University of Alberta

Integrated Approach for Older Adult Friendly Home Architectural Design

by

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ABSTRACT

The concept of designing/modifying home environments plays an important role in maintaining safety for older adults. Poor staircase architectural design could contribute to increasing the risk of falling for older adults. This research provides an integrated evidence-based assessment of staircase architectural design to support independent living for older adults (65 years and older). The staircase assessment has been developed through dividing the staircase into four design elements: staircase geometrical design, handrail design, lighting, and step design. Each element is divided into a number of features that define its architectural design; for instance, step design is divided into four features: 1) going depth; 2) riser height; 3) nosing; and 4) steps finishing material. A rating factor is assigned to each feature representing how much it reduces the risk of falling for older adults based on previous evidence-based studies. Moreover, the aim of this research is to provide the proposed methodological approach to assess the staircase design and not the value or true meaning of the rating numbers. Different staircase types, shapes and architectural design are investigated and presented in this thesis. The proposed methodology for staircase assessment has been incorporated into a mathematical model that is represented through a decision tree analysis module called “Design Assessment Tree” (DAT). Case studies are presented in order to illustrate the effectiveness of the proposed methodology.

Acknowledgements

First, I want to thank God for providing me with the strength and the knowledge light that I needed to finish my research work.

I would like to express my deepest gratitude and sincere appreciation to my supervisors, Dr. Mohamed Al-Hussein and Dr. Belinda Parke, for their guidance and continuous support throughout all stages of this research.

Great thanks are due to my wonderful father, Khalil, and my wonderful mother, Suzan, who always believe in me, and I devote this work for both of them. Also, I want to thank my husband, Ahmed, for his encouragement and support all the way through this study.

CONTENTS

LIST OF TABLES

LIST OF FIGURES

CHAPTER 1: INTRODUCTION

1.1 Research Motivation

The older adult population (those aged 65 and older) formed 14.1% of the total Canadian population in 2010, which amounts to 4.8 million of a total 34 million people. The older adult population is projected to increase to 22.8% of the total population in 2031, and continue accelerating to 25.5% of the total Canadian population by 2061 (HRSDC 2011). In Alberta, the older adult population formed 10.5% of the total population in 2005, and is expected to reach 19.2% by 2026 (Turcotte and Schellenberg 2007). The same study reported that 7.9% of older adults aged 65 to 74 in Canada have mobility challenges and require physical support. This percentage increases to 22.9% for older adults aged 75 to 85, and it increases to 46.6% for those over 85 (Turcotte and Schellenberg 2007). This reality makes normal daily activities difficult for older adults and promotes the need for older adult friendly environment. This thesis refers to this group of the population (65 years and older) as older adults.

Climbing staircases is one of the daily activities that has been reported as being difficult for older adults and a cause of falling (Turcotte and Schellenberg 2007). Descending and ascending staircases contributes to 26% of falls, which means one out of four seniors are expected to fall on staircases (Scott et al. 2005); this creates a need to study the staircases as it leads to more than a quarter of falling incidents. Moreover, 70% of people who die in an accident on staircases are older adults 65 years and older (Health-Canada 2002). By improving staircase design, however, falls for older adults could be reduced (Haslam and Stubbs 2006; Roys 2001). This research focuses on developing a staircase assessment based on an evidence-based architectural approach to support older adults who are living independently in their homes.

1.2 Research Objectives

The objective of this research is to provide an evidence-based assessment for the staircase architectural design through investigating the risk of falling associated with staircase elements (staircase geometrical design, handrail design, lighting, and step design). This objective will be addressed through three phases:

a. Develop staircase elements and features analysis.
b. Build a rating system for staircase architectural design, represented by a mathematical model.
c. Develop the Design Assessment Tree (DAT), which represent a complete vision of different staircase design scenarios.

1.3 Thesis Organization

Chapter 2, the literature review, consists of three sections: 1) background on home design opportunities for older adults, which addresses three alternatives: home modifications, lifetime home design and smart homes; 2) background on falling for older adults on staircases; 3) background on staircases' architectural design and history. Chapter 3, proposed research methodology and implementation, consists of three stages: 1) develop staircase elements analysis constructed through four elements (staircase geometrical design, handrail design, lighting, and step design), followed by staircase feature analysis representing the division of each element, for example, the lighting element is divided into three features (illumination level, consistency of lighting amount, and lighting switches); 2) build a rating system for staircase design elements and features which represented by a mathematical model; 3) develop a Design Assessment Tree (DAT) to represent different staircase design scenarios. This chapter also includes case studies as an implementation of the developed rating system. Chapter 4, conclusion, summarizes the research, proposes the research contribution, and also recommends future areas of research.

CHAPTER 2: LITERATURE REVIEW

2.1 Introduction

This literature review provides a background on older adult friendly home architectural design to define an integrated staircase design that might reduce the risk of falling for older adults. This chapter consists of three subjects: 1. Background on home design for older adults, which discusses home modifications, life time home design and smart home opportunities. 2. Background on falling for older adults on staircases, which discusses the consequences of and the reasons for falling for older adults. 3. Architectural approach, focusing on staircase design and history, which discusses different staircase designs and shapes throughout history and their associated challenges.

2.2 Background on Home Design Opportunities for Older adults

Although some people age with significant health challenges, others have a relatively healthy life, depending on a number of factors, including their preferred life styles (Byerts et al. 1982; Martel et al. 2005). As a result of these different backgrounds, older adults experience varying degrees of sensory and mobility impairment which may increase their risk of accidents and falling (Rogers et al. 2004). This increased risk supports the need for a safe, aging-friendly environment (Edwards and Mawani 2006). In the context of this research, older adult friendly architectural home design is the design that ensures safety, comfort and accessible spaces (zones) so that older adults can live independently in their homes. The importance of independent living is supported by older adults' desire to avoid being "segregated" from their communities (Lawton 1986). Furthermore, in addition to being a place that provides shelter and comfort, a house may also become associated over time with one's family history and sentimentalities (Lanspery and Hyde 1997). Despite that older adults have a personal attachment to their homes, they are not completely satisfied with the current aging-friendly home modification methods. Bayer indicates that 21% of older adults believe that the current home modification philosophy will not improve their homes' aesthetic (Bayer 2000). In addition, most older adults do not feel comfortable with the home modifications in their houses, such as rearranging the furniture, or increasing the lighting level in different spaces (Lord et al. 2001). Older adult friendly architectural home design should thus focus on enhancing and respecting the original home style.

2.2.1 Home modifications, life time home design and smart homes

Although healthcare facilities play an important role in satisfying older adults accommodation requirements, 93% of older adults prefer aging at their own homes rather than moving to continuing care retirement communities, assisted living facilities, or other personal care facilities (Turcotte and Schellenberg 2007). This section discusses home design alternatives in order to accommodate older adults' desire to reside at home. These home design alternatives include home modification, life time home design and smart homes as follows:

1) Home modification, adapts the existing home to improve functionality for older adults by inserting new objects and adjusting the original design (Gitlin 2009). As growing independently is a genuine need for older adults (Butler-Jones 2010; Pynoos et al. 2009; Vander-Burg 2008), adapting the home environment (home modification), plays an important role in maintaining safety for older adults (Bakker 1999; Bayer 2000). The concept of home modification and its implementation has been applied by replacing or adding existing design elements, such as replacing the steps' finishing material with uniform, non-slip material (Pauls 1982; Templer 1992b), and adding a second handrail to each side of the staircase (Ishihara et al. 2002).

2) Life time home design, also known as flexible housing or universal design (DCLG 2008), is to build to meet future demand (Ostroff and Preiser 2001). This concept adapts the design environment to allow inexpensive adjustments related to aging-friendly design to be made in the future. Examples of life time home design include lowering the height of window sills and building non-structural walls which can be removed in the future to improve accessibility, such as the wall between the washroom and master bedroom, as shown in Figure 2.1 (Barlow and Venables 2004; DCLG 2008). Although Ostroff and Preiser (2001) argue that "Universal design is not yet a coherent and systematic approach to designing for people, it has many missing pieces in its complex jigsaw puzzle", lifetime home design is now an applicable concept for new home design, which is expected to suit the upcoming older adult generations (DCLG 2008).

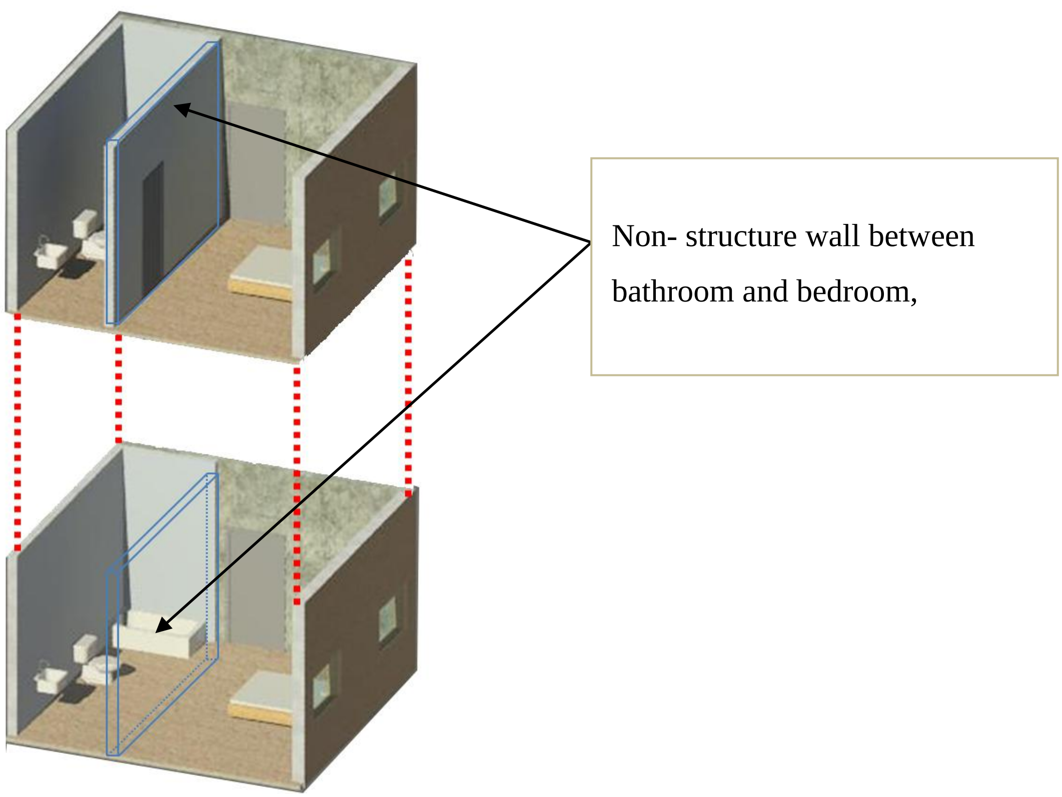


Figure 2.1 Design flexibility of the life time home design

3) Smart homes, involves inserting devices in an existing or new home which work as an internal network, such as sensors to control lighting and water outlet temperature controls (Demiris et al. 2004; Warren et al. 1999). Vertical mobility, movement up and down staircases, is a challenge for older adults, especially those with disabilities (Lord et al. 2001). One smart home application involves creating electromechanical devices for vertical movement, such as the independence IBOT mobility system, which is an electronic wheelchair which can climb staircases. However, these mobile robots are expensive and are still associated with technical challenges (Stefanov et al. 2004; Watanabe 2009). A cheaper alternative is the wheelchair staircase lift; however, the wheelchair staircase lift can be challenging to implement depending on the staircase design and the older adult's ability to independently manipulate the chair (Lorentsen 1995). Currently, the smart applications that are easily installed for staircase home modifications for a large sector of older adults are remote-controlled devices for staircase lighting. These devices could be applied to control doors and lighting in other home spaces, such as the bathroom (Stefanov et al. 2004).

2.3 Background on Falling for Older adults

As people age, the risk of falling increases; a minimum of 33% of older adults (65 years and older) living independently in their homes experience falling every year (Donald and Bulpitt 1999; Kannus et al. 1999; Scott et al. 2005). Approximately 1.4 million older adults experienced a fall at least once in 2005, and this number is expected to increase to 3.3 million older adults in 2036 (Scott et al. 2010). In addition to experiencing harm, older adults who fall might develop a Fear of Falling (FOF) that decreases their confidence and activity level (Rogers et al. 2004; Scott et al. 2005; Vellas et al. 1997). In this research, the risk of falling is defined as the probability of falling for older adults (Lord et al. 2001).

In addition to the possibility of developing a fear of falling, falling was the greatest cause of injuries in 2000/2001 (Turcotte and Schellenberg 2007), and caused the highest number of hospital admissions and emergency department visits due to injury in 2006 (ACICR 2009). Older adults with additional medical conditions, such as dementia, cancer, or heart disease, might experience a higher rate of falling (Rowe and Fehrenbach 2004; Turcotte and Schellenberg 2007). In addition, Voermans et al. (2007) mentioned that chronic diseases are frequently associated with older adults falling without preceding loss of consciousness or with transient loss of consciousness, such as cataracts or cardiac arrhythmias, respectively (Voermans et al. 2007). According to Statistics Canada (2009), approximately 63.7% of older adult Canadians are injured every year from falling. As illustrated in Figure 2.2, approximately 50% of older adults who fall experience minor injuries and from 5% to 25% experience major injuries; 37% of the injuries that are caused by falling are in the leg, including the hip (falling causes 90% of hip fractures for older adult Canadians), knee, ankle, and foot (ACICR 2009; Scott et al. 2005). The dangers of falling are further highlighted when one considers that most fall-related injuries in the older adult population result in death (Kannus et al. 1999; Rogers et al. 2004).

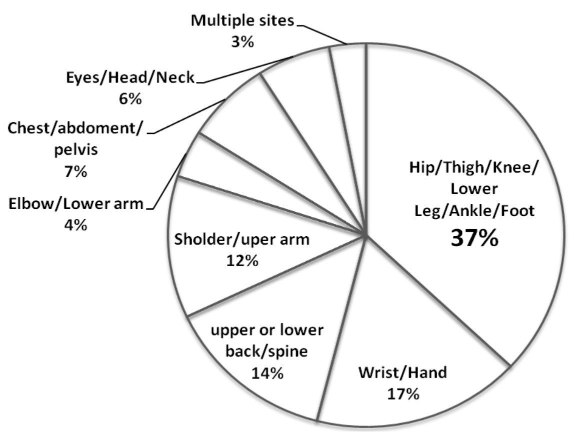


Figure 2.2 Injuries resulting from falls (Scott et al. 2005)

The reasons older adults fall could be related to either a) physical and/or psychological impairment, and/or b) the physical surrounding environment, and how older adults behave within that environment. The risk of falling for older adults has been found to increase with physical impairment, such as vision impairment and reduced muscle strength; and/or psychological impairment such as developing Fear of Falling (FOF) or loss of confidence because of health problems (Haslam and Stubbs 2006; Rogers et al. 2004; Vellas et al. 1997). Tinetti (2003) mentioned that physical problems, such as gait unsteadiness and decreased muscle strength, could be treated by a physical therapist or it might require the diagnosis and treatment of the underlying cause. One of the psychological problems that has been investigated recently is developing a fear of falling for older adults. A recent study by Oh-Park, M., et al. (2011) investigating the incidence of fear of falling for 380 participants aged 70 and older, found that as the risk factors increase, the number of older adults who gain fear of falling also increases. The risk factors in the previous study are represented by older adults' limitations, such as obesity, visual limitation, depression, and balance problems. This study concluded that further investigation and understanding of risk factors of developing the fear of falling is needed for older adults (Oh-Park et al. 2011). That emphasizes the need for investigating the home environment modifications as one of the risk factors that could reduce the development of fear of falling for older adults. It should be noted that the physical and the psychological impairment of older adults is not the focus of this research.

