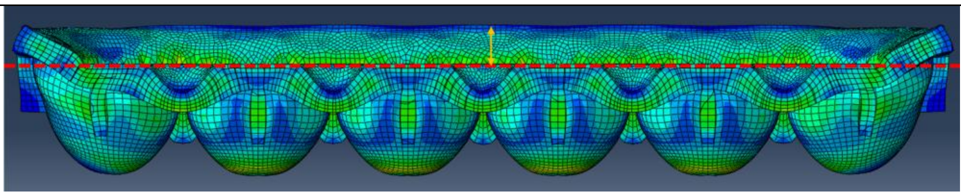
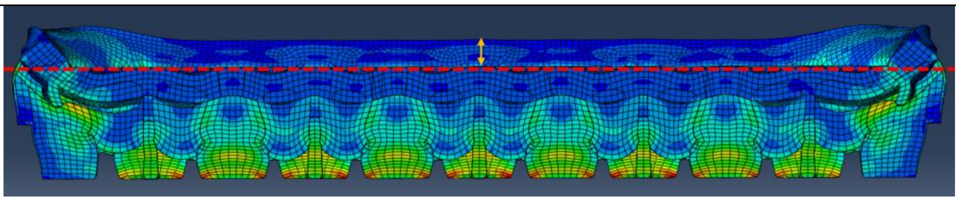
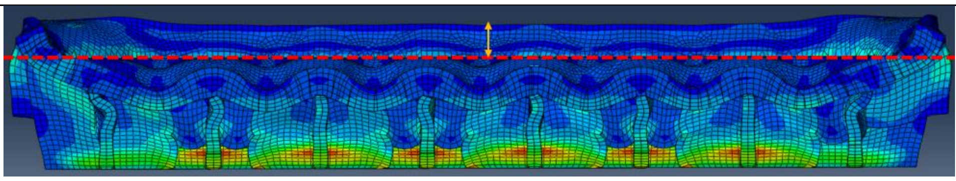


Simplify jump simulation in FEM - graphical display:



Graphical display of vertical displacement and force changes in CF tiles during impact:

Velocity: 3000mm/s		
Tile	FORCE (N)-Graphical Transformation	DISPLACEMENT (mm)
SOIL	 3866	D<1
Solid Rubber	 2149	D<3.5
CF-Cylinder	 1698	6.41
CF-Cylinder-without stiffener	 1481	7.40
CF-Hourglass	 1888	6.70

CF-Pyramid	 1732	6.34
Pin	 1656	5.90
CF-Dome 1	 1660	5.10
F-Dome 2	 1613	6.33
CF-Rectangle	 1663	6.45
CF-Square	 1617	6.36

List of mechanical and physical information about Cork, Marble and SB Rubber:

Properties	**Unit**	**Marble**	**Cork**	**Styrene-Butadiene Rubber -SBR**
Density	Kg/m^3	2720	180	950
Abrasion weight loss	%	0.20		
Hardness				Shore 50 A
Abrasion resistance	Mm	1.17		
Compressive (crushing) strength	MPa	540	1.0	15
Compression modulus	MPa		6.0	
Impact resistance	Cm	63		
Flexural strength	MPa	7		
Modulus of rupture	MPa	7		15
Elastic (young's ,Tensile) modulus	MPa	5400	20.0±1.0	1
Poisson's Ratio		0.2	0.0	0.48
Yield stress	MPa		0.51±0.05	
Hexagonal boron nitride – HBN	MPa		1.20±0.05	
Tensile Strength	MPa	9.0	0.75	14
Shear modulus	MPa	2700	5.9 10	0.7
Shear strength	MPa		0.9	2.2
Elongation at Break	%		15%	530%
Dielectric strength (breakdown potential)	KV/m	8.5		
Stiffness to weight: bending	points	47	60	
Strength to weight: bending	points	3.6	13	11
Bending strength	MPa	12.10		

FIFTHE TEST – SLR-T

The rules and standards of the restrictions defined for the verification of floors are given in the table below. The test was conducted with a specific device with a pendulum piece that works based on the coefficient of friction. The test was conducted in two main areas of wet and dry and the results were verified in four main classes.

Slip Resistance Test -Classification of floors according to their slipperiness- Technical Building Code (CTE), Section SUA-1. Photos during Slip Resistance pendulum test on site:

Slip Resistance Pendulum Test -28.06.2019

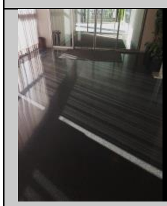
According to the Technical Building Code (CTE), Section SUA-1 SECURITY AGAINST RISK OF FALLS, carrying out the test of resistance to slip/slip of pavements (USRV) with the wet surface with abundant water as indicated by the UNE ENV 12633: 2003, the following classification is available:

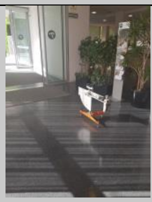
The class required for the floors according to their location	
Location and characteristics of the floor	Class
Dry interior areas - surfaces with a slope less than 6% - surfaces with slope equal to or greater than 6% and stairs	- 1 2
Wet interior areas, such as entrances to buildings from outer space *, covered terraces, changing rooms, bathrooms, toilets, kitchens, etc. - surfaces with a slope less than 6% - surfaces with slope equal to or greater than 6% and stairs	 2 3
External areas. Swimming pools**. Showers	3
*Except in the case of direct access to areas of restricted use. **In areas provided for barefoot users and at the bottom of the vessels, in areas where the depth does not exceed 1.50 m.	