Physical surrounding environment, and how older adults behave within that environment; this research identifies the temporary or permanent home design features as a physical surrounding environment, which may increase the risk of falling for older adults. There are a number of design-related reasons for falling in the physical surrounding environment including unsuitable older adult home design or poor long-term home maintenance. As illustrated in Figure 2.3, slipping, tripping and stumbling on different surfaces form 44% of the common causes of falling for older adult Canadians; however, falling on staircases contributes to 26% (more than a quarter of falling accidents) (Scott et al. 2005). Moreover, in one study, about 50% of the subjected group of older adults reported difficulties ascending staircases, and about 25% reported difficulties descending staircases (Verghese et al. 2008). As an example of unsuitable staircase design for older adults, having an inappropriate lighting intensity or placing objects on staircases act as a barriers for older adults while ascending or descending staircases (see Figure 2.4). As an example of poor maintenance, a slippery staircase surface increases the risk of falling for older adults. The way older adults behave within the physical surrounding environment also might result in increasing the risk of falling; these behaviours include speeding up or lifting objects while ascending or descending staircases (Hill et al. 1999). It is important to note that staircase design, as part of the physical surrounding environment, contributes to older adults' behaviour (Lawton et al. 1982). Commonly, unsuitable design such as inappropriate lighting, hand railing or staircase finishing material, could orient older adults to behave in ways which could increase the risk of falling (Haslam and Stubbs 2006; Hill et al. 1999; Horstman and Fanning 2004; Rogers et al. 2004; Voermans et al. 2007)

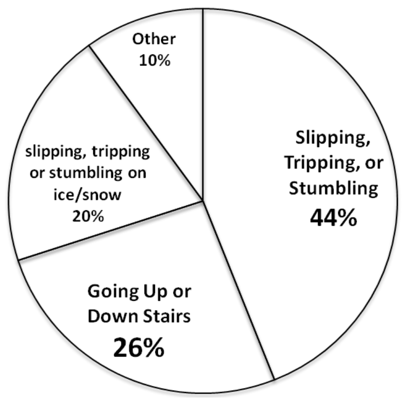


Figure 2.3 Common causes of falling for older adults (Scott et al. 2005)

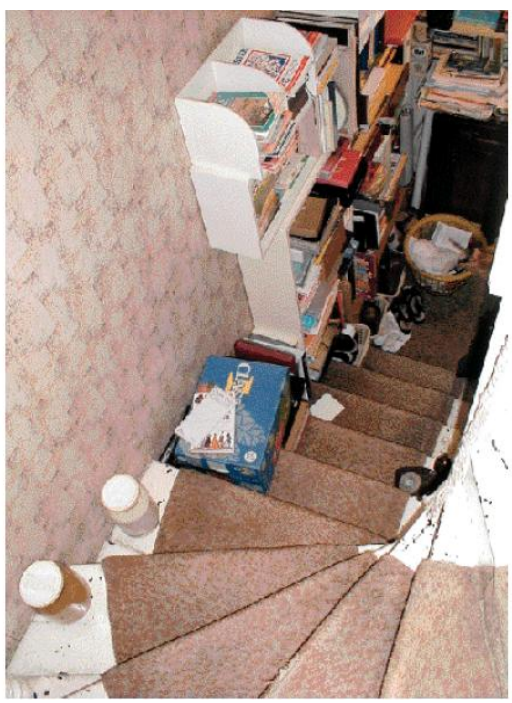


Figure 2.4 Illustration of objects in the staircase (Hill et al. 1999)

2.4 Background on Architectural Staircases' Design and History

Since this research is mainly concerned with the staircase design, it is necessary to study the concept of staircases, and how they have reflected the image of human needs through history. Developing staircases is a unique element that has played a central role in the history of humanity. Throughout history, people have used staircases as a movement element toward a higher virtual or tangible point in space. The concept of using staircases to a virtual point was clear since ancient civilization; the pyramid of Zoser, Egypt, 2750 B.C.E, illustrated in Figure 2.5, is known to be one of the first buildings that modeled the conceptual approach of using staircases as a formation of movement toward the after death world, and that concept was urbanized later for the Giza pyramids (2680-2560 B.C.E) (Helmy 2004; Roth 2007). Staircases have been used to direct the user through a certain path to a tangible point, usually sacred place; in the temple of Khonsu, Egypt, staircases has been used as an interior design tool to elevate a human being to the most spiritual sacred place that connect people with god, the Holy of Holies (or Sanctuary). The perspective section of the Temple of Khonsu, shown in Figure 2.6, emphasizes the ceremonial boat of khons by elevating the ground level and dropping the ceiling level simultaneously, which emphasizes the sacred place's importance (Roth 2007).

Figure 2.5 Pyramid of Zoser, Saqqara, Egypt, 2750 B.C.E (Roth 2007)

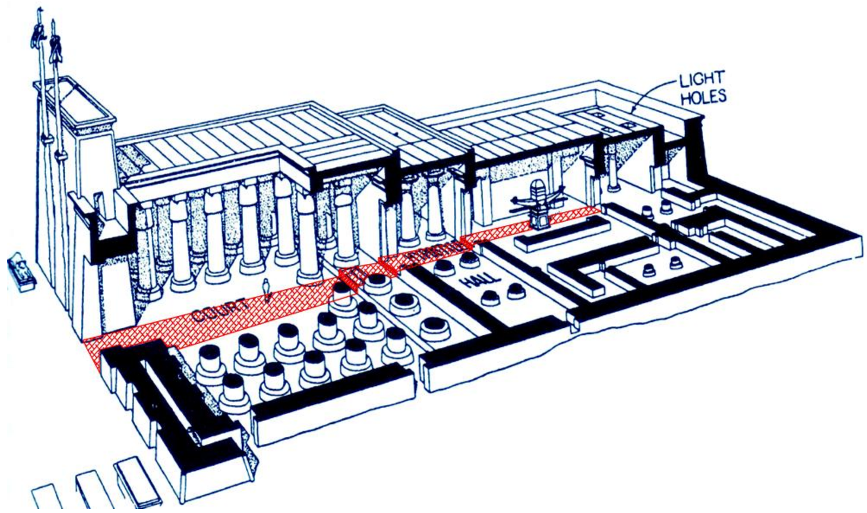


Figure 2.6 Modified perspective section of temple of Khonsu (Roth 2007)

Away from the huge historical building that formed the history of the world, ancient staircases have been used as a functional element in houses and other related facilities. In late Egyptian architecture, staircases have appeared in the dwelling as a connection between the ground floor and the roof in its regular shape. As illustrated in Figure 2.7, a prototype of artisans' houses in Deir el Madineh in 1530 B.C.E., staircases were found to be functional: straight staircases had no landing slab, a wall on one side and handrail on the other, risers were very high (about 200 m and the tread were regular sizes (about 280 mm) (Roth 2007). Staircases have not only been considered as an interior or an exterior element in the home space, but also as a part of the architectural space formation, as illustrated in Figure 2.8. Scala Regia, Vatican (1663-1666 B.C.E.), shown in Figure 2.8, is one of the unique buildings that illustrates the use of staircases as a complete floor for the entire building space (Templer 1992a).

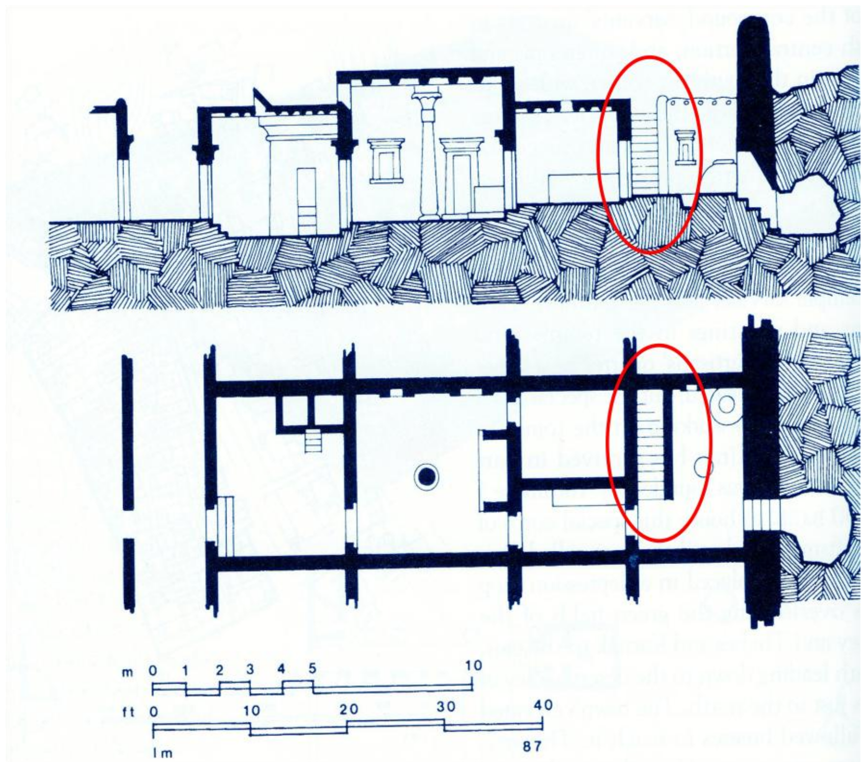


Figure 2.7 Plan and section of a house in Deir El-Medinah (Roth 2007)

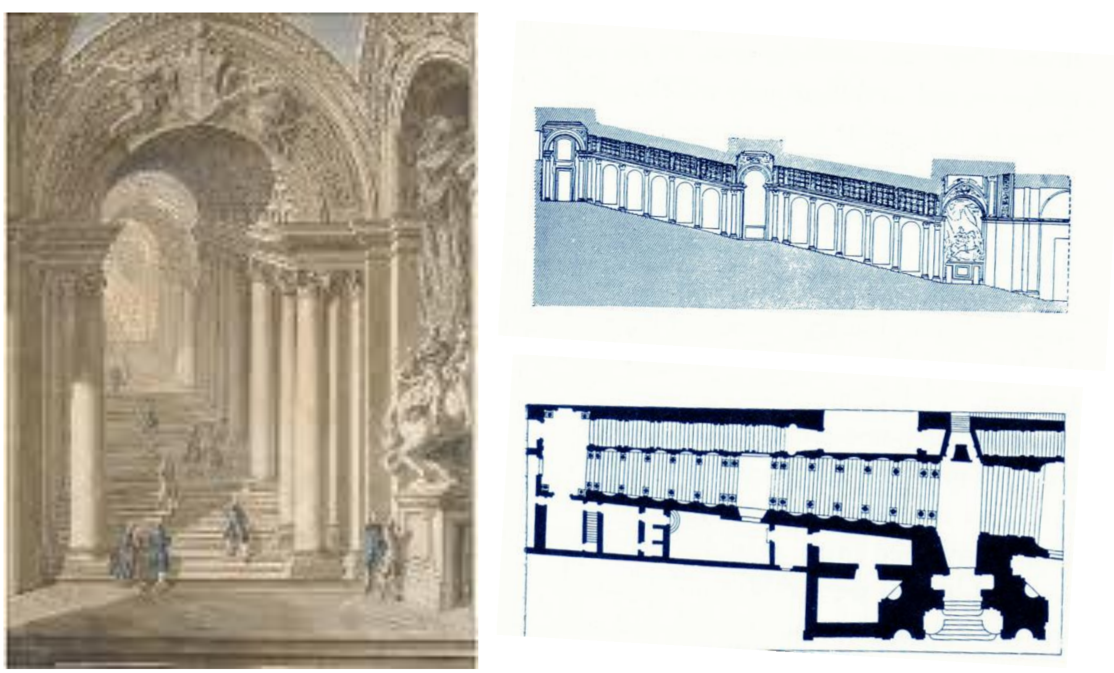
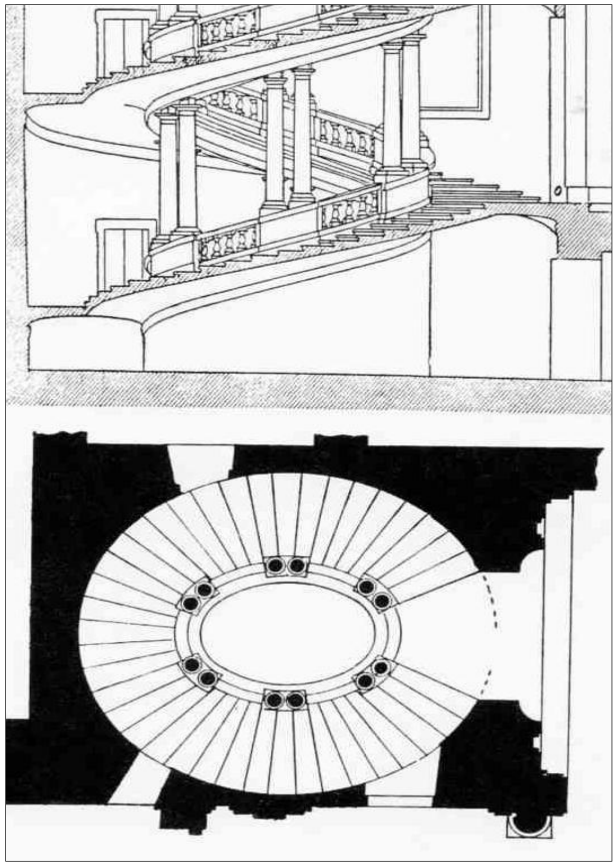


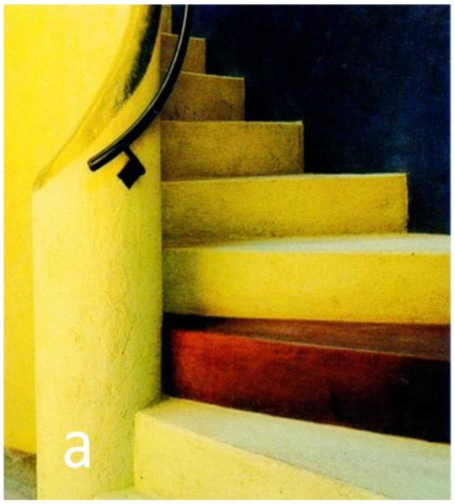
Figure 2.8 Plan, section and interior view for Scala Regia (Templer 1992a)

Staircases have taken different shapes in houses throughout history, such as straight shaped staircases, helical shaped staircases, and composite shaped staircases. Straight functional staircases were one of the most important elements in introducing functional linearity in modern architecture, emphasizing the rule of “less is more”, Ludwig Mies van der Rohe (Robertson 1952; Roth 2007). Staircases have been inspirational focal points that provide a distinctive theme to a building, which appears clearly through the concept of helical staircases design. Helical staircases were one of the most remarkable elements at the end of the Renaissance period, and in the Baroque period, they appeared in palaces as a focal point emphasizing the artistic direction of staircase formation, as shown in Figure 2.9, Barberini Palace, Rome in 1638 (Templer 1992a). Helical staircases are still an artistic modern element as shown in Figure 2.10, Palace of the Arches, Brasilia (Templer 1992a). Composite staircases contain a different step combination, such as inconsistency of color or material of staircase steps, as illustrated in Figures 2.11a (House and House 2008). Composite staircases also might be formed with inconsistent step dimensions, as demonstrated by the interior staircase design of the House + House Architects firm in Figures 2.11 b and c (House and House 2008). Composite staircases have appeared in both historical and modern buildings, as they provide both design flexibility and an artistic value that could be suitable for different spaces in the home. For older adults, helical staircases are not the best choice, as the inconsistent tread could cause confusion while they ascend or descend the staircase. Ultimately, this inconsistency found in composite staircases increases the risk of falling for older adults (Haslam and Stubbs 2006; Templer 1992b).



Figur 2.9 The helical staircases in Barberini Palace (Templer 1992a)

Figure 2.10 Palace of the Arches, Brasilia (Templer 1992a)



Legend:

(a) House in San Miguel, Mexico, shows inconsistency in the color of the steps (House and House 2008)

(b) House in California, US, shows inconsistency in the first four steps (House and House 2008)

(c) House in San Francisco, US, shows inconsistency in the first three steps (House and House 2008)

Figure 2.11 The composite staircases

CHAPTER 3: PROPOSED METHODOLOGY AND IMPLEMENTATION

3.1 Introduction

In order to create a staircase integrated architectural design approach aiming to reduce the risk of falling for older adults, the research process is divided into three stages. Stage 1 constructs a set of four elements which represent the architectural design of the staircase as follows: 1) staircase geometrical design; 2) handrail design; 3) lighting; and 4) step design, listed from highest to lowest impact of reducing the risk of falling for older adults. A rating number will be assigned to each of the elements representing the importance of each element from the perspective of reducing the risk of falling for older adults. Each element will be divided to a number of features; for example, staircase geometrical design has two features: 1) staircase geometry; and 2) number of steps per flight. Each feature will be divided into number of scenarios representing the different architectural design alternatives for that feature. For example, the feature of geometry feature in the staircase geometrical design element will contain 7 scenarios that represent different types of staircase geometry: 1) straight flight staircases with landing; 2) straight flight staircases without landing; 3) quarter turn staircases; 4) U-Shape staircases; 5) spiral staircases; 6) helical staircases; 7) composite staircases. A rating factor will be assigned to each scenario in each feature to represent the degree of reducing the risk of falling for older adults.

Stage 2 develops a rating system for the analyzed staircase elements and features which present the degree to which each element and its features reduce the risk of falling for older adults. A mathematical model is developed to calculate the rating value for different staircase design scenarios. Stage 3 develops a Design Assessment Tree (DAT), a computer model which represents a complete vision for different staircase design scenarios.

The proposed research methodology is summarized in Figure 3.1 which consists of the following: 1) the input parameters for the proposed staircase design, which is based on the staircase geometric design, handrail design, lighting, and step design information. These input parameters are needed for the three stages of the research process which are: 1) develop a staircase elements and features analysis; 2) build a rating system for staircase design; and 3) develop the Design Assessment Tree (DAT). In order to achieve the following output: friendly staircase design and assessment of the proposed staircase design, these outputs are proposed satisfying research criteria such as building code specifications and design and space limitations. For each design element and its associated features, building code specifications is checked to get a background about the actual design specifications that's been followed by designers and architects. However, in this research, the selected features specifications have been selected based on previous evidence-based research. If there is no previous evidence-based research for a specific feature, the building code specifications are followed.

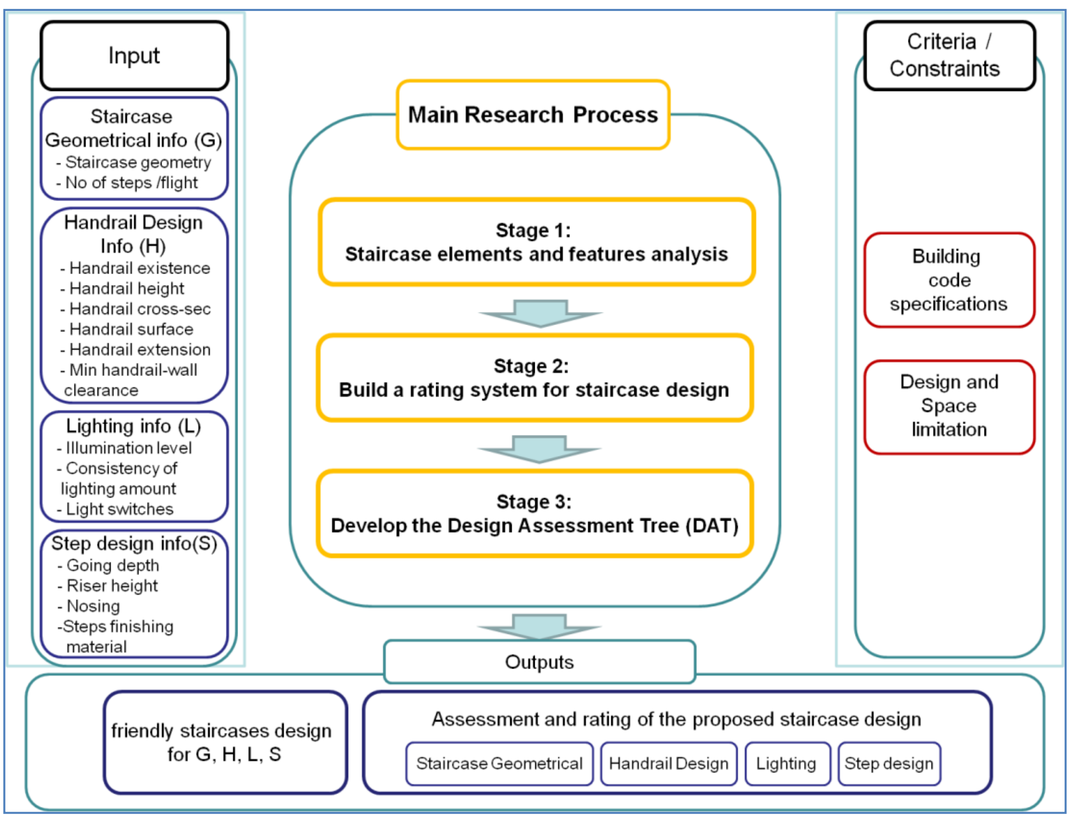
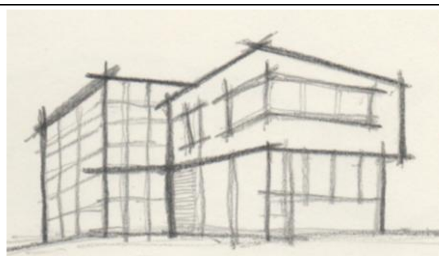


Figure 3.1 Proposed Research Methodology

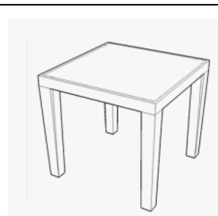
3.2 Staircase Element Analysis

Prior to creating a rating system for a proposed staircase design, the staircase first needs to be broken down into elements that express its architectural design. Handrail, lighting and step specifications are provided in the building code as subdivisions of the staircase design specifications; therefore, in this research, handrail design, lighting and step design will be considered as three staircase design elements. In addition, staircase geometric design is considered to be a design element, for reasons which will be further explained. From architecture perspective, there is a difference between an object's formation and its detailed design component. An object is designed by 1) the design formation that's been represented in this research as staircase geometrical design and 2) the detailed component of that object that's been represented in this research as the staircase design elements, which are handrail design, lighting and step design. To illustrate the difference between building/object formation and its detailed design components, Figure 3.2 illustrates building exterior design (a1 and a2) and object interior design for a table (b1 and b2).

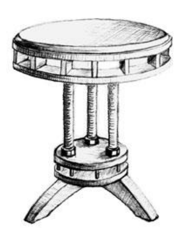


(a1)

(a2)



(b1)



(b2)

Figure 3.2 The importance of staircase geometrical design as an element

Both buildings in Figure 3.2 (a1) and (a2) have the same design components, such as, windows and walls; however, the two buildings have different building formations. That differentiation in formation affects the whole building design in different ways; for example, the pattern of arranging the design components will be affected by the building formation, such as the pattern of windows throughout the building façade (which is known as windows rhythm) (Roth 2007). Therefore, building formation is the dominant factor that affects any design component; otherwise there is no way to track the pattern of arranging the design components, such as windows rhythm.

Choosing the building formation is one of the challenges that exist in various design scales; on a building scale or a smaller object scale. For example, for smaller scale objects such as the two tables illustrated in Figure 3.2 (b1) and (b2), both tables have the same components, such as legs and surface; however they have different design formations. For example, the pattern of arranging the table legs as a design component can be recognized by the differentiation of the table formations. Based on that, the geometry of the staircase, as a formation of the staircase object, is considered to be a design element, as it expresses the architectural spatial context of any staircase design component which can only be tracked by the geometry of the staircase (this point will be farther illustrated in the following section). Therefore, the elements that define staircases are as follows: 1) staircase geometrical design; 2) handrail design; 3) lighting; and 4) step design. The following section explains the previous elements, starting with the one that has the highest impact on reducing the risk of falling for older adults.

3.2.1 First: staircase geometrical design (G):

Staircase geometrical design is considered to be the dominant staircase design element. Staircase geometrical design affects: 1) handrail geometrical shape; 2) step shape; and 3) the location of lighting fixtures. To investigate the importance of the staircase geometrical design, a comparison between straight flight without landing staircases and helical staircases is constructed, as illustrated in Figure 3.3.

As illustrated in Figure 3.3, whereas straight flight without landing staircases have a continuous straight line handrail, helical staircases have a circular plan shape handrail, which varies between the two sides of the helical staircase. For helical staircases, the individual handhold placement distances are not even for the circular handrails on each side. These uneven distances will create an unspecific target to grasp, due to the dissimilarity of the handhold placement distances between the two sides of helical staircases' handrail; however, in the case of lost balance, the hand must have a specific target to grasp (Ghafouri et al. 2004). Therefore, handrail geometrical shape is affected by the staircase geometrical design.

For straight flight without landing staircases shown in Figure 3.3, the steps have a straight direction and uniform shapes; however, for helical staircases, the direction of staircases is circular, and the step has a non-uniform shape. This differentiation in the helical step causes unnatural gait patterns which increase the risk of accidents (Cohen et al. 2009). Therefore, it can be concluded that the staircase geometrical design has an effect on the shape of the steps.

As illustrated in Figure 3.3, if two lighting features are placed after the first and last two steps of each set of staircases, a shaded area will be created by the effect of the geometrical design of the helical staircases, and additional lighting fixtures may thus be required in these shaded areas of the helical staircases. Therefore, the staircase geometrical design can affect the location of lighting fixtures. As a result of the staircase geometrical design element's impact on the handrail and step shape, and lighting fixture locations, it will be the first factor to consider in reducing the risk of falling for older adults.

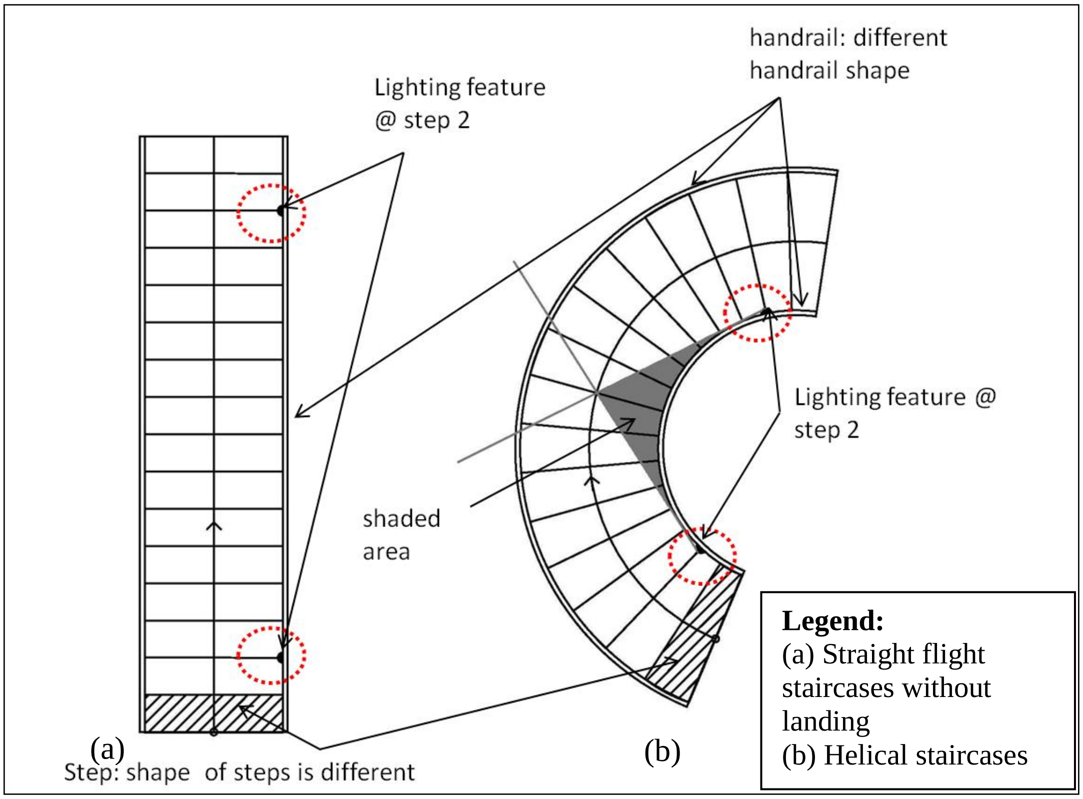


Figure 3.3 The importance of staircase geometrical design as an element

3.2.2 Second: handrail design (H):

From the perspective of reducing the risk of falling for older adults, handrails could be considered as the second most significant staircase element for the following reasons: 1) the handrail is an essential tool for older adults to assess their movement up or down staircases; of a total of 157 older adult participants in a study, 72% reported that they always rely on the handrail to assist their movement while ascending and descending staircases (Hill et al. 1999). 2) By default, people tend to grasp the handrail when losing their balance in order to prevent falls (Bateni et al. 2004). Moreover, people are likely to extract information about staircases' edges, handrail or different objects to grasp before climbing staircases (Ghafouri et al. 2004; Maki and McIlroy 2006; Miyasike-daSilva et al. 2011) which emphasizes the importance of the handrail as a safety element in staircases' design.

As 93% of older adults prefer aging in their own homes rather than moving out (Turcotte and Schellenberg 2007), the home becomes a familiar environment for older adults. Therefore, older adults form a visual-spatial map for a home in which they have spent their lives (Miyasike-daSilva et al. 2011). As such the importance of lighting and step design may come after the handrail because older adults can rely on the visual-spatial map to locate the handrail and climb the staircases without appropriate lighting or step design (in the worst case scenario). For these reasons, the handrail design element could be represented as the second factor in reducing the risk of falling for older adults.

3.2.3 Third: lighting (L) and step design (S):

Appropriate vision is required when ascending and descending staircases to recognize the step dimensions and reduce the risk of falling by detecting the hazards (Templer 1992b). Additionally, in a study by Zietz and Hollands (2009), the visual information gathered while ascending and descending staircases is used to map 3 steps ahead (Zietz and Hollands 2009). Therefore, in order to use the steps effectively, it is essential to provide appropriate vision for older adults. Improving the ability of older adults to see staircases clearly can be accomplished by maintaining the appropriate amount and location of lighting throughout the staircases (IESNA 2007). Therefore, the lighting element is considered to be the third factor in reducing the risk of falling for older adults, which makes the step design to be the fourth factor in reducing the risk of falling for older adults.

3.2.4 Rating system of staircase elements

In this thesis, the staircase is broken down into four elements, starting with the element that has the highest impact on reducing the risk of falling for older adults, as follows: 1) staircase geometrical design; 2) handrail design; 3) lighting; and 4) step design. A rating number will be assigned to each of the elements, based on the importance of each element. The sum of the four assigned rating numbers will be a total of 100. The total value of 100 will be reduced or remain the same based on the rating factor (R) for the selected scenario for each feature under each element. The more the staircase design reduces the risk of falling for older adults, the closer the sum of the total rating numbers will be to 100. The value of 100 represents an optimum staircase design that is suited to reduce the risk of falling for older adults.

To highlight the importance of each element over another, a constant percentage of 25% assumed to be the percentage difference between the rating number of each element and the one that follows it. The percentage of 25% was chosen to create a slight difference between each design elements' rating number (a sensitivity analysis is provided at the end of this chapter). Therefore, the developed rating numbers N(H), N(G), N(L), and N(S) can be calculated satisfying constraints' equations 3.1, 3.2, 3.3 and 3.4:

$$N(H) \leq 75\%\, N(G) \quad \textbf{3.1}$$

where:

- N(H) is the handrail design rating number.
- N(G) is the staircase geometrical design rating number.

$$N(L) \leq 75\%\, N(H) \quad \textbf{3.2}$$

where:

- N(L) is the lighting rating number.
- N(H) is the handrail design rating number.

$$N(S) \leq 75\%\, N(L) \quad \textbf{3.3}$$

where:

- N(S) is the step design rating number.
- N(L) is the lighting rating number.

$$N_{total} = \sum_{X=G,H,S \text{ or } L} N(X) = N(G)+N(H)+N(S)+N(L)=100 \quad \textbf{.......................... 3.4}$$

where:

- N_{total} is the summation of all staircase elements' rating numbers.
- N(X) is the rating number for element X.
- X is a designated parameter for G, H, S or L.

By solving equations 3.1, 3.2, 3.3 and 3.4, a certain value can be assigned as a rating number for each element. The resultant rating number for each element is represented in Table 3.1. As illustrated in Table 3.1, the staircase is broken down into four elements, starting with the element that has the highest impact on reducing the risk of falling for older adults listed as follows: 1) staircase geometrical design; 2) handrail design; 3) lighting; and 4) step design.

Table 3.1: Rating number of staircase four elements

STAIRCASE ELEMENTS ANALYSIS	**G**	**H**	**L**	**S**
	Staircase Geometrical Design	**Handrail Design**	**Lighting**	**Step design**
Rating number of each element (N)	37	27	21	15

3.3 Staircase Features Analysis

Each element is divided into a number of features that define the architectural design of that element, as illustrated in Figure 3.4; for example, staircase geometrical design is divided into two features: 1) staircase geometry; and 2) number of steps per flight. Handrail design is divided into six features: 1) handrail existence; 2) handrail height; 3) handrail cross-section; 4) handrail surface texture; 5) handrail extension; and 6) minimum handrail-wall clearance. The lighting element is divided into three features: 1) illumination level; 2) consistency of lighting amount; and 3) lighting switches. Step design is divided into four features: 1) going (tread without nosing) depth; 2) riser height; 3) nosing; and 4) steps finishing material.