Applus Company-WESSEX Slip Resistance Pendulum device

Classification of floors according to their slipperiness		**Result:** *Red: Failed *Green: Passed
Slip resistance Rd	**Class**	
Rd ≤ 15	**0**	
15 < Rd ≤35	**1**	
35< Rd ≤45	**2**	
Rd > 45	**3**	





Residence Entrance-Ground floor-10

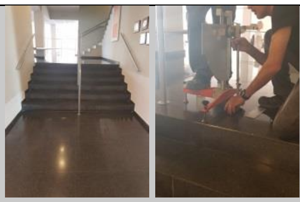
Class2-35<Rd≤45


Corridor- Lift- Ground floor-10

Class1-15<Rd≤35

Lobby-Ground floor-10

Class2 - $35<Rd\leq45$



Stair-Ground floor-10

Class2 - $35<Rd\leq45$

Bath Room-Ground floor-8

Class2 - $35<Rd\leq45$

TV Room-Ground floor-10

Class1 - $15<Rd\leq35$

Ramp between Apartment and Residence Section-First floor - Terrazo: 9 and Anti-slip band: 35- **(6→ 10.51%)**

Class2 - $15<Rd\leq35$

*Although the bands passed the test the whole ramp is still slippery

Dining Room-First floor → 15-Vinyl

Class1 - $15<Rd\leq35$

Residence Room116-117-first floor

Class2 (Bath.R) - $35<Rd\leq45$ → 20

Class 1 (Living. R)- $15<Rd\leq35$→ 10

Dining Room-Second floor- 12

Class1-$15<Rd\leq35$

Dining Room-Third floor- 10

Class1 - $15<Rd\leq35$

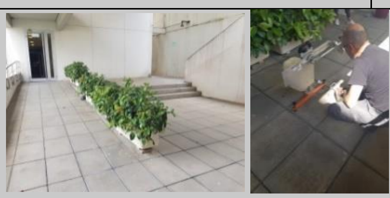
Dining Room-Fourth floor - 11

Class1 - $15<Rd\leq35$

Physiotherapy Salon-First floor - 12
Vinyl

Class1 - $15<Rd\leq35$

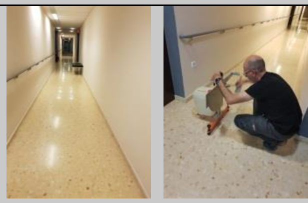
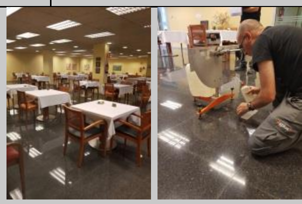
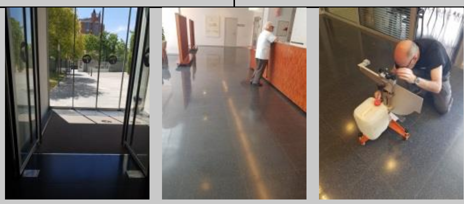
Corridor in front of the physiotherapy salon- First floor - 12



Ramp in patio between Apartment and Residence Section-First floor - 39
concrete 60x40am- **(4→ 6.99%)**

Swimming pool- Second floor - 15

Ceramic 25x25cm

<table>
<tr><th>Class1 - 15<Rd≤35</th><th>Class2 - 35<Rd≤45</th><th>Class3 - Rd>45</th></tr>
<tr>
<td>
Gym- Second floor - 15- Vinyl
Class1 - 15<Rd≤35</td>
<td>
Club- Second floor - 10- Terrazzo 60x40cm
Class1 - 15<Rd≤35</td>
<td>
Corridor in Apartment Section-Third floor - 12 - Terrazzo 40x40cm
Class1 - 15<Rd≤35</td>
</tr>
<tr>
<td colspan="2">
Apartment Unit-Third floor (Living.R, Bath.R)
Bath Ceramic 5x5cm: 20 - Class2 - 35<Rd≤45
Living.R Terrazzo 40x40cm: 10 - Class1- 15<Rd≤35</td>
<td>
The dining room of Apartment Section-Ground floor-Terrazzo 60x40cm - 13
Class1 - 15<Rd≤35</td>
</tr>
<tr>
<td colspan="3">
Apartment Entrance-Ground floor - Terrazzo 60x40cm - 10
Class2 - 35<Rd≤45</td>
</tr>
</table>

APPENDIX E - SOLID MECHANIC AND ELASTOMERS

MECHANISM OF WALKING

The complex structure of the human beings' foot as a column has a significant role in locomotion and balance in constant contact with the ground. (Gray, 2008) (Moore, 2018). The foot can tolerate high tensions and provide enough flexibility and resilience. The different footwear designs in females and males are the various physical and muscular parameters in them. With increasing age, the difference in these parameters also increases. The musculoskeletal system for males provides approximately 40% and for females about 23% of body weight. Dimensional parameters increase by age. The average female foot may be thinner and slender than the average male foot. Females have a narrower heel than the forefoot (Steele, 1976) (Murphy, 2005). Although the contact area of the foot is different, there are no notable differences in the peaks of plantar pressure. (Putti AB, 2010). The gait cycle (Figure 0-2) is separated into two phases—the support phase, which response to 60% of the velocity, and the balance phase, corresponding to the remaining 40%.5. A gait is marked by the initial contact of the foot made by the heel on the floor and ends when the same foot contacts the floor again by the most lateral region of the foot sole and toes. (Novacheck, 1998)

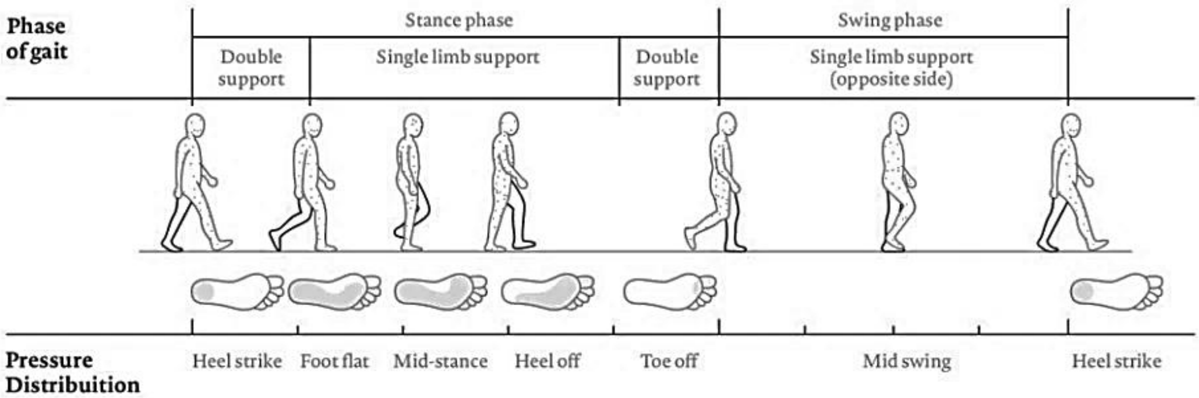


Figure 0-2. Gait cycle phases and pressure distribution, adapted from Standing (Gray, 2008).

Flexible or soft surfaces may impact human balance during walking or standing. A recent study by Patel et al. (Patel M. P.-A., 2008) on three types of firm foam, medium foam, and soft foam results that body mobility variance increased considerably when standing on all kinds of foam surfaces compared with the rigid surface. Foam reduced the ability to apply accurate corrective reactions due to its visco-elastic essence. However, the properties of the foam can considerably change body mobilities during activities. Movement variance was larger on the firm foam on the standing position compared with the softer foams. It is also found that the body mobility pattern differed when standing on foam and rigid surfaces, with larger reliance on movements at the knee to give postural stability on foam than on the rigid surface. Findings indicate that modified mechanoreceptive information might not only contribute to the significant decrease of postural stability on foam. He noted that foam decreased the ability to precisely detect stress and force distribution and body orientation (MacLellan, 2006)

SOLID MECHANICS OF MATERIAL

Any material has specific mechanical and physical properties that help engineers use proper material in their design. Any object may deform after applying force, but the object's reaction depends on the material properties and the amount of applied energy. The deformation in materials can be elastic, plastic, or lead to a fracture. Elastic behavior means that the object returns to its primary form after the force is removed. Still, if the force continues more than the materials yield strength, it will entail plastic deformation, which is a permanent deformation that never back to the original shape after unloading. Insisting on more force may entail a fracture, which means that the object tears or breaks into pieces. Stress and Strain (Chawla, 2012) following equations are common expressions in solid mechanics measured by tensile test[2].

Stress (σ) is defined as a force (F) applied per unit area (A). The unit of stress is Pascal (Pa) or N/m^2.

$$\sigma=\frac{F}{A} \qquad 0.7$$

Strain (Ɛ) is determined as the amount of deformation gained by the body in the direction of force applied (change in length δ), divided by initial dimensions/length of the body (L). the strain is a dimensionless quantity and has no unit.

$$\varepsilon=\frac{\delta}{L} \qquad 0.8$$

Modulus of Elasticity or Young´s modulus (E) is used to describe the properties of the material ([N/m^2] or [Pa]) and a criterion for defining and measuring the stiffness of solid materials. It is the ratio between stress and strain, and the relationship is also called Hooke´s law. Hooke's law is only valid for linear-elastic materials.

$$E=\frac{\sigma}{\varepsilon} \qquad \sigma=E\varepsilon \qquad 0.9$$

$$k=\frac{F}{d}$$

k is stiffness F is the force on the body d is the displacement produced by force along the same degree of freedom

Young's modulus (modulus of elasticity-MOE) is one of the most significant mechanical properties in building materials utilized to assess the material's proportion and mechanical consistency. The elastic moduli are divided into static and dynamic moduli. (Martínez-Martínez, 2012)

Dynamic moduli (E_d) is a property of the viscoelastic materials and usually refers to the elastic stiffness that can be deduced from elastic wave velocities combined with density. Dynamic modulus is sometimes known as complex modulus, is the ratio of stress to strain under vibratory situations calculated from data obtained from either free or forced vibration tests in shear, compression, or elongation. (Sabbagh, 2002)

$$E_d = 0.9465(m \int_t^2 /b)(L^3/t^3)T_1 \qquad 0\text{-}10$$

m: mass of the bar *ft:* fundamental frequency of the bar in flexure *b:* width of the bar

L: Length of the bar *t:* thickness of the bar

T_1*:* correction factor for a fundamental flexural mode to account for finite thickness of the bar, Poisson's ratio, and other constants

Static moduli (E_{st}), refers to the elastic stiffness that relates deformation to exerted stress in a quasi-static loading condition. The slope of the stress-strain curve shows the static moduli. (Fjær, 2019) The evaluation of the static elastic moduli is carried out using the standard method UNI9724 uniaxial

[2]Tensile testing, also known as tension testing, is an engineering test process in which a sample is subjected to a controlled tension until failure. It provides information about the tensile strength, yield strength, and ductility of the metallic material.

compression machine on specimens along with longitudinal and transverse strain gauges. (Ciccotti, 2004).