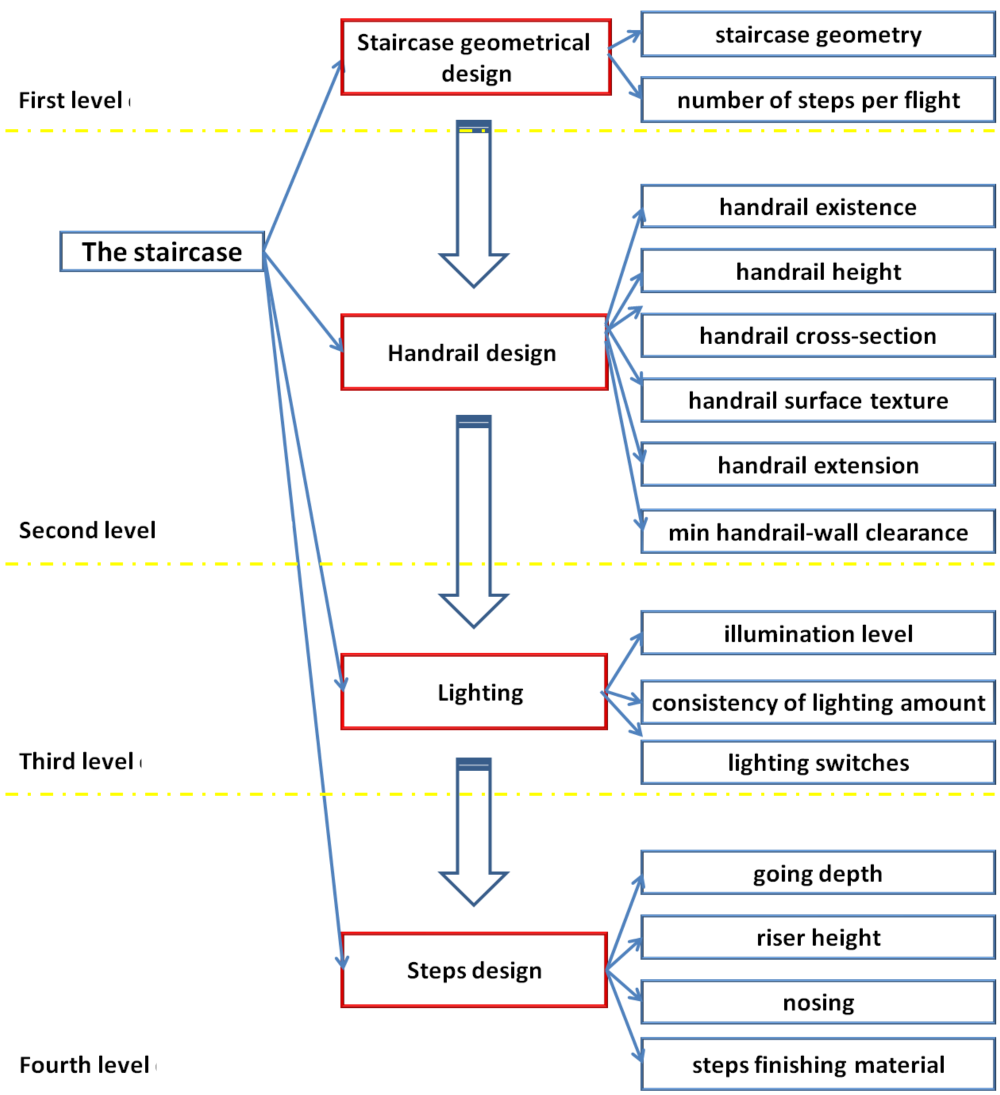


Figure 3.4 A flow chart represents staircase elements and features analysis

3.3.1 Rating system of staircase features

A rating factor (R) will be assigned to each scenario in each feature to represent the degree of reducing the risk of falling for older adults based on an evidence-based comparison with other alternative scenarios for that feature. The absolute value of the rating factors have been assigned based on my assessment as an architect. Note that the aim of this research is to provide a framework for staircase assessment, not the actual values of the rating factors provided. Saaty (2008) has provided a brief explanation about the analytical hierarchy process by defining the problem and objectives, then assigning the criteria that the elements depend on through constructing the decision hierarchy from top to bottom, and finally comparing the elements and weighing each element according to the criteria provided. In order to make a comparison between the elements, Saaty developed a scale of numbers representing the degree of importance of each element over the others. In this research, the concept of having that scale has been adopted to represent the rating factor of each design feature.

The rating factors will be assigned values between 1.00 and 0.0. A rating factor of 1.00 means that the risk of falling for older adults is optimally reduced; a rating factor of 0.0 means that the feature does not exist, for example, if there is no handrail, the rating value of the handrail existing feature will be 0.00. For scenarios of different features, the developed rating factors are represented in 3.2. For a proposed staircase design, one scenario will be selected as to represent the rating factor for the targeted feature; for example, if the staircase geometry is spiral staircase, the rating factor for the staircase geometry feature will be 0.25.

Table3.2: Rating factors explanation

Design designation	Rating Factor	Explanation
Optimal Design	1.00	The risk of falling for older adults is optimally reduced by the selected design feature (Optimal design feature)
	0.95	The design feature is slightly under the optimal design feature
	0.90	The design feature is under the optimal design feature
Strong Design	0.85	The design feature is over the strong design feature
	0.80	The design feature is slightly over the strong design feature
	0.75	The risk of falling for older adults is strongly reduced by the design feature (Strong design feature)
	0.70	The design feature is slightly under the strong design feature
	0.65	The design feature is under the strong design feature
Moderate Design	0.60	The design feature is over the moderate design feature
	0.55	The design feature is slightly over the moderate design feature
	0.50	The risk of falling for older adults is moderately reduced by the design feature (moderate design feature)
	0.45	The design feature is slightly under the moderate design feature
	0.40	The design feature is under the moderate design feature
Risk Promoting Design	0.35	The design features is over the risk promoting design feature
	0.30	The design features is slightly over the risk promoting design feature
	0.25	The risk of falling for older adults is promoted by the design features (Risk promoting design feature)
	0.20	The risk of falling for older adults is highly promoted by the design features
	0.15	The risk of falling for older adults is strongly promoted by the design features
Highest Risk Design	0.10	The risk of falling for older adults is over the highest risk of falling
	0.05	The risk of falling for older adults is slightly over the highest risk of falling
	0.00	Highest risk of falling or the design features does not exist

3.3.2 First: staircase geometrical design

3.3.2.1 Feature 1: staircase geometry

3.3.2.1.1 Types of staircase geometry

Based on the literature review, the staircase geometry feature can be divided into three scenarios: 1) straight staircases; 2) circular staircases; and 3) composite staircases (Bangash and Bangash 1999; Beneke 1997; Templer 1992a). Straight staircases consist of straight flights (Bangash and Bangash 1999; Beneke 1997), which can be listed as follows:

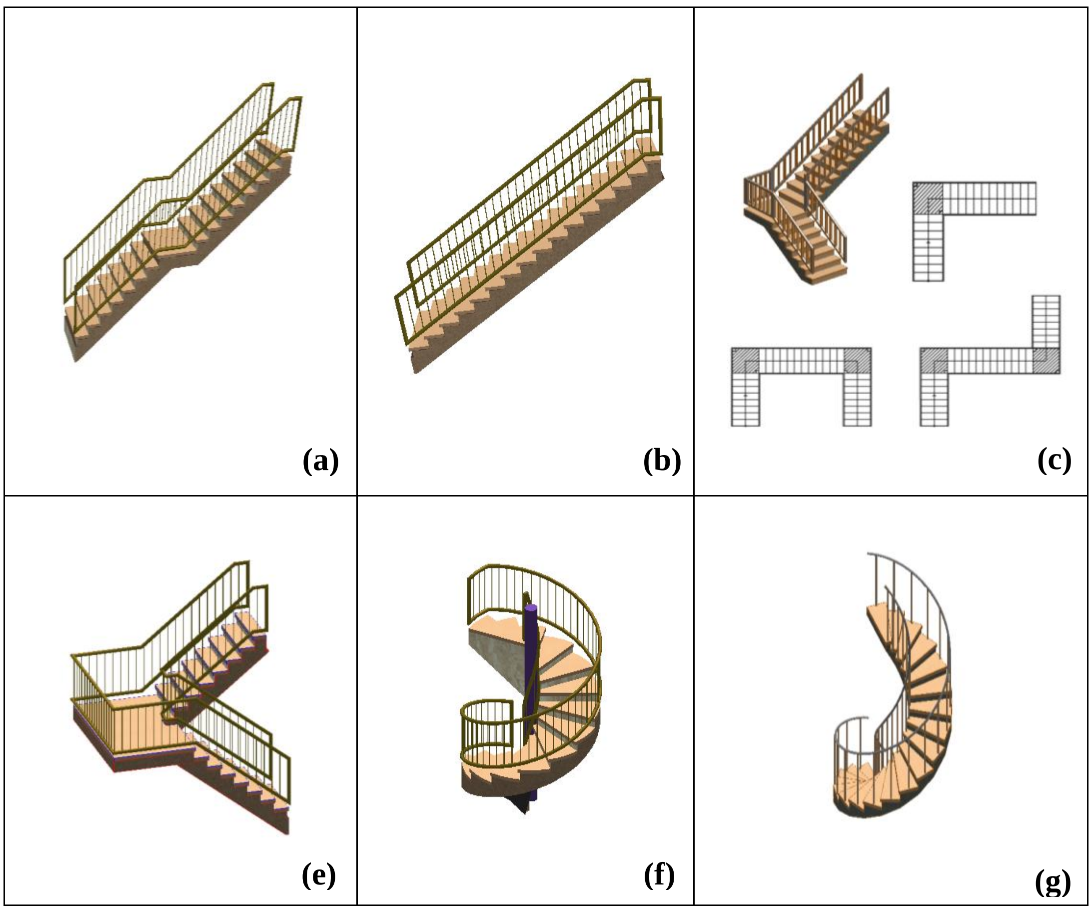
1. Straight flight staircases with landing (Bangash and Bangash 1999), as shown in Figure 3.5a. These staircases connect two floors in one direction with a landing.
2. Straight flight staircases without landing (Bangash and Bangash 1999; Beneke 1997), as shown in Figure 3.5b. These staircases connect two floors in one direction without a landing.
3. Quarter turn staircases (Bangash and Bangash 1999; Beneke 1997), as shown in Figure 3.5c. These staircases have a minimum of two flights with a quarter turn landing, turning 90° between the two flights.
4. U-Shape staircases (Half turn staircases with one landing) (Bangash and Bangash 1999; Beneke 1997). U-Shape staircases connect two floors through two straight runs (flights) and one landing between them, turning 180° between the two runs, as shown in Figure 3.5e.

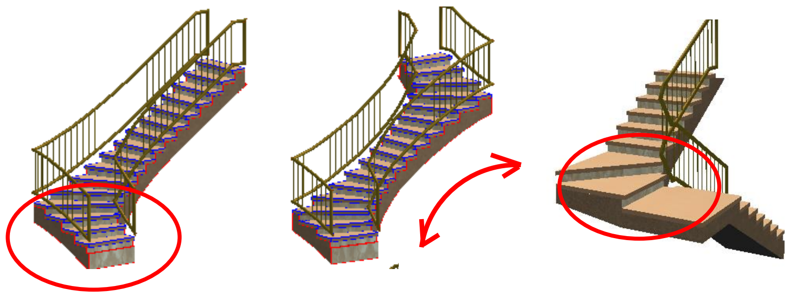
Circular staircases consist of circular flights; two categories can be assigned to circular staircases as follows (Bangash and Bangash 1999):

1. Spiral staircases (Bangash and Bangash 1999) are circular shaped staircases that are supported by a central pole in the middle of the staircase steps and have no landing, as shown in Figure 3.5f.

2. Helical staircases (Bangash and Bangash 1999) are circular shaped staircases which do not contain a central pole in the middle of the staircase steps and have no landing, as shown in Figure 3.5g.

Composite staircases are any other staircase shapes with inconsistent step dimensions in one flight throughout the entire staircase; they may contain winders, a mix of straight and circular flights, or inconsistency in the first or last steps, as illustrated in Figure 3.5h.





Legend:
(a) Straight flight staircases with landing, **(b)** Straight flight staircases without landing, **(c)** Quarter turn staircases, **(e)** U-Shape staircases, **(f)** Spiral staircases, **(g)** Helical staircases, **(h)** Composite staircases: (h1) Example illustrates inconsistency of step dimensions throughout the staircase, (h2) Example illustrates mixing straight and circular flights, (h3) Example illustrates winder staircase

Figure 3.5 The staircase geometry

3.3.2.1.2 Analysis of staircase geometry

To facilitate the staircase geometry analysis, the following assumptions are stated: 1) The different types of staircase geometry illustrated in Figure 3.5 have the same floor height and number of steps; 2) The effect of clockwise and anticlockwise directions of staircases will be neglected, assuming that older adults are already familiar with the virtual-spatial map of their staircase design (Miyasike-daSilva et al. 2011).

Composite staircases:

The first 3 steps at the top or the bottom of the staircase are reported to be associated with a higher risk of falling (Templer 1992b), especially the first and last step in the staircase (Lee and Chou 2007; Wild et al. 1981). In the case of composite staircases, irregularity in the first 3 steps at the top or bottom of the staircase forms an irregular gait pattern which highly increases the risk of falling (Haslam and Stubbs 2006; Lord et al. 2001; Templer 1992b). As an example: a) winder staircases, a part of the composite staircases, are expected to be an unsuitable design for older adults, more than spiral staircases, as winder staircases contain inconsistent steps that cause more confusion for older adults (Haslam and Stubbs 2006; Templer 1992b). b) the composite staircases could contain an oblique staircase geometry which causes irregular foot placement through the oblique path, which increases the risk of falling (VandenBussche et al. 2011). Therefore, from the perspective of the design that reduces the risk of falling for older adults, composite staircases will be rated as the lowest of all staircase types.

Circular staircases:

In order to determine the more preferable design between helical and spiral staircases, from the perspective of reducing the risk of falling for older adults, schematic plans of both staircases have been developed. As illustrated in Figure 3.6, the difference between X and Y distances in spiral staircases is very large which creates a limited favorable side to ascend or descend staircases; this is expected to be the outer side of the staircases. Additionally, the step width X near the pole of the spiral staircases is extremely small, which could create a serious risk of falling as it does not provides appropriate foot placement. (Haslam and Stubbs 2006). Furthermore, in the case of falling, people are more likely to grasp the handrail (Bateni et al. 2004), which usually does not exist in the spiral staircases, and if it does, the slope of the inner-handrail is too sharp, which could affect the grasping ability (Maki 1988a). This could increase the risk of falling while an individual is trying to recover. Therefore, the helical staircases will have a higher rating than the spiral staircases.

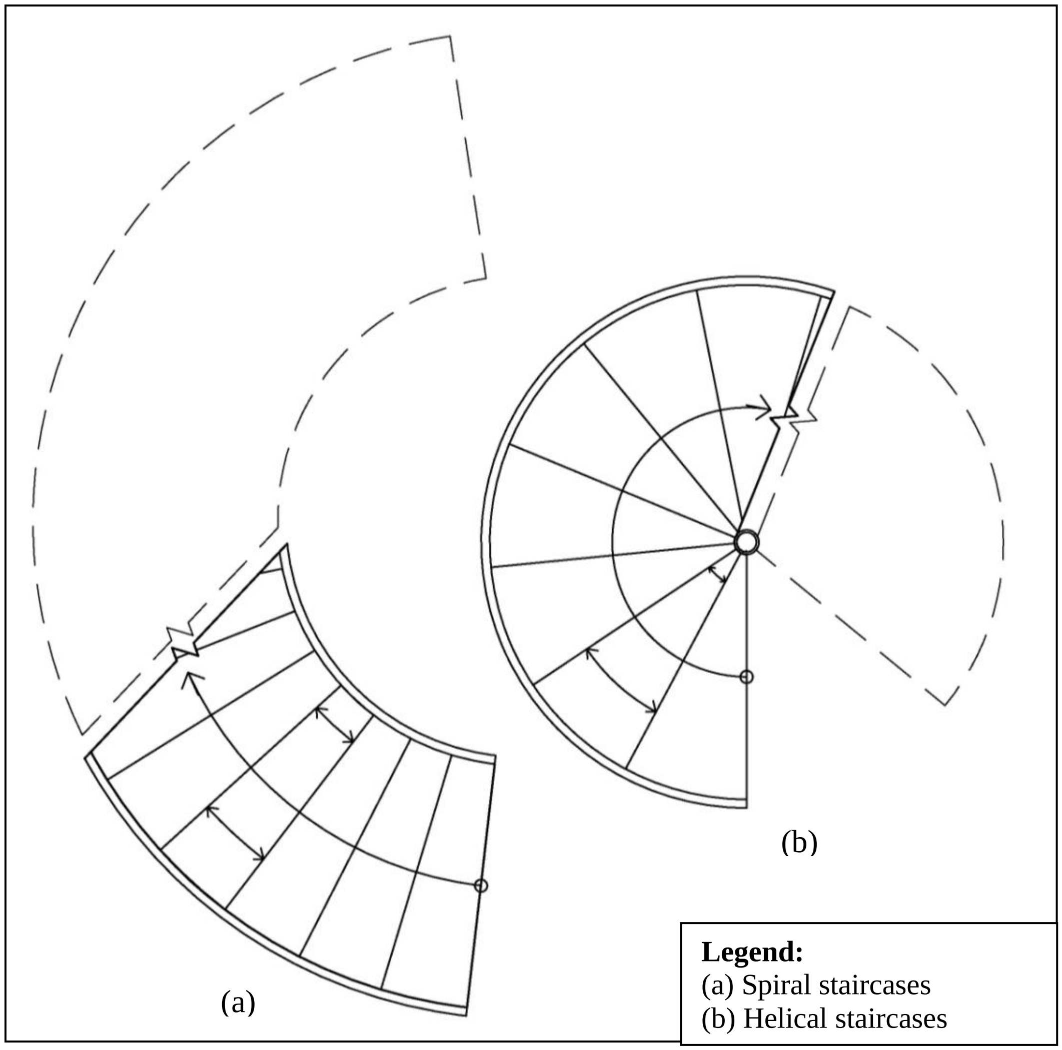


Figure 3.6 The theoretical geometry of spiral staircase versus helical staircase

<u>Straight staircases verse circular staircases:</u>

Based on the study by VandenBussche et al. (2011), oblique staircases, illustrated in Figure 3.7a, do not provide a regular gait pattern; by applying the same measurements on circular staircases, as illustrated in Figure 3.7b, circular staircases provide an irregular gait pattern. This irregular gait pattern increases the risk of falling (Haslam and Stubbs 2006; Lord et al. 2001; Templer 1992b; VandenBussche et al. 2011). Therefore, spiral and helical staircases are considered to have a lower rating than straight staircases.