$$E_s = FL^3/4bh^3d \qquad \text{0-11}$$

F: load *l:* distance between the support *b:* width of the bar *h:* thickness of the bar

d: deflexion corresponding to load F

Poisson ratio (V) is a measure of the Poisson effect. If the material is compressed in one direction, it is normally willing to extend in the direction perpendicular to the direction of the compression force. Poisson's ratio is nearly 0.3 for metals, 0.35 for polymers and 0.5 for elastomer materials (*mm/mm* or *cm/cm*)

$$v = -\frac{Strain\ in\ direction\ of\ load}{Strain\ at\ right\ angle\ to\ load} \qquad \text{0.12}$$

$$v = -\frac{\varepsilon_{lateral}}{\varepsilon_{axial}} \qquad \text{0.13}$$

Hardness (Pascal or N/m^2) is a physical property that measures the material's ability to resist localized plastic deformation, penetration, indentation, and scratching under loading. (Okan J.-S. S., 2015). The most common scales of shore durometer[3] are ASTM D2240 used for type A and type D, for softer (0) and more rigid materials (100), respectively (Intertek, 2019). Equation (0.14) demonstrates the relation between the ASTM D2240 hardness and Young´s modulus for elastomers, where E is Young´s modulus in the unit [*MPa*] and S is the *ASTM D2240* type A hardness, or shore-hardness (Gent A. N., 1958.).

$$E = \frac{0.0981\ x\ (56 + 7.62336\ x\ S)}{0.137505\ x\ (254 - 2.54\ x\ S)} \qquad \text{0.14}$$

Young's modulus is proportional to hardness regardless of the type of material. But it must be noted that more brittle materials need higher Young's modulus and hardness to achieve the same tensile strength. In general, materials classified in three main groups (Figure 0-3) stress and strain curves for brittle, hard (but not ductile), and plastic materials are different:

[3] A shore durometer is a device typically used to measure hardness in materials such as polymers, elastomers, and rubbers.

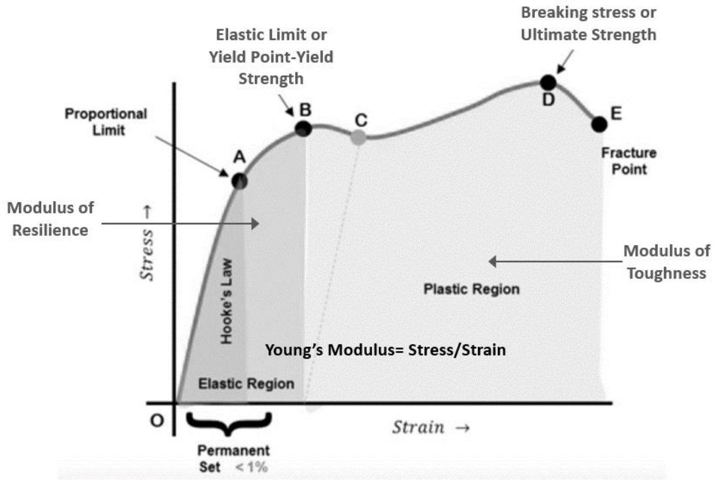


Figure 0-3. Stress and Strain diagram of material[4] - Elastic region shows the resilience of the material (With a few corrections in the figure by the author)

Ductile materials show substantial plastic deformation under external loading before failure. The strength is small in Ductile materials, and the plastic region is great under tensile stress. They tolerate more strain (deformation) before failure includes aluminum, gold, silver, and copper.

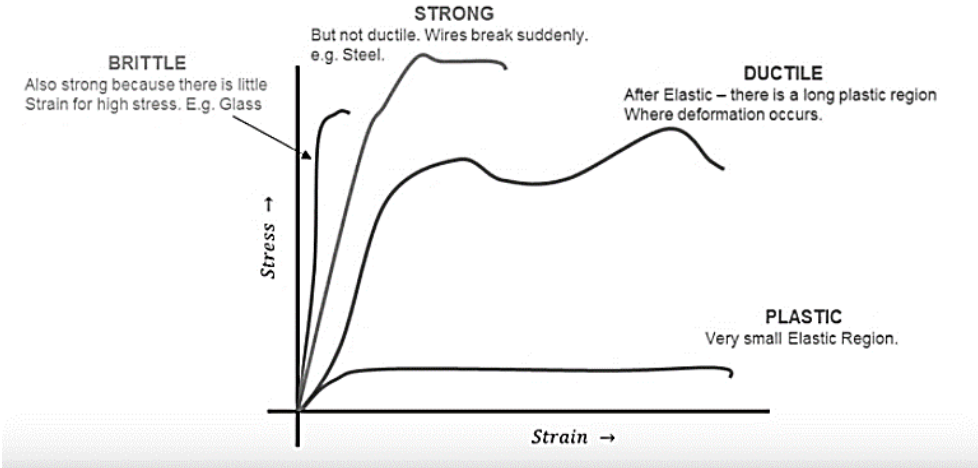


Figure 0-4. Stress-Strain curves of the material[5].

Brittle materials in brittle materials, the plastic region is small, and the strength of the material is high. Bone, cast iron, ceramic, stone, and concrete are examples of brittle materials.

Elastomeric materials extend after stretching and return to the original state and shape quickly once the loaded is removed like rubber and other polymers (Figure 0-4).

[4] https://www.scienceabc.com/innovation/what-is-the-stress-strain-curve.html
[5] https://www.quora.com/If-a-stress-strain-graph-does-not-pass-through-the-origin-then-on-which-side-should-a-correction-be-applied-stress-or-strain

ELASTOMER MATERIAL-RUBBER

Rubber as an Elastomer Material has good viscoelasticity and relatively weak intermolecular forces. Thermoplastic elastomers (TPEs) materials are widely used in sports equipment to absorb impact. Elastomer materials have a low Young's modulus and very high elongation at fracture points compared with other polymers (Nunes, 2000).