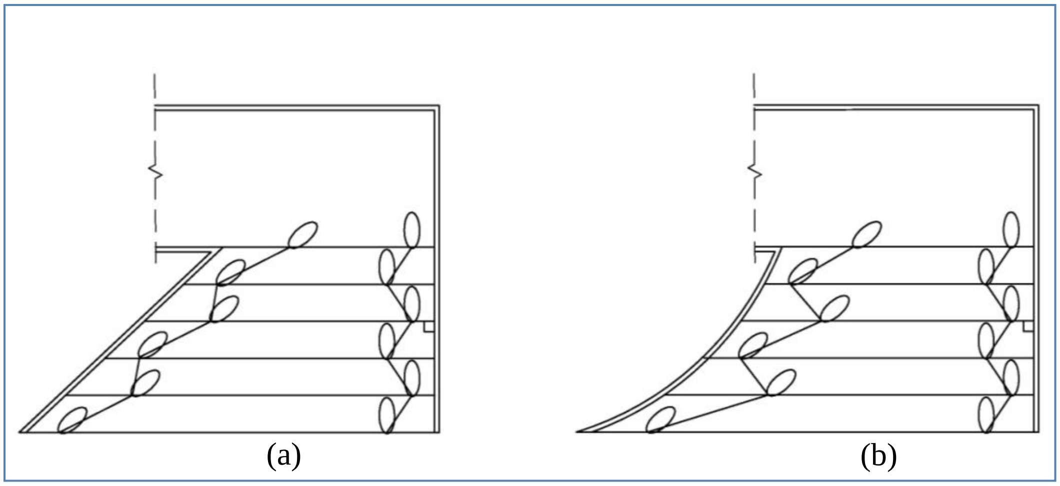


Figure 3.7 Schematic plan of (a) oblique and (b) circular staircase

Straight flight staircases without landing versus other straight staircase types

As illustrated in Figure 3.5, straight flight staircases without a landing have a longer flight compared to other straight staircase types, which have shorter flights that connect with a landing. Long flights are associated with a higher risk of falling than short flights (Templer 1992b). In one study, individuals tend to have more difficulty climbing the one flight staircases than climbing staircases with several short flights, especially for older adults, 90 years and older (Covinsky et al. 2009). Therefore, straight flight staircases without a landing will have the lowest rating of all straight staircase types.

Straight staircases with landing versus straight staircases without landing:

Straight staircases with and without a landing have a similar geometrical design, as illustrated in Figure 3.5 a and b. However, in straight staircases with a landing, the landing reduces the number of accidents by two and half times compared to the straight staircases without a landing (Templer 1992b). Therefore, straight staircases with a landing will have a higher rating than straight staircases without a landing.

Straight flight staircases with landing versus U-Shape and quarter turn staircases

Generally, U-shape and quarter turn staircase designs contribute in reducing the risk of falling more than the straight flight staircase designs (Templer 1992b). Also, U-shape staircases cause significantly fewer accidents than the straight flight staircases with landing (Svanstrom 1974). The design of the landing area in the U-shape and quarter turn staircases breaks the feeling of the staircase continuity, while the feeling of steep staircases might be associated with the visual continuity of a straight flight staircase with a landing in the middle. The feeling of long or steep staircases might not allow older adults to have a mental rest when climbing the staircases (Williams and RHS 1995). Therefore, U-shape and quarter turn staircases will have a higher rating than straight flight staircases with a landing.

U-shape staircases versus quarter turn staircases

The difference between quarter turn staircases and U-shape staircases is the rotation angle, which is 180^o in U-shape staircases and 90^o in quarter turn staircases, as illustrated in Figure 3.5 e and c. The rotation angle of 180^o in U-shape staircases allows a flat handrail between the two flights on the landing area, providing appropriate handholds and appropriate areas for foot placement, through the resting time between the two flights as illustrated in Figure 3.8. Templer (1992b) recommended providing appropriate handhold and foot placement throughout the entire staircases in order to reduce the risk of falling. Moreover, U-shape staircases have a long rectangular landing; however, quarter turn staircases have a smaller landing area (almost half the length of the one in U-shape staircases). The long, rectangular landing in U-shape staircases might allow a comfortable area to rest by providing a bigger landing area. Therefore, the quarter turn staircases will have a lower rating than the U-shape staircases.

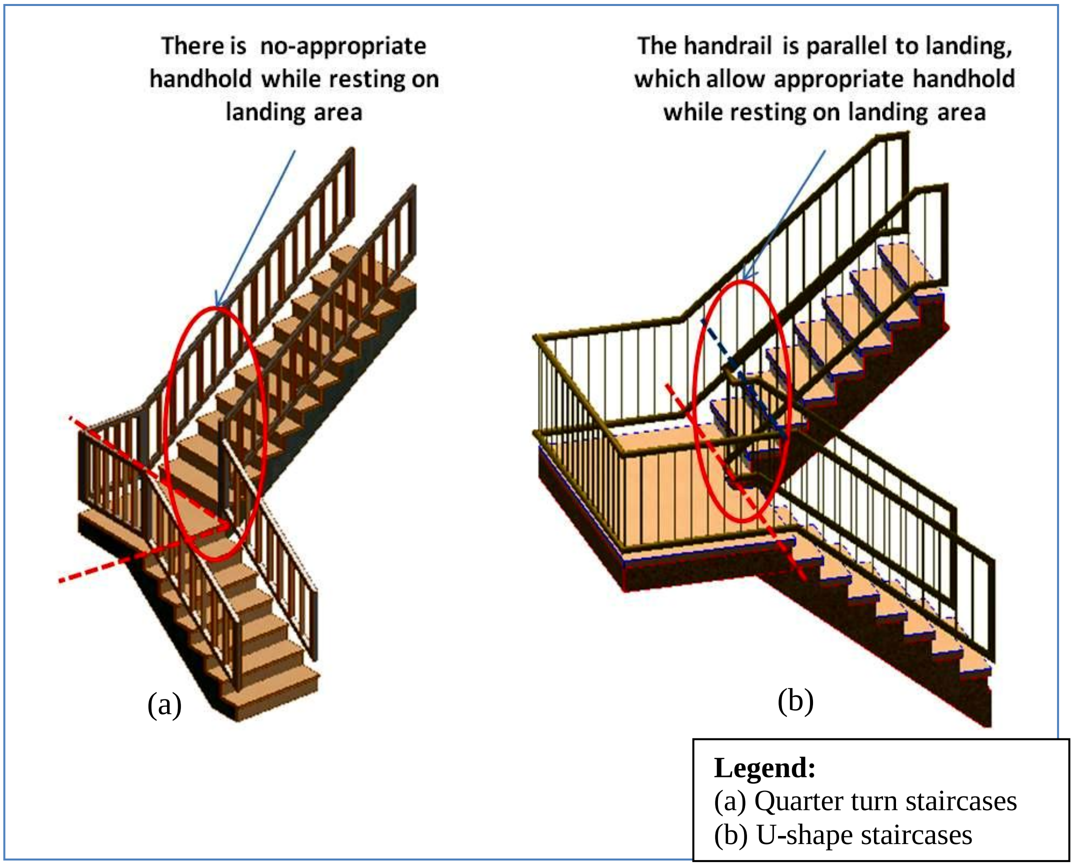


Figure 3.8 Quarter turn staircases versus U-shape staircases

From the previous analysis, the staircase geometrical design scenarios of staircase geometry feature could be arranged, starting from the optimal design feature scenario, as follows:

1. U-shape staircases;
2. Quarter turn staircases;
3. Straight staircases with landing;
4. Straight staircases without landing;
5. Helical staircases;
6. Spiral staircases;
7. Composite staircases.

The previous feature scenarios arrangement can be ranked using rating factors, represented in Table 3.2, as is illustrated in Table 3.3.

Table 3.3: Rating factors for scenarios of staircase geometry

Scenarios order number	Staircase geometrical design scenarios: staircase geometry	Rating factor	Rating reason
1	U-shape staircases	1.00	Appropriate handholds and foot placement on landing area - break the visual continuity (Williams and RHS 1995)
2	Quarter turn staircases	0.80	Inappropriate handholds and foot placement on landing area at the 90 degree angle
3	Straight staircases with landing	0.60	Reduce accidents by providing landing (Templer 1992b)
4	Straight staircases without landing	0.40	Long flight not recommended (Covinsky et al. 2009; Templer 1992b)
5	Helical staircases	0.30	Prevents appropriate foot placement (but better step angle than spiral staircases)
6	Spiral staircases	0.25	Prevents appropriate foot placement (Haslam and Stubbs 2006) - could lead to misplacing hand on one side of the staircase
7	Composite staircases	0.20	First steps irregularity 7 (Lee and Chou 2007; Templer 1992b; Wild et al. 1981) - gait pattern irregularity (Haslam and Stubbs 2006; Lord et al. 2001; Templer 1992b).

3.3.2.2 Feature 2: number of steps per flight

This section focuses on evaluating the feature of the flight length of staircases from the perspective of reducing the risk of falling for older adults. It has been found that the first and last 3 steps of the staircase, especially the transition step which connects the staircase with the floor or the floor with the staircase, are associated with a higher risk of falling (Lee and Chou 2007; Templer 1992b; Wild et al. 1981). Moreover, gaze fixation, the time that individuals need to extract visual information about the surrounding environment, on the middle steps was considerably larger than the transition steps, allowing the user to build a better spatial map for those middle steps (Miyasike-daSilva et al. 2011). Therefore, Templer (1992b) assigned a number of 6 steps or less per flight to be associated with a very high risk of falling, followed by a lower risk for flight containing 7 to 10 steps, and the lowest risk for flights with more than 10 steps, except for long flights, on which the risk increases again. No specific research has investigated the maximum number of steps preferable for older adults in one flight; however, most of the studies that investigate the body's physical performance have assigned 12 steps per flight as a standard number for experimental testing samples for older adults (Cataneo and Cataneo 2007; Rudy et al. 2007; van Weely et al. 2009). In addition, Williams and RHS (1995) recommended 10 to 12 steps to provide comfort and safety for older adults. Having a long flight is considered to be the worst of all, as it is associated with a very high risk of falling (Templer 1992b). Therefore, by using the same rating factors in Table 3.2, the number of steps per flight could be rated, from the perspective of reducing the risk for older adults, as illustrated in Table 3.4.

Table 3.4: Rating factors for scenarios of number of steps per flight

Scenarios order Number	Staircase geometrical design scenarios : Number of steps per flight	Rating factor
1	10 ≤ number of steps per flight ≤ 12	1.00
2	7 ≤ number of steps per flight < 10	0.60
3	number of steps per flight ≤ 6	0.35
4	number of steps per flight ≥ 12	0.25

3.3.3 Second: handrail design

3.3.3.1 Feature 1: handrail existence

The Alberta building code requires one handrail on one side of the staircase if the staircase's width is less than 1100-mm; if the staircase's width is greater than 1100-mm, two handrails need to be installed, one on each side of the staircase (NRC 2006). Generally, an individual is more likely to grasp a handrail to generate a stabilizing force while ascending or descending the staircase (Bateni et al. 2004); however, for older adults, the rule for handrail existence is elevated to assist their movement on the staircase (Hill et al. 1999). Based on a survey study of 2800 participants aged 60 and older, Ishihara et al. (2002) found that the necessity of handrail existence increases with aging. In another study by Hill et al. (1999) with 157 older adults' participants, 74% who have two handrails in their homes reported using both of handrails. In addition, Temple (1992b) mentioned that staircases with no handrails are associated with a higher percentage of accidents. Therefore, the proposed optimal design scenario for older adults is to have one handrail on each side of the staircase; the second design option is to have one handrail on one side of the staircase; and the worst design scenario is to have no handrail on either side of the staircase. Rating factors in Table 3.2are used to assess the handrail existence as illustrated in Table 3.5.

Table 3.5: Rating factors for scenarios of handrail existence

Scenarios order number	Handrail existence scenarios	Rating factor
1	Two handrails	1.00
2	One handrail	0.7
3	No handrail	0.00

3.3.3.2 Feature 2: handrail height

Handrail height is the vertical height from a line drawn through the outside edge of the staircases nosing to the top of the rail (NRC 2006), as illustrated in Figure

3.9b. The Alberta building code requires that the handrail height not to exceed 965-mm, and not to be less than 800-mm (NRC 2006). Maki (1988a) investigated the influence of various handrail heights with two slopes (41^o and 49^o) on the level of safety for 20 young participants and 20 older adults' participants (aged 59 and older). From this study, the preferred handrail height for older adults is 910-mm and 970-mm for both 41^o and 49^o slopes. Therefore, the optimal handrail height for older adults will be considered to range from 910-mm to 970-mm. Considering individual comfort, the height of the handrail will be out of the comfort zone if it is over 1,000-mm (Haslam and Stubbs 2006; Templer 1992b). In the case of a handrail height ≤ 910, this will be the lowest rating as it is difficult to grasp and associated with a high risk of falling (Templer 1992b). Therefore, the handrail height could be ranked using the rating system in Table 3.2, as illustrated in Table 3.6.

Table 3.6: Rating factors for scenarios of handrail height

Scenarios order Number	Handrail height scenarios (mm)	Rating factor
1	910 ≤ Handrail height ≤ 970	1.00
2	970 ≤ Handrail height ≤ 1,000	0.7
3	Handrail height ≥ 1,000	0.5
4	Handrail height ≤ 910	0.4

3.3.3.3 Feature 3: handrail cross-section

The Alberta building code specified that the circular handrail cross-section was limited to a range from 30-mm to 43-mm in diameter, and the non-circular cross section was limited to range from a 100-mm to 125-mm perimeter with a maximum of 45-mm for the longest cross section dimension (NRC 2006). Risk of falling could be reduced by facilitating the grasp ability for the handrail (Maki 1988b). In order to increase the ability to grasp, the handrail cross-section needs to form the best combination of shape and size (Haslam and Stubbs 2006). The best combination was found to be a circular handrail shape with a diameter ranging from 32-mm to 50-mm or an oval handrail shape with a circumference ranging from 100-mm to 150-mm (Haslam and Stubbs 2006). In a study by Maki (1988b), three different handrail shapes (circular, horizontal rectangle and square with different circumferences) along with four other commonly-used shapes (oval, decorative, and two different dimensions of long vertical rectangle) were tested on 20 young and 20 older adults' participants. Maki (1988b) found that the best two shapes for older adults, were: 1) circular shape with circumferences of 100-mm (32-mm diameter), 120-mm, 140-mm, and 160-mm (51-mm diameter); and 2) the vertical oval shape with dimensions of 50-mm height and 37-mm width. Other shapes and dimensions were found to have a similar level of comfort that was lower than that found for the circular and the oval shapes (Maki 1988b). Therefore, the circular and oval shapes will receive the highest rating, and other shapes and sizes will have a lower rating. The handrail cross-section could be rated using the rating system in Table 3.2, as illustrated in Table 3.7.

Table 3.7: Rating factors for scenarios of handrail cross-section

Scenarios order number	**Handrail cross-section scenarios**	**Rating factor**
1	Handrail circular shape with circumferences between 100-mm (32-mm diameter) and 160-mm (51-mm diameter), and handrail oval shape with dimension of 50-mm height and 37-mm width	1.00
2	Other handrail shapes and dimensions	0.7

3.3.3.4 Feature 4: handrail surface texture

The Alberta building code states that handrails should be graspable through the entire length of the handrail (NRC 2006). For the purpose of preventing falling, Templer (1992b) illustrated that handrail surface texture is important for grasping ability. A handrail surface texture that is too smooth might move the grasping hand under the body's weight causing instability for an individual, which might lead to falling (Haslam and Stubbs 2006). Even though a rough handrail surface texture reduces slippage, Maki (1988b) found it to be uncomfortable and to be associated with a high percentage of avoidance from the participants of different age groups. Therefore, handrail material that is too rough or too smooth will receive a lower rating. Rating factors in Table 3.2 are used to assess the handrail surface texture as illustrated in Table 3.8.

Table 3.8: Rating factors for scenarios of handrail surface texture

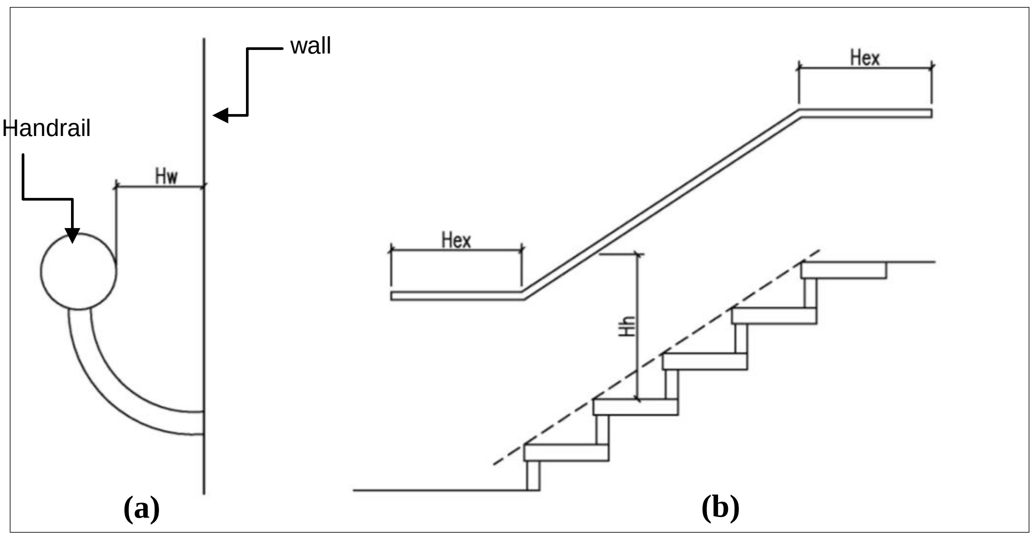
Scenarios order number	Handrail surface texture scenarios	Rating factor
1	comfortable handrail surface texture (not too smooth or not too rough)	1.00
2	difficult to grasp (too smooth handrail surface texture or too rough handrail surface texture)	0.5

3.3.3.5 Feature 5: handrail extension

Handrail extension is the continuity of the handrail throughout the floor with a certain length (Ishihara et al. 2002), as illustrated in Figure 3.9b. The Alberta building code specification for handrail extension is to have not less than 300-mm at the top and bottom of each flight of the staircases, except for staircases in one-dwelling units (NRC 2006). In a study based on a questionnaire to over 2,800 older adults (60 years and older), Ishihara et al. (2002) stated that older adults tend to stop for a while after they finish descending the staircases, and the risk of falling could increase if there is no handrail extension; in addition, providing a short handrail extension was associated with a greater hazard of falling than the one with no handrail extension. Ishihara et al. (2002) recommended the handrail extension to be a minimum of 320-mm to a maximum of 480-mm. Therefore, the optimal rating for the handrail extension will be considered to be from 320-mm to 480-mm. Rating factors in Table 3.2are used to assess the handrail surface texture, as illustrated in Table 3.9.

Table 3.9: Rating factors for scenarios of handrail extension

Scenarios order number	Handrail extension scenarios (mm)	Rating factor
1	320≤Handrail extension on at least one handrail ≤ 480	1.00
2	Handrail extension on at least one handrail ≥ 480	0.8
3	No handrail extension	0.5
4	Handrail extension on at least one handrail ≤320	0.4



Legend: (a) Section through the handrail (b) Section through the staircase	Hh: Handrail Height Hex: Handrail extension Hw: Handrail-wall clearance

Figure 3.9 Schematic diagram for handrail and staircase section

3.3.3.6 Feature 6: minimum handrail-wall clearance

Handrail-wall clearance is the distance between the handrail and the surface behind it, as illustrated in Figure 3.9a. The handrail-wall clearance exists to provide a sufficient space to grasp the handrail in case of a falling emergency (Templer 1992b). This clearance should be not less than 40-mm if the surface of the wall is smooth, and a minimum of 50-mm-60-mm if the wall is rough, as stated in the Alberta building code (NRC 2006). However, in the recommendation for improving the safety of staircases, provided by national research council of Canada, the minimum recommended handrail-wall clearance is 57-mm, and even greater clearance in the case of rough walls, to prevent finger injuries (Pauls 1982). The barrier-free design guide recommended the handrail-wall clearance to be a minimum of 75-mm for heavily textured walls (SCC 2008). Therefore, the optimal minimum handrail-wall clearance will be considered as 57-mm for smooth wall surfaces and 75-mm for rough surfaces. The handrail-wall clearance could be rated using the rating system in Table 3.2, as illustrated in Table 3.10.

Table 3.10: Rating factors for scenarios of min handrail-wall clearance

Scenarios order number	Minimum handrail-wall clearance scenarios	Rating factor
1	Smooth wall surface and handrail-wall clearance ≥ 57-mm	1.00
2	Rough wall surface and handrail-wall clearance ≥ 75-mm	1.00
3	Smooth wall surface and handrail-wall clearance < 57-mm	0.4
4	Rough wall surface and handrail-wall clearance < 75-mm	0.4

3.3.4 Third: lighting

3.3.4.1 Feature 1: illumination level

A normal amount of lighting is not enough for older adults, as they often need a larger amount of lighting and consistent lighting throughout the entire staircases (IESNA 2007). It has been found that poor vision increases the risk of falling for older adults, as it reduces their postural stability (Lord and Dayhew 2001). In addition, the speed of walking up and down staircases has been found to be reduced when the amount of lighting provided on staircases is decreased (Zietz et al. 2011). In order to enhance the safety of older adults on staircases, an adequate amount of lighting needs to be provided (IESNA 2007). The Alberta building code requires minimum of 50-lux (NRC 2006). Templer (1992b) recommended

54-lux to 215-lux to be adequate illumination for staircases. Lighting for the aged and partially sighted committee at illuminating engineering society of North America recommended a minimum of 300-lux throughout the entire length of the staircases (IESNA 2007). Therefore the minimum amount of 300-lux will be considered to be the adequate illumination level for older adults. The adequate amount of lighting for older adults could be rated using the rating system in Table 3.2, as illustrated in Table 3.11.

Table 3.11: Rating factors for scenarios of the illumination level

Scenarios order number	Illumination level scenarios	Rating factor
1	illumination level ≥ 300-lux	1.00
2	illumination level ≤ 300-lux	0.4

3.3.4.2 Feature 2: consistency of lighting amount

IESNA (2007) recommended that lighting levels should be accomplished with consistency. Inconsistency of lighting throughout the length of staircases might result in bright light or shaded areas, which could cause confusion and falling (Templer 1992b); for example, as illustrated in Figure 3.3b, an extra lighting unit will be needed to eliminate the shaded area. For natural lighting, as the direction and amount of natural lighting changes throughout the day, Haslam and Stubbs (2006) recommended that windows should be positioned perpendicular to the flight direction. If the window is positioned in the right direction, it will provide a consistency of lighting throughout the length staircases. Rating factors in Table 3.2 are used to assess the consistency of lighting of artificial or daylight throughout the staircases, as illustrated in Table 3.12.

Table 3.12: Rating factors for scenarios of consistency of lighting amount

Scenarios order number	consistency of lighting amount scenarios	Rating factor
1	lighting throughout staircases is consistent	1.00
2	lighting throughout staircases is not consistent	0.4

3.3.4.3 Feature 3: lighting switches

The place in which the lighting switches are located is highly recommended to be away from the staircases' path and to be a two-way light switch (Haslam and Stubbs 2006; Templer 1992b). Templer (1992b) recommended that the switches should be placed away from the staircases' path, so an individual can reach it before initiating the process of ascending or descending the staircase, which reduces the hazard while searching for the light switch. Therefore, the optimal case is to have a light switch away from the staircases' path, and to be a two-way lighting switch. Rating of the lighting switch can be proposed as illustrated in Table 3.13, using the rating factors in Table 3.2.

Table 3.13: Rating factors for scenarios of lighting switches

.

Scenarios order number	light switches scenarios	Rating factor
1	Light switch away from staircases path and two ways light switch	1.00
2	Light switch through staircases path and two way light switch	0.6
3	Light switch through staircases path and one way light switch	0.6
4	Light switch away from staircases path and one way light switch	0.4

3.3.5 Fourth: step design

Step geometry is mainly controlled by tread and riser dimension, as illustrated in Figure 3.10. Building codes have provided minimum requirements for step dimensions, illustrated in Table 3.14 as follows: the Alberta building code requires riser height ranges between 125-mm and 200-mm, and tread depth ranges between 235-mm and 355-mm (NRC 2006); the building code of New York state requires riser height ranges between 178-mm and 102-mm, and tread depth ranges between 305-mm and 279-mm (BCNY 2007); the recommendation for improving safety on staircases, issued as a building practice note by national research council of Canada, recommended riser height ranges between 180-mm and 125-mm, and tread depth ranges between 350-mm and 280-mm (Pauls 1982).

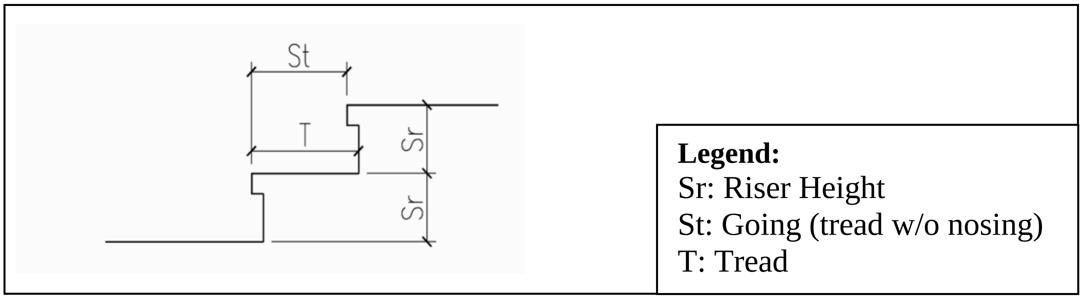


Figure 3.10 Schematic diagram of staircase section shows step dimensions

Table 3.14: Staircase step dimensions in different building codes

Code name	min riser (mm)	max riser (mm)	min tread (mm)	max tread (mm)
Alberta Building Code (ABC)	125	180	235	355
Building Code of New York state (BCNY)	102	178	279	305
National research council of Canada	125	180	280 or 300	350

3.3.5.1 Feature 1: going depth

In a study conducted by Irvine et al. (1990), the optimal staircase dimensions were investigated through 19 sets of staircases with different riser and tread dimensions, based on the most preferred and acceptable staircases for different age groups (from 19 to 69 years); the optimal going (tread without nosing) dimension was 279-mm or 300-mm, and the author highly recommended that the going dimension should not to be more than 330-mm or less than 254-mm. To assure safety on staircases, Templer (1992b) recommended a minimum going depth of 280-mm. For a very large going depth, it has been found to be difficult to climb (Templer 1992b), and the going depth should not exceed 330-mm (Irvine et al. 1990). Therefore, in this research, a minimum of 280-mm for going depth will be considered as the optimal case, and the optimal maximum limit for going depth will be 330-mm. Rating of the going (tread without nosing) depth can be proposed as illustrated in Table 3.15, using rating factors in Table 3.2.

Table 3.15: Rating factors for scenarios of going depth

Scenarios order number	Going (Tread without nosing) dimension scenarios (mm)	Rating factor
1	280 ≤ Tread depth dimension (w/o nosing) ≤ 330	1.00
2	Tread depth dimension (w/o nosing) ≤ 280	0.4
3	Tread depth dimension (w/o nosing) ≥ 330	0.4

3.3.5.2 Feature 2: riser height

The recommended dimension of optimal riser height for Irvine et al. (1990) study was 183-mm and the author highly recommended that risers less than 152-mm and over 203-mm should not be allowed. Templar (1992b) recommended not increasing the riser height over 190-mm as it becomes very difficult for an individual of different age to perform a one-legged balancing act while descending staircases. Also, Templer (1992b) recommended a minimum riser height of 127-mm to reduce the risk of falling on staircases for different ages. Therefore, in this research, the maximum riser height will be considered to be 190-mm, and the minimum riser height will be considered to be 127-mm. Rating of the riser height can be proposed as illustrated in Table 3.16, using rating factors in Table 3.2.

Table 3.16: Rating factors for scenarios of riser height

Scenarios order number	Riser dimensions scenarios (mm)	Rating factor
1	152≤ riser height dimension ≤190	1.00
2	riser height dimension ≤152	0.4
3	riser height dimension ≥190	0.4

3.3.5.3 Feature 3: nosing

Staircases without nosing have been found to be associated with higher risks of falling than ones with nosing (Templer 1992b). The Alberta building code requires nosing ranges from 15-mm to 25-mm (NRC 2006). The building code of New York state requires nosing ranges from 19.1-mm to 32-mm (BCNY 2007). As long nosing is found to be associated with a higher risk of falling (Templer 1992b), in this research, the safe nosing range will be considered to be from 15-mm to 25-mm. In addition, it is highly recommended that edges of staircases nose be rounded, to reduce the effect of shading through the staircases and reduce the severity of injury in case of falling (Pauls 1982). Therefore, nosing can be rated using the rating system in Table 3.2, as illustrated in Table 3.17.

Table 3.17: Rating factors for scenarios of nosing

Scenarios order number	nosing scenarios	Rating factor
1	15 ≤ nosing dimension ≤ 25 (mm) and rounded	1.00
2	15 ≤ nosing dimension ≤ 25 (mm) and not rounded	0.8
3	nosing dimension ≤ 15 (mm) and rounded	0.7
4	nosing dimension ≥ 25 (mm) and rounded	0.7
5	nosing dimension ≤ 15 (mm) and not rounded	0.5
6	nosing dimension ≥ 25 (mm) and not rounded	0.5

3.3.5.4 Feature 4: steps finishing material

Type of steps finishing material is more likely not to affect the risk of falling for older adults (Templer 1992b). However, for finishing materials of steps: 1) the material should be even throughout the entire staircases, so an individual does not trip or lose balance; and 2) the martial should provide uniform slip-resistance to prevent an individual from slipping (Pauls 1982; Templer 1992b). Therefore, regardless of the kind of finishing material on staircases, the optimal case is that finishing material should be even throughout the entire length of the staircases, and it should provide uniform slip-resistance. Therefore, finishing materials of steps can be rated using the rating system in Table 3.2 as illustrated in Table 3.18.

Table 3.18: Rating factors for scenarios of steps finishing material

Scenarios order number	Steps finishing material scenarios	Rating factor
1	Finish material provide evened throughout the staircases and provide uniform slip-resistance	1.00
2	Finish material provide un-evened throughout the staircases and provide uniform slip-resistance	0.6
3	Finish material provide evened throughout the staircases and provide not uniform slip-resistance	0.6
4	Finish material provide un-evened throughout the staircases and provide not uniform slip-resistance	0.4

3.4 Rating System for Staircase Design Elements and Features

3.4.1 Assessment procedures of staircase design

As it was illustrated before, staircase architectural design can be divided into four elements. These four elements are as follows: 1) staircase geometrical design element (G); 2) handrail design element (H); 3) lighting element (L); 4) step element (S).

Number of feature (n), under staircase geometrical design element (G), is 2 features represented in Table 3.19.

Table 3.19: features of staircase geometrical design element (G)

Feature No	Feature's name	Feature symbol	Alternative design scenarios in each feature
1	staircase geometry	G_g	-U-shape staircases -Quarter turn staircases -Straight staircases with landing -Straight staircases without landing -Helical staircases -Spiral staircases -Composite staircases
2	Number of steps per flight	G_s	- $10 \leq Gs \leq 12$ - $7 \leq Gs < 10$ - $Gs \leq 6$ - $Gs \geq 12$

Number of feature (n), under handrail design element (H), is 6 features represented in Table 3.20.

Table 3.20: Features of handrail design element (H)

Feature No	Feature's name	Feature symbol	Alternative design scenarios in each feature
1	Handrail existence	H_e	-Two handrail - One handrail - No handrail
2	Handrail height	H_h	- 910 ≤ H_h ≤ 970 (mm) - 970 ≤ H_h ≤ 1,000 (mm) - H_h ≥ 1,000 (mm) - H_h ≤ 910 (mm)
3	Handrail cross-section shape	H_c	- Handrail circular shape with circumferences between 100-mm (32-mm diameter) and 160-mm (51-mm diameter); and handrail oval shape with dimension of 50-mm height and 37-mm width. - Other handrail shapes and dimensions
4	Handrail surface texture	H_s	- comfortable handrail surface texture (not too smooth or not too rough) - difficult to grasp (too smooth handrail surface texture or too rough handrail surface texture)
5	Handrail extension	H_{ex}	- 320≤ H_{ex} on at least one handrail ≤ 480 (mm) - H_{ex} on at least one handrail ≥ 480 (mm) - No H_{ex} - H_{ex} on at least one handrail ≤320 (mm)
6	Minimum handrail-wall clearance	H_w	- Smooth wall surface and H_{ex} ≥ 57-mm - Rough wall surface and H_{ex} ≥ 75-mm - Smooth wall surface and H_{ex} < 57-mm - Rough wall surface and H_{ex} < 75-mm

Number of feature (n), under lighting element (L), is 3 represented in Table 3.21.

Table 3.21: Features of lighting element (L)

Feature No	Feature's name	Feature symbol	Alternative design scenarios in each feature
1	Illumination level	L_i	- $L_i \geq 300$-lux - $L_i \leq 300$-lux
2	Consistency of lighting amount	L_c	- Lighting throughout staircases is consistent - Lighting throughout staircases is not consistent
3	Light switches	L_s	- Light switch away from staircases path and two ways light switch - Light switch through staircases path and two way light switch - Light switch through staircases path and one way light switch - Light switch away from staircases path and one way light switch

Number of feature (n), step design element (S), is 3 represented in Table 3.22.