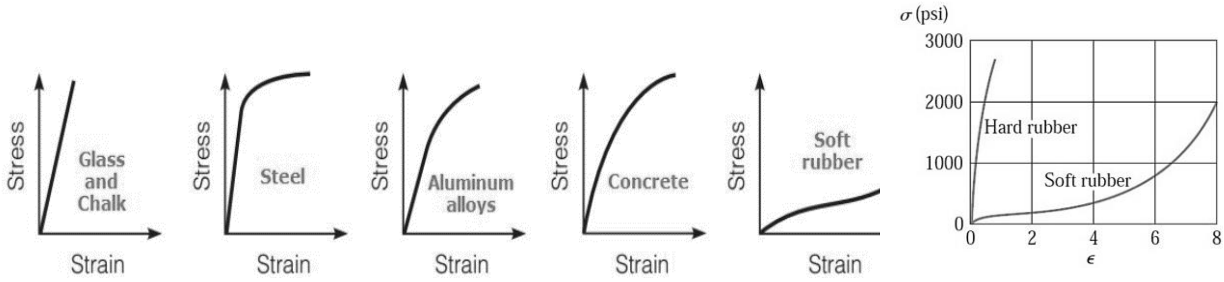


Figure 0-5 Typical uniaxial stress-strain diagrams for some building materials[6]

Rubber is an excellent example of hyperelastic materials far beyond the proportional limit. As it shows in a stress-strain diagram for rubber in Figure 0-5, the stress-strain chart remained linear for a partly high strain amount of 0.1 to 0.2 at the proportional limit. For instance, some kinds of soft rubber will tolerate great elongation without failure, but hard rubber will oppose the load with minimal stretching. Hence the curve in the diagram will relatively go up sharply. It can easily sense this characteristic treatment by stretching a rubber band. The criteria for the classification of elastomeric materials are very diverse, although none of them is accepted. Often, materials of the same category require quite different properties depending on the type of application. Natural rubber without fillers displays minimal hysteresis.

Consequently, it presents energy dissipation or damping in a system exposed to vibrational forces. Unlike steel, rubber has an Intrinsic damping ability. On the other hand, elastic and viscous features of rubber cause inherent damping, deflection capacity, and energy storage. Also, the rubber reduces the low-frequency vibrations because of the viscous damping properties. Rubber is described by high elasticity and viscosity. The interplay across rubber molecules prevents the movement of molecular chains and presents viscous properties.

Rubber has high linear flexibility. It can be broken without losing its elasticity in excessive stretch mode, and it has a high resistance to intermittent stress without fatigue. Rubber has the same character as water. It is Non-compressible. Its volume remains the same against compression and only causes elastic deformation. Rubber has a much higher compressive strength than tensile strength. Rubber can usually be stretched up to about six times its length (HoanIsolator, 2019). The natural oscillation frequency of the tire is not the same during tension or compression because of the rubber long-chain molecular structure (Kasatochkin, 1952) (can block vibration, absorb shock, sound insulation, and cushioning functions. That's because of damping and excellent reversible deformation properties (Chandrasekaran, 2017) (Silva, 2009).

[6]https://mycourses.aalto.fi/pluginfile.php/272892/course/section/60458/Lec01_Properties_of_building_materials.pdf

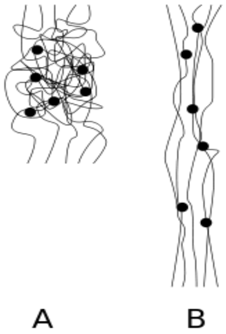


Figure 0-6. Relationship between molecular chains in an elastomer material- (A) is an unstressed polymer; (B) is the same polymer under tensile stress. After removing the stress, the object will return to the initial A configuration[7].

Hysteresis loop[8]: The area between the stress-strain curve during loading and removing the load is called the hysteresis loop. If we have two rubber tires with different hysteresis loops, then rubber B should be used to make the car tires. The area under the curve, i.e., work done in rubber "B", is lesser. Hence, the car tire will not get excessively heated. Rubber "A" should be used to absorb the vibration of the machinery because of the larger area of the curve, a large amount of vibrational energy can be dissipated (Figure 0-7). Different densities affect young's modulus and displacement behavior after applying force (Verdejo, 2004) Figure 0-7 (D & E).

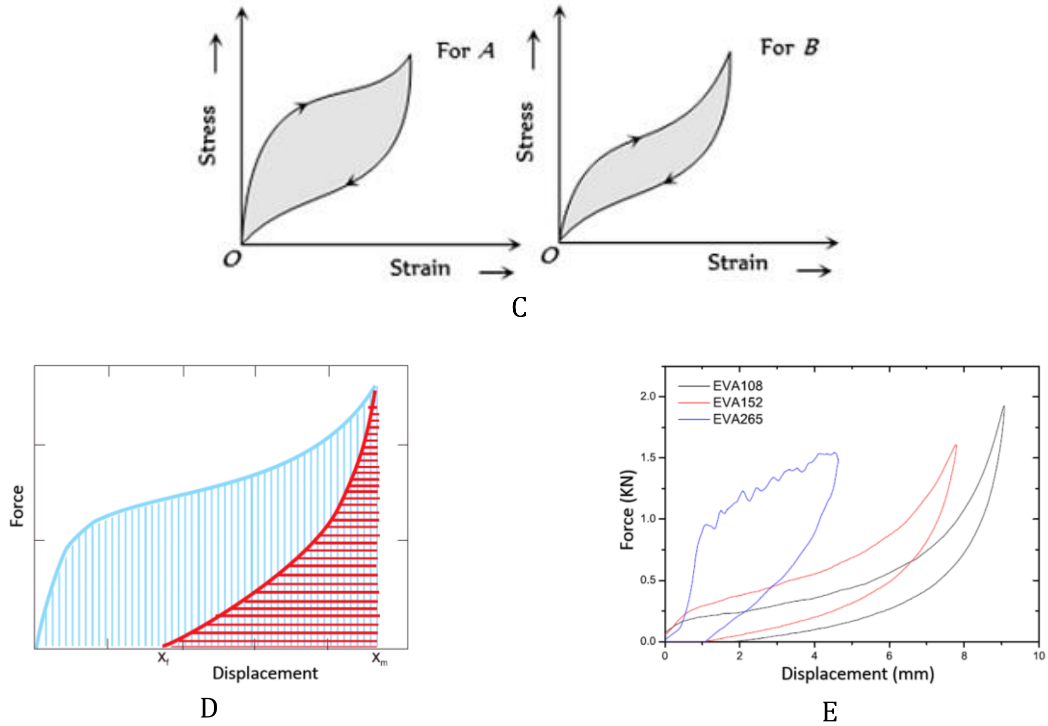


Figure 0-7. loading and unloading diagram of Rubber[9] (C), Force-displacement curve where the vertical lines correspond to Ei and the horizontal lines to Er (D), Force-displacement behavior after impact in different EVA foam with different density[10].

[7] https://en.wikipedia.org/wiki/Elastomer

[8] the area in the centre of a hysteresis loop is the energy dissipated due to material. As it is numerically equal to the work done in loading the material and then unloading it.

[9] https://www.embibe.com/study/elastic-hysteresis-concept#Description

[10] https://etheses.bham.ac.uk/id/eprint/231/

Ei is the impact energy *Er* is the recovery energy[11]

$$E_i = \int_0^{x_m} F dx \quad 0.15$$

$$E_r = \int_{x_m}^{x_f} F dx$$

x_m is the maximum displacement x_f is the remaining displacement of the foam once the exerted force returns to zero.

$$E_a = E_i + E_r \quad 0.16$$

Ea is the absorbed energy (Richardson, 1985)

Elastomers have an extremely non-linear mechanical behavior, defined by hyperelastic deformation. The stress-strain relationship in uniaxial tensile states does not comply with Hooke's law, and, except in the case of minor strains, it is not possible to assign a defined value of Young's modulus (Glazoff, 2018). After loading and subsequent unloading, a loaded elastomer does not usually recover its initial state corresponding to the natural stress-free configuration (Kim T. K., 2011) but instead acquires a residual, inelastic deformation.

HYPERELASTIC MATERIAL

Polymeric or hyperelastic materials are widely utilized in sports floorings and insole of shoes due to their high ability to reduce the damage and severity of the shock waves that pass through the body system during activities (Silva, 2009).

An Elastic Material is a linear material. This means that the stress changes linearly concerning strain. This material, such as paper, metal, and wood, provided that the deformation is minimal.

Hyperelastic Materials or Green elastic materials are non-linear elastic materials with a viscoelastic behavior (Figure 0-8), isotropic, incompressible, and generally independent of strain rate. The elastic deformation can be extremely large. The macroscopic behavior in elastomer material is complex. It varies depending on the period of load application, the temperature, the vulcanizing, the historic loads, and the state of deformation. Hyperelastic materials are described in terms of a strain energy potential, U (ε), which defines the strain energy stored in the material per unit volume as a function of strain.

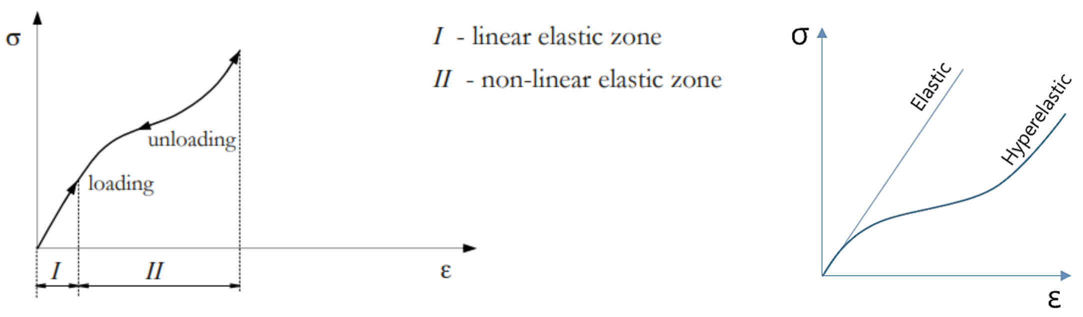


Figure 0-8. The stress-strain curve for elastic and hyperelastic materials[12].

[11] The energy of the loading and unloading cycle respectively.

[12] https://medium.com/@getwelsim/neo-hookean-hyperelastic-model-for-nonlinear-finite-element-analysis-16ac996aa507

They are designed for modeling foam, adhesive, rubber, rubber-like materials, and biological matter (arteries, muscles, skin, etc.) (Chaves, Hyperelasticity, Notes on continuum mechanics, Lecture Notes on Numerical, 2013). Hyperelastic material is elastic even at very high strains. Even if they are stretched to a maximum strain of say 700%, they return to the original shape and still recover the deformation when the applied load is removed without entering the plastic region, i.e., there is no internal energy dissipation (a reversible process). They show a highly non-linear relationship between stress and strain. Hyperelastic materials use a Strain Energy Density (Ψ) or the strain energy function (SEF) or the elastic potential to conclude the correlation between stress and strain. It should be mentioned that strain energy function (Ψ) is only dependent on the deformation gradient (F).

$$\Psi = \Psi(F) \qquad 0.17$$

Various hyperelastic models are accurate over a different range of strains. Depending on the expected range of strains, the formulation and the amount of data that have to be defined in the stress-strain are different (Muhr, 2005). More information about the mechanical test and hyperelastic models is given in appendix D.