Table 3.22: Features of step design element (S)

Feature No	Feature's name	Feature symbol	Alternative design scenarios in each feature
1	Going (Tread without nosing) depth	S_g	- 280 ≤ S_g (w/o nosing) ≤330 (mm) - S_g (w/o nosing) ≤ 280 (mm) - S_g (w/o nosing) ≥330 (mm)
2	Riser height	S_r	- 152≤ S_r ≤190 (mm) - S_r ≤152 (mm) - S_r ≥190 (mm)
3	Nosing	S_n	- 15 ≤ nosing dimension ≤ 25 (mm) and rounded - 15 ≤ nosing dimension ≤ 25 (mm) and not rounded - Nosing dimension ≤15 (mm) and rounded - Nosing dimension ≥25 (mm) and rounded - Nosing dimension ≤15 (mm) and not rounded - Nosing dimension ≥25 (mm) and not rounded
4	steps finishing material	S_f	-Finish material provide evened throughout the staircases and provide uniform slip-resistance -Finish material provide un-evened throughout the staircases and provide uniform slip-resistance -Finish material provide evened throughout the staircases and provide not uniform slip-resistance -Finish material provide un-evened throughout the staircases and provide not uniform slip-resistance

3.4.2 Assessment calculations of staircase design

Giving the assumption that each feature, under each element, is affecting its element independently, an average rating factor ($\bar{R}$) for each element will be calculated based on the rating factor (R) for its features, which is calculated satisfying equation 3.5:

$$\bar{R}(Y)=\left(\sum R(X)\right)/n \quad \textbf{......... 3.5}$$

Where:

- Y is index for element symbol.
- $\bar{R}(Y)$ is the average rating factor ($\bar{R}$) for any element Y (for optimum staircase design, $\bar{R}(Y)$ will be equal to 1.00).
- R(X) is the rating factor (R) for feature X (for optimum staircase design features, R(X) will be equal to 1.00).
- n is the total number of features under element Y (from Tables 3.19, 3.20, 3.21 and 3.22, n=2 for staircase geometric design (G), n=6 for handrail design element (H), n=3 for lighting element (L), and n=3 for step design element (S), respectively).
- X is index for feature symbol.

Equation 3.5 can be expanded for staircase geometric design element (G), using n=2, as follows:

$$\bar{R}(G)=\left(R(G_g)+R(G_f)\right)/2 \quad \textbf{......... 3.6}$$

where:

- $\bar{R}(G)$ is average rating factor ($\bar{R}$) of staircase geometric design element (G).

- $R(G_g)$ is rating factor (R) for types of staircase geometric design (G_g)
- $R(G_s)$ is rating factor (R) for number of steps per flight (G_s).

Equation 3.5 can be expanded for handrail design element (H), using n=6, as follows:

$$\bar{R}(H)=\left(R(H_e)+R(H_h)+R(H_c)+R(H_s)+R(H_{ex})+R(H_w)\right)/6 \quad \textbf{3.7}$$

where:

- $\bar{R}(H)$ is average rating factor ($\bar{R}$) of handrail design element (H).
- $R(H_e)$ is rating factor (R) for existing of handrail (H_e).
- $R(H_h)$ is rating factor (R) for handrail height (H_h).
- $R(H_c)$ is rating factor (R) for handrail cross-section (H_c).
- $R(H_s)$ is rating factor (R) for handrail surface texture (H_s).
- $R(H_{ex})$ is rating factor (R) for handrail extension (H_{ex}).
- $R(H_w)$ is rating factor (R) for minimum handrail-wall clearance (H_w)

Equation 3.5 can be expanded for lighting element (L), using n=3, as follows:

$$\bar{R}(L)=\left(R(L_i)+R(L_c)+R(L_s)\right)/3 \quad \textbf{3.8}$$

where:

- $\bar{R}(L)$ is average rating factor ($\bar{R}$) of staircase geometric design element (L).
- R(Li) is rating factor (R) for illumination level (Li).
- R(Lc) is rating factor (R) for consistency of lighting amount (Lc).
- R(Ls) is rating factor (R) for consistency of light switches (Ls).

Equation 3.5 can be expanded for step design element (S), using n=3, as follows:

$$\bar{R}(S)=\left(R(S_g)+R(S_r)+R(S_n)+R(S_f)\right)/4 \text{ .... } \mathbf{3.9}$$

where:

- $\bar{R}(S)$ is average rating factor ($\bar{R}$) of staircase geometric design element (S).
- $R(S_g)$ is rating factor (R) for Going (Tread without nosing) dimension (S_g).
- $R(S_r)$ is rating factor (R) for Riser height dimension (S_r).
- $R(S_n)$ is rating factor (R) for nosing (S_n).
- $R(S_f)$ is rating factor (R) for steps finishing material (S_f).

The developed $\bar{R}$ will be multiplied by the rating number (N) of the element; the resultant rating number will be known as corrected rating number (N_c) satisfying equation 3.10:

$$N_c(Y)=\bar{R}(Y)\,N(Y) \text{ .... } \mathbf{3.10}$$

where:

- Y is index for element symbol (i.e. G for staircase geometric design element, H for handrail design element, L for lighting element, and S for step design element)
- $N_c(Y)$ is corrected rating number (N_c) for design element Y.
- $\bar{R}(Y)$ is the average rating factor ($\bar{R}$) for any element Y (for optimum design scenario: $\bar{R}(Y)=1.0$ and Nc(Y) will be equal to N(Y)).
- N(Y) is rating number (N) for design element Y (from Table 3.1: N(G)=37, N(H)= 27, N(L)= 21 and N(S)=15).

For staircase geometric design element (G), equation 3.10 will be represented as follows:

$$N_c(G)=\overline{R}\,(G)\,N(G) \qquad \textbf{3.11}$$

where:

- Nc(G) is corrected rating number (Nc) for staircase geometric design element (G).
- $\overline{R}$(G) is the average rating factor ($\overline{R}$) for staircase geometric design element (G).
- N(G) is rating number (N) for staircase geometric design element (G) (from Table 3.1: N(G)=37).

For handrail design element (H), equation 3.10 will be represented as follows:

$$N_c(H)=\overline{R}\,(H)\,N(H) \qquad \textbf{3.12}$$

where:

- N_c(H) is corrected rating number (N_c) for handrail design element (H).
- $\overline{R}$(H) is the average rating factor ($\overline{R}$) for handrail design element (H).
- N(H) is rating number (N) for handrail design element (H) (from Table 3.1: N(H)=27).

For lighting element (L), equation 3.10 will be represented as follows:

$$N_c(L)=\overline{R}\,(L)\,N(L) \qquad \textbf{3.13}$$

where:

- N_c(L) is corrected rating number (N_c) for lighting element (L).

- $\overline{R}(L)$ is the average rating factor ($\overline{R}$) for lighting element (L).
- N(L) is rating number (N) for lighting element (L) (from Table 3.1: N(L)=21).

For step design element (S), equation 3.10 will be represented as follows:

$$N_c(S)=\overline{R}(S)\,N(S) \quad \textbf{3.14}$$

where:

- $N_c(S)$ is corrected rating number (N_c) for step design element (S).
- $\overline{R}(S)$ is the average rating factor ($\overline{R}$) for step design element (S).
- N(S) is rating number (N) for step design element (S) (from Table 3.1: N(S) =15).

The developed N_c for each element, from equation 3.10, will be added to each other, forming a general rating number (N_{total}) for the whole staircase architectural design. The final N_{total} for the staircase will reflect the degree this staircase can reduce the risk of falling for older adults. N_{total} can be calculated satisfying the following equation 3.15:

$$N_{total}=\sum N_c(X) \quad \textbf{3.15}$$

where:

- Ntotal is general rating number of the whole staircase architectural design scenario (for optimum staircase architectural design scenario Ntotal will be equal to 100).
- Nc (X) is corrected rating number (Nc) for staircase design element (X).
- X is a designation parameter for design element symbol.

Equation 3.15 can be expanded for staircase design elements as follows:

$$N_{total} = N_c(G) + N_c(H) + N_c(L) + N_c(S) \quad \textbf{3.16}$$

where:

- N_{total} is general rating number of the whole staircase architectural design scenario (for optimum staircase architectural design scenario Ntotal will be equal to 100).
- $N_c(G)$ is corrected rating number (N_c) for staircase geometric design element (G).
- $N_c(H)$ is corrected rating number (N_c) for handrail design element (H).
- $N_c(L)$ is corrected rating number (N_c) for lighting element (L).
- $N_c(S)$ is corrected rating number (N_c) for step design element (S).

The calculated values of N_c and N_{total} will be evaluated using assessment tables in the following section.

3.4.3 Assessment tables of staircase design

This section illustrates the key assessment tables that are used to assess the developed rating values for different staircase architectural design scenarios from perspective of reducing the risk of falling for older adults. The assessment of corrected rating number (N_c) values for staircase geometrical design, handrail design, lighting and step design elements are represented by Tables 3.23, 3.24, 3.25 and 3.26, respectively.

Table 3.23: $N_c(G)$ assessment for staircase geometrical design element

Design Designation	Assessment range	Assessment Explanation
Optimal Design	37	The risk of falling for older adults is optimally reduced by the selected design element (Optimal design element)
	35-37	The design element is slightly under the optimal design element
	33-35	The design element is under the optimal design element
Strong Design	31-33	The design element is over the strong design element
	30-31	The design element is slightly over the strong design element
	28-30	The risk of falling for older adults is strongly reduced by the design element (Strong design element)
	26-28	The design element is slightly under the strong design element
	24-26	The design element is under the strong design element
Moderate Design	22-24	The design element is over the moderate design element
	20-22	The design element is slightly over the moderate design element
	19-20	The risk of falling for older adults is moderately reduced by the design element (moderate design element)
	17-19	The design element is slightly under the moderate design element
	15-17	The design element is under the moderate design element
Risk Promoting Design	13-15	The design element is over the risk promoting design element
	11-13	The design element is slightly over the risk promoting design element
	9-11	The risk of falling for older adults is promoted by the design element (Risk promoting design element)
	7-9	The risk of falling for older adults is highly increased by the design element
	6-7	The risk of falling for older adults is strongly increased by the design element
Highest Risk Design	4-6	The risk of falling for older adults is over the highest risk of falling
	2-4	The risk of falling for older adults is slightly over the highest risk of falling
	0-2	The highest risk of falling or the design element does not exist

Table 3.24: $N_c(H)$ assessment for staircase handrail design element

Design Designation	Assessment range	Assessment Explanation
Optimal Design	27	The risk of falling for older adults is optimally reduced by the selected design element (Optimal design element)
	26-27	The design element is slightly under the optimal design element
	24-26	The design element is under the optimal design element
Strong Design	23-24	The design element is over the strong design element
	22-23	The design element is slightly over the strong design element
	20-22	The risk of falling for older adults is strongly reduced by the design element (Strong design element)
	19-20	The design element is slightly under the strong design element
	18-19	The design element is under the strong design element
Moderate Design	16-18	The design element is over the moderate design element
	15-16	The design element is slightly over the moderate design element
	14-15	The risk of falling for older adults is moderately reduced by the design element (moderate design element)
	12-14	The design element is slightly under the moderate design element
	11-12	The design element is under the moderate design element
Risk Promoting Design	9-11	The design element is over the risk promoting design element
	8-9	The design element is slightly over the risk promoting design element
	7-8	The risk of falling for older adults is promoted by the design element (Risk promoting design element)
	5-7	The risk of falling for older adults is highly increased by the design element
	4-5	The risk of falling for older adults is strongly increased by the design element
Highest Risk Design	3-4	The risk of falling for older adults is over the highest risk of falling
	1-3	The risk of falling for older adults is slightly over the highest risk of falling
	0-1	The highest risk of falling or the design element does not exist

Table 3.25: N_c(L) assessment for lighting element

Design Designation	Assessment range	Assessment Explanation
Optimal Design	21	The risk of falling for older adults is optimally reduced by the selected design element (Optimal design element)
	20-21	The design element is slightly under the optimal design element
	19-20	The design element is under the optimal design element
Strong Design	18-19	The design element is over the strong design element
	17-18	The design element is slightly over the strong design element
	16-17	The risk of falling for older adults is strongly reduced by the design element (Strong design element)
	15-16	The design element is slightly under the strong design element
	14-15	The design element is under the strong design element
Moderate Design	13-14	The design element is over the moderate design element
	12-13	The design element is slightly over the moderate design element
	11-12	The risk of falling for older adults is moderately reduced by the design element (moderate design element)
	9-11	The design element is slightly under the moderate design element
	8-9	The design element is under the moderate design element
Risk Promoting Design	7-8	The design element is over the risk promoting design element
	6-7	The design element is slightly over the risk promoting design element
	5-6	The risk of falling for older adults is promoted by the design element (Risk promoting design element)
	4-5	The risk of falling for older adults is highly increased by the design element
	3-4	The risk of falling for older adults is strongly increased by the design element
Highest Risk Design	2-3	The risk of falling for older adults is over the highest risk of falling
	1-2	The risk of falling for older adults is slightly over the highest risk of falling
	0-1	The highest risk of falling or the design element does not exist

Table 3.26: $N_c(S)$ assessment for step design element

Design Designation	Assessment range	Assessment Explanation
Optimal Design	15	The risk of falling for older adults is optimally reduced by the selected design element (Optimal design element)
	14-15	The design element is slightly under the optimal design element
Strong Design	13-14	The design element is under the strong design element
	12-13	The design element is over the strong design element
	11-12	The risk of falling for older adults is strongly reduced by the design element (Strong design element)
	10-11	The design element is under the strong design element
Moderate Design	9-10	The design element is over the moderate design element
	8-9	The risk of falling for older adults is moderately reduced by the design element (moderate design element)
	7-8	The design element is slightly under the moderate design element
	6-7	The design element is under the moderate design element
Risk Promoting Design	5-6	The design element is over the risk promoting design element
	4-5	The risk of falling for older adults is promoted by the design element (Risk promoting design element)
	3-4	The risk of falling for older adults is highly increased by the design element
	2-3	The risk of falling for older adults is strongly increased by the design element
Highest Risk Design	1-2	The risk of falling for older adults is slightly over the highest risk of falling
	0-1	The highest risk of falling or the design element does not exist

Staircase general rating number (N_{total}) for whole staircase design scenario can be assessed using Table 3.27.

Table 3.27: N_{total} assessment for whole staircase design scenario

Design Designation	Assessment range	Assessment Explanation
Optimal Design	100	The risk of falling for older adults is optimally reduced by the selected staircase design (Optimal staircase design)
	95-100	The staircase design is slightly under the optimal staircase design
	90-95	The staircase design is under the optimal staircase design
Strong Design	85-90	The staircase design is over the strong staircase design
	80-85	The staircase design is slightly over the strong staircase design
	75-80	The risk of falling for older adults is strongly reduced by the staircase design (Strong staircase design)
	70-75	The staircase design is slightly under the strong staircase design
	65-70	The staircase design is under the strong staircase design
Moderate Design	60-65	The staircase design is over the moderate staircase design
	55-60	The staircase design is slightly over the moderate staircase design
	50-55	The risk of falling for older adults is moderately reduced by the staircase design (moderate staircase design)
	45-50	The staircase design is slightly under the moderate staircase design
	40-45	The staircase design is under the moderate staircase design
Risk Promoting Design	35-40	The staircase design is over the risk promoting staircase design
	30-35	The staircase design is slightly over the risk promoting staircase design
	25-30	The risk of falling for older adults is promoted by the staircase designs (Risk promoting staircase design)
	20-25	The risk of falling for older adults is highly increased by the staircase design
	15-20	The risk of falling for older adults is strongly increased by the staircase design
Highest Risk Design	10-15	The risk of falling for older adults is over the highest risk of falling
	5-10	The risk of falling for older adults is slightly over the highest risk of falling
	0-5	The highest risk of falling

3.5 Developed Design Assessment Tree (DAT)

Design Assessment Tree (DAT) can be described as a decision tree that has only decision nodes; therefore, there are no portability values for the tree branches. An individual Design Assessment Tree (DAT) is developed for each staircase element, representing the scenarios of each feature, as illustrated in Figure 3.11.