APPENDIX F - MATERIAL

1- Polylactic acid (PLA)

Polylactic acid, or polylactic acid, or polylactide (PLA) is a thermoplastic polyester. It has become a popular material due to it being economically produced from renewable resources. Polylactic Acid (PLA) is different than most thermoplastic polymers in that it is derived from renewable resources like corn starch or sugar cane. Most plastics, by contrast, are derived from the distillation and polymerization of nonrenewable petroleum reserves. Polylactic Acid is biodegradable and has characteristics similar to polypropylene (PP), polyethylene (PE), or polystyrene (PS). PLA has the second largest production volume of any bioplastic (the most common typically cited as thermoplastic starch). Some of the most common uses include plastic films, bottles, and biodegradable medical devices (e.g. screws, pins, rods, and plates that are expected to biodegrade within 6-12 months). PLA bottle left in the ocean would typically degrade in six to 24 months. Compared to conventional plastics (which in the same environment can take several hundred to a thousand years to degrade) this is truly phenomenal.

Table 0-2 General characteristics of a commercial amorphous PLA, injection mold grade (96:4 L:D ratio content produced by NatureWorks Co (Shady Farah, Physical and mechanical properties of PLA, and their functions in widespread applications — A comprehensive review, 2016) [13]

Property	Value
Technical Name	Polylactic Acid (PLA)
Chemical Formula	(C3H4O2)n
Melt Temperature	PLLA: 157-170 °C
Heat Deflection Temperature (HDT)	49-55 °C at 0.46 MPa
Tensile Strength	PLLA: 59-66 MPa
Flexture Strength	PLLA: 48-110 MPa
Shrink Rate	PLLA: 0.37-0.41%
Solid Density	1.210-1.430 g/cm3
Melt Density	1.073 g/cm3
Crystallinity	37%
Tensile Modulus	2.7-1 GPa
Young's Modulus	1280 MPa
Yield Strength	70 MPa

[13] http://www.matweb.com/search/DataSheet.aspx?MatGUID=ab96a4c0655c4018a8785ac4031b9278

Poisson's Ratio	0.36
Shear Modulus	1287 MPa
Elastic Modulus	3500 MPa
Elongation at break	7%
Hardness	Shore D 59-77

2- Polypropylene (PP)

Polypropylene (PP) is a rigid and crystalline thermoplastic used widely in everyday objects like packaging trays, household products, battery cases, medical devices, etc. Explore this comprehensive guide and learn everything you need to know about this widely used thermoplastic. Polypropylene is a tough, rigid, and crystalline thermoplastic produced from propene (or propylene) monomer. It is a linear hydrocarbon resin. The chemical formula of polypropylene is (C3H6)n. PP is among the cheapest plastics available today. PP belongs to the polyolefin family of polymers and is one of the top three widely used polymers today. Polypropylene has applications both as a plastic and a fiber in:

1. Automotive Industry
2. Industrial Applications
3. Consumer Goods, and
4. Furniture Market

The follow table shows the Polypropylene Properties and Their Values:

Table 0-3 The Definitive Guide to Polypropylene (PP)[14]

Property	Value
Technical Name	Polypropylene (PP)
Chemical Formula	C3H6
Melt Temperature	200-300°C
Heat Deflection Temperature (HDT)	-
Tensile Strength	13.8 - 460 MPa
Flexture Strength	28.0 - 55.0 MPa
Flexture Modulus	0.650 - 3.20 GPa
Compressive Yield Strength	4.00 - 14.0 MPa
Shrink Rate	1-3%
Solid Density	0.9-0.91 g/cm3
Melt Density	-
Crystallinity	-
Tensile Modulus	20-40 MPa
Young's Modulus	1.1-1.6 GPa
Yield Strength	35-40 MPa
Poisson's Ratio	-
Shear Modulus	-
Elastic Modulus	0.680 - 3.60 GPa
Elongation at break	-
Hardness	Shore D 49-83

3- Polyethylene (PE)

Polyethylene is a lightweight, durable thermoplastic with a variable crystalline structure. It is one of the most common thermoplastic materials available today. It is used in applications ranging from

[14] https://omnexus.specialchem.com/selection-guide/polypropylene-pp-plastic

films, tubes, plastic parts, plastic containers, bottles, bags to plastic toys, laminates, etc. in several markets (packaging, automotive, electrical, etc.). Polyethylene is made from the polymerization of ethylene (or ethene) monomer. Polyethylene chemical formula is (C2H4)n.

Applications:

5. Packaging bottles & films
6. Medical and healthcare
7. Pipes, Hoses & Fittings
8. Households products/ Consumer Goods
9. Agriculture
10. Wiring & Cables

PE belongs to the polyolefin family of polymers and is classified by its density and branching. The most common types of polyethylene are:

11. Branched Versions
    - Low-density polyethylene (LDPE)
    - Linear low-density polyethylene (LLDPE)
12. Linear Versions
    - High-density polyethylene (HDPE)
    - Ultra-high-molecular-weight polyethylene (UHMWPE)
13. Cross-linked polyethylene (PEX or XLPE)

In addition, PE is also available in other types such as (not discussed in detail in this guide):

14. Medium-density polyethylene (MDPE)
15. Very-low-density polyethylene (VLDPE)
16. High-molecular-weight polyethylene (HMWPE)
17. Ultra-low-molecular-weight polyethylene (ULMWPE)
18. Chlorinated polyethylene (CPE)

The table below shows the difference between the three types of PP properties of LDPE, LLDPE, and HDPE. From physical properties, dimensional stability, electrical efficiencies to fire and thermal properties:

Table 0-4 Comparison Between Main Types of Polyethylene (PE)[15]

Property	Value		
Technical Name	Polyethylene (PE)		
Chemical Formula	(C2H4)n		
	LDPE (Low-Density Polyethylene)	LLDPE (Linear Low-Density Polyethylene)	HDPE (High Low-Density Polyethylene)
Melt Temperature	122–124 °C	110–120 °C	130 °C
Heat Deflection Temperature (HDT)			
Tensile Strength	-	-	-

[15] https://omnexus.specialchem.com/selection-guide/polyethylene-plastic/hdpe-ldpe-lldpe-comparison

Flexure Strength	-	-	-
Flexture Modulus	0.245-0.335 GPa	0.28-0.735 GPa	0.75-1.575 GPa
Compressive Yield Strength	-	-	-
Shrink Rate	-	-	-
Solid Density	0.917-0.94 g/cm3	0.915-0.95 g/cm3	0.94-0.97 g/cm3
Melt Density	-	-	-
Crystallinity	-	-	-
Tensile Strength	10-20 MPa	25-45 MPa	30-40 MPa
Tensile Modulus	0.130–0.300 GPa	0.266–0.525 GPa	0.500–1.100 GPa
Young's Modulus	0.13-0.3 GPa	0.266-0.525 GPa	0.5-1.1 GPa
Yield Strength	-	-	-
Poisson's Ratio	-	-	-
Shear Modulus	-	-	-
Elastic Modulus	-	-	-
Elongation at break	-	-	-
Hardness	Shore D 40-50	Shore D 55-56	Shore D 60-70

Though Polyethylene and Polypropylene are similar in physical properties but here are key points to consider to select the polymer suitable to demands.

4-Thermoplastic Polyurethane (TPD)

Polyurethane (PU) elastomer is a fundamental commercial thermoplastic elastomer that has been widely used in applications including automotive instrument panels, caster wheels, power tools, sporting goods, medical devices, drive belts, footwear, inflatable rafts, and a variety of extruded film, sheet or profile, outer cases of mobile electronic devices or keyboard protectors for laptops. (Defonseka, 2019) (lubrizol, 2021).Because of their excellent mechanical properties and comparatively good tissue and blood compatibility, it is also widely used in the field of biomedical applications such as vascular prostheses, pacemaker lead wire insulation, catheters, and artificial hearts and tissue engineering during the past few decades (Liu, 2005).

Table 0-5 The Definitive Guide to Thermoplastic Polyurethane (TPD)[16]

Property	Value
Technical Name	Thermoplastic Polyurethane (TPD)
Chemical Formula	-
Melt Temperature	15.6 - 60.0 °C
Density	1.28 - 1.66 g/cc
Heat Deflection Temperature (HDT)	51.0 - 199 °C
Tensile Strength	28.0 - 96.0 MPa
Flexture Strength	19.0 - 95.1 MPa
Flexture Modulus	0.520 - 4.50 GPa
Compressive Yield Strength	-
Shrink Rate	0.000400 - 0.00300 cm/cm
Solid Density	-
Melt Density	-
Crystallinity	-
Tensile Modulus	-
Young's Modulus	-
Yield Strength	52.4 - 79.3 MPa
Poisson's Ratio	-
Shear Modulus	-
Elastic Modulus	0.621 - 5.50 GPa
Elongation at break	-
Hardness	Shore D 55.0 - 83.0

[16]http://www.matweb.com/search/DataSheet.aspx?MatGUID=2fe782a31c4b4bed984b49651762b086&ckck=1

In addition, it must be mentioned that TPU is well known for its applications in wire and cable jacketing, hose and tube, in adhesive and textile coating applications (Avanzini, 2011).Also is used in high-impact resistant glass structures (TPU glass lamination Films). TPU is used in FFD fused filament deposition 3D printing and it is ideal for filament 3D printers when objects need to be flexible and elastic. TPU allows those filaments to be melted again by the 3D printer "extrusion" head and then cooled back into the solid-elastic piece (Omnexus, 2021). It should be mentioned that in addition to fillers and matrices, the compatibilizers also play an important role in the structure of a composite.

APPENDIX G - ACTIVITIES

Conference presentation: BBConstrumat exhibition 14-17.06.2019 - (https://www.construmat.com/en/)

Conference lecture: Mashhouria, Leila, Ximena Aguirre Suarezb, & Zamora i Mestre, JL (2019, June). Apply safe flooring in housing environments related to elderly. In Doctoral Conference of the Architecture, Building and Urbanism Technology program: Book of Minutes 2019 (pp. 4-9). Escola Politècnica Superior d'Edificació de Barcelona[17]. (Lacasta Palacio, AM (2019). Book of Proceedings of the 2nd Doctorate Day of the 2019 Architecture, Building and Urbanism Technology program - II Jornada de doctorado TAEU conference- 6Junio 2019) - (https://upcommons.upc.edu/handle/2117/173073)

Collaboration: Aguirre Suarez, X. (2019). In situ evaluation of the capacity of various pavements to absorb the impact derived from the fall of elderly residents in interior architectural environments (Master's thesis, Universitat Politècnica de Catalunya)[18] - (https://upcommons.upc.edu/handle/2117/171363)

[17] https://upcommons.upc.edu/handle/2117/173073
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