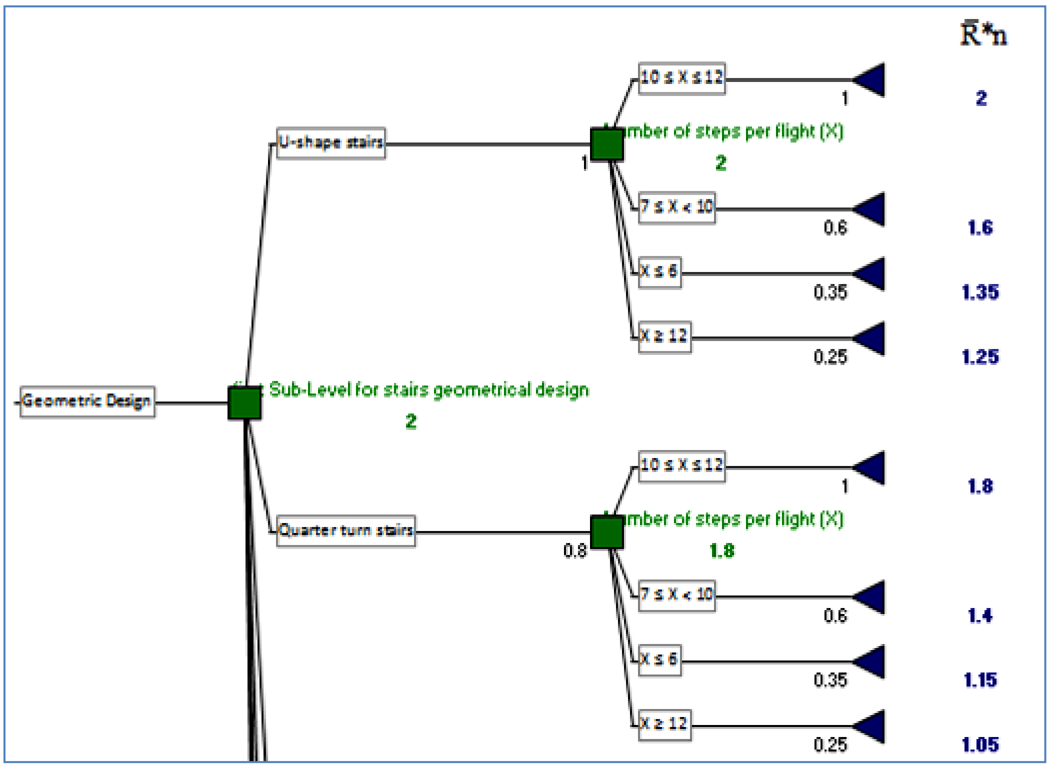


Figure 3.11 Screen shot of the staircase geometric design DAT

As illustrated in Figure 3.12, each individual branch in the DAT will carry the rating factor (R) of each scenario. At the end of each DAT branches, there will be 3 columns: 1st column is for $\bar{R}$ (calculated satisfying equation 3.5) multiplied by n (total number of features in the DAT); 2nd column is $\bar{R}$ value for each design scenario, and it is calculated by satisfying equation 3.5; 3rd column is for N_c value for each design scenario, and it is calculated by satisfying equation 3.10. N_{total} is the summation of N_c values for selected design scenario from each DAT. N_{total} is calculated satisfying equation 3.16. DAT for each design element is capable to show optimum and worst design scenarios, as illustrated if Figure 3.13.

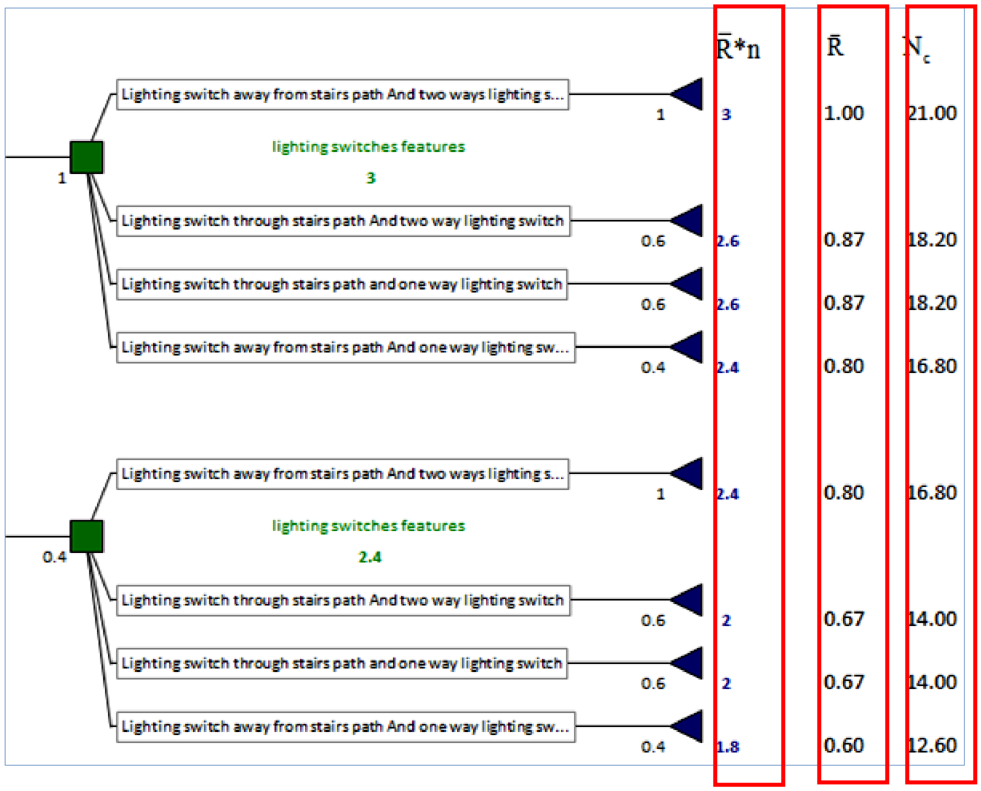


Figure 3.12 Screen shot of the lighting DAT illustrates $\bar{R}$ and N_c

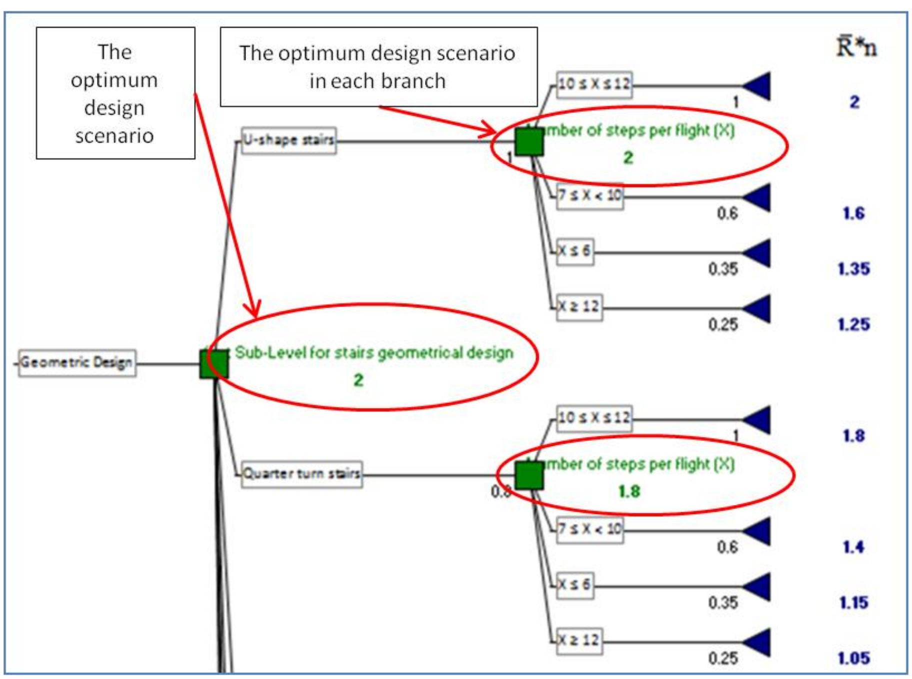


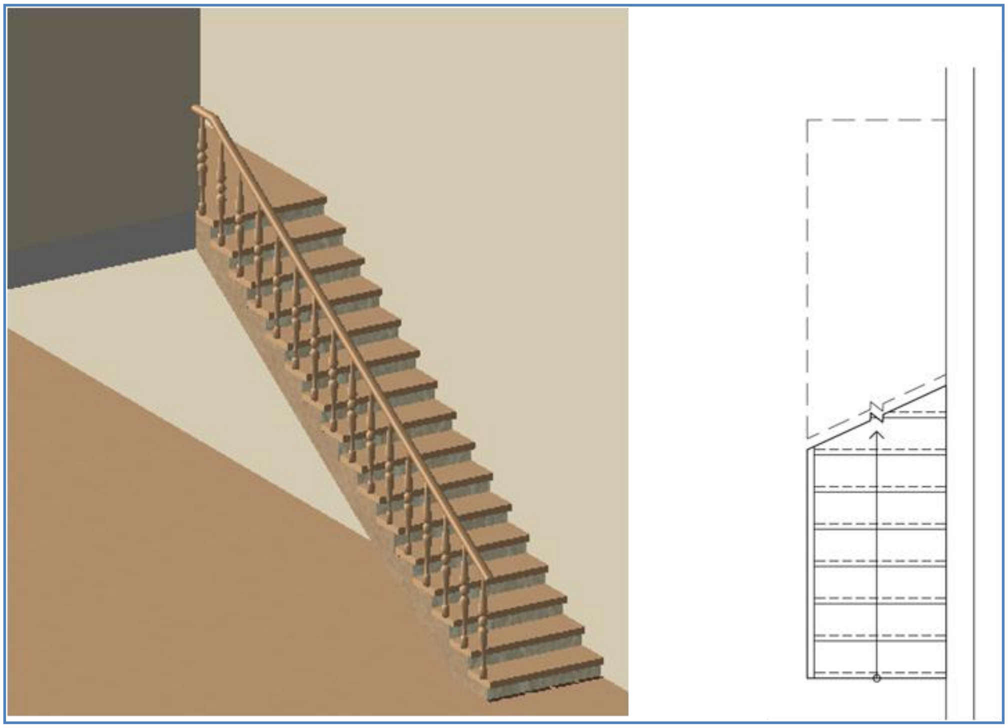
Figure 3.13 Screen shot of the staircase geometrical design DAT

3.6 Implementation of the Developed Rating System – Case Studies

In this section, three practical case studies of staircases are evaluated from the perspective of reducing the risk of falling for older adults using the proposed methodology. The three case studies are: 1) straight staircases without landing, 2) U-shape staircases, and 3) quarter turn staircases. The purpose of this section is to provide an example of how to implement the proposed calculations provided in the methodology and how to use DAT for the same purpose. A comparison between U-shaped staircases and quarter turn staircases is provided in this section. U-shaped staircases and the quarter turn staircases are chosen to represent two close staircase geometries, in order to track the effect of the staircase geometrical design element in the final assessment of the staircase. In addition, a sensitivity analysis is provided at the end of this section in order to examine the level of confidence in the assumption of having a 25% difference between the rating numbers of the four elements. This sensitivity analysis is applied through a comparison between the U-shaped staircases and the straight staircases without landing.

3.6.1 Straight staircases without landing

The proposed staircase, illustrated in Figure 3.14, is for straight staircases without landing with the following specifications: number of steps per flight = 16, handrail height = 900-mm and it exists in one side only, handrail cross-section shape is rectangle with smoothed edges, illumination level = 250-lux, lighting throughout staircases is consistent, light switch away from staircases path and two ways light switch, going dimension = 269-mm, riser height = 174-mm, nosing dimension = 40-mm.



(a) (b)

Figure 3.14(a) Perspective of straight staircases without landing and (b) plan for it

3.6.1.1 Staircase assessment using tables and calculations

The following Tables (3.28, 3.29, 3.30 and 3.31) illustrate: 1) the different features under each design element; 2) R values for all design features; and 3) tables used to get values of R.

Table 3.28: Features of staircase geometric design element (G)

Feature No	**Feature's name**	**Feature symbol**	**Proposed design**	**Rating factor (R)**	**Table used to get (R)**
1	Staircase geometry	G_g	Straight staircases without landing	0.4	Table 3.1
2	Number of steps per flight	G_s	(G_s=16 steps) ≥ 12	0.25	Table 3.4

Table 3.29: Features of handrail design element (H)

Feature No	Feature's name	Feature symbol	Proposed design	Rating factor (R)	Table used to get (R)
1	Handrail existence	H_e	One handrail	0.7	Table 3.5
2	Handrail height	H_h	$(H_h = 900) \leq 910$-mm	0.4	Table 3.6
3	Handrail cross-section shape	H_c	Other handrail shapes and dimensions	0.7	Table 3.7
4	Handrail surface texture	H_s	comfortable handrail surface texture (not too smooth or not too rough)	1	Table 3.8
5	Handrail extension	H_{ex}	No handrail extension	0.5	Table 3.9
6	Minimum Handrail-wall clearance	H_w	Smooth wall surface and handrail-wall clearance ≥ 57-mm	1	Table 3.10

Table 3.30: Features of lighting element (L)

Feature No	Feature's name	Feature symbol	Proposed design	Rating factor (R)	Table used to get (R)
1	illumination level	L_i	$(L_i$=250-lux$) \leq 300$-lux	0.4	Table 3.11
2	consistence lighting amount	L_c	Lighting throughout staircases is consistent	1	Table 3.12
3	light switches	L_s	Light switch away from staircases path and two ways light switch	1	Table 3.13

Table 3.31: Features of step design element (S)

Feature No	Feature's name	Feature symbol	Proposed design	Rating factor (R)	Table used to get (R)
1	Going (Tread without nosing) depth	S_g	(S_g= 269-mm) $\leq$ 280-mm	0.4	Table 3.15
2	Riser height	S_r	152$\leq$ (S_r = 174-mm)$\leq$190-mm	1	Table 3.16
3	nosing	S_n	(Nosing dimension=40-mm) $\geq$25-mm and not rounded	0.5	Table 3.17
4	steps finishing material	S_f	Finish material provide evened throughout the staircases and provide uniform slip-resistance	1	Table 3.18

The average rating factor ($\bar{R}$) for staircase geometrical design element (G) is calculated satisfying equation 3.6 as follows:

$$\bar{R}(G) = \left(0.4 + 0.25\right)/2 = 0.325 \quad \textbf{3.17}$$

The average rating factor ($\bar{R}$) for handrail design element (H) is calculated satisfying equation 3.7 as follows:

$$\bar{R}(H) = \left(0.7 + 0.4 + 0.7 + 1 + 0.5 + 1\right)/6 = 0.72 \quad \textbf{3.18}$$

The average rating factor ($\bar{R}$) for lighting element (L) is calculated satisfying equation 3.8 as follows:

$$\bar{R}(L) = (0.4 + 1 + 1)/3 = 0.8 \quad \textbf{3.19}$$

The average rating factor ($\bar{R}$) step design element (S) is calculated satisfying equation 3.9 as follows:

$$\bar{R}(S) = (0.4 + 1 + 0.5 + 1)/4 = 0.725 \quad \textbf{3.20}$$

The corrected rating number for staircase geometric design element (G) is calculated satisfying equation 3.11 as follows:

$$N_c(G) = \bar{R}\,(G)\;N(G) = 0.325*37 = 12.025 \quad \textbf{3.21}$$

The corrected rating number for the staircase geometrical design ($N_c(G)$) is 12.025; from Table 3.23, $N_c(G)$= 12.025 means that the design element is slightly over the risk promoting design element (risk promoting design).

The corrected rating number for handrail design element (H) is calculated satisfying equation 3.12 as follows:

$$N_c(H) = \bar{R}\,(H)\;N(H) = 0.72*27 = 19.35 \quad \textbf{3.22}$$

The corrected rating number for the handrail design ($N_c(H)$) is 19.35; from Table 3.1, $N_c(H)$=19.35 means that the risk of falling for older adults is moderately reduced by the design element (moderate design).

The corrected rating number for lighting element (L) is calculated satisfying equation 3.13 as follows:

$$N_c(L) = \bar{R}\,(L)\;N(L) = 0.8*21 = 16.8 \quad \textbf{3.23}$$

The corrected rating number for lighting element ($N_c(L)$) is 16.80; from Table 3.1, $N_c(L)$=16.80 means that the risk of falling for older adults is strongly reduced by the design element (strong design).

The corrected rating number for steps design element (S) is calculated satisfying equation 3.14 as follows:

$$N_c(S) = \bar{R}(S)\, N(S) = 0.725*15 = 10.88 \quad \textbf{3.24}$$

The corrected rating number for the step design ($N_c(S)$) is 10.88; from Table **3.26**, $N_c(S)$=10.88 means that the design element is under the strong design element (strong design).

The general rating number (N_{total}) for the whole staircase architectural design is calculating satisfying equation 3.16 as follows:

$$\begin{aligned} N_{total} &= N_c(G)+N_c(H)+N_c(L)+N_c(S) \\ &= 12.025+19.35+16.8+10.875 = 59.05 \end{aligned} \quad \textbf{3.25}$$

N_{total}, general rating number of the whole proposed staircase architectural design, is 59.05; from Table 3.27, N_{total}=59.05 means that the staircase design is slightly over the moderate staircase design (moderate design).

3.6.1.2 Staircase assessment using DAT

The corrected rating numbers of different elements can be extracted directly from the DAT for each design scenario. The corrected rating number $N_c(G)$ can be extracted from DAT for staircase geometrical design, as illustrated in Figure 3.15 (the highlighted part). $N_c(G)$ value extracted from DAT is 12.03 which is the same as the value that has been calculated previously in equation 3.21. Other corrected rating numbers ($N_c(H)$, $N_c(L)$ and $N_c(S)$), can be found using the same procedures used for $N_c(G)$, and their values are the same as the values that has been calculated previously using equations 3.22, 3.23 and 3.24, respectively. By using equation 3.16, the general rating number of the whole staircase architectural design scenario (N_{total}) is the same as the value that has been previously calculated (N_{total}=59.05) by using equation 3.25.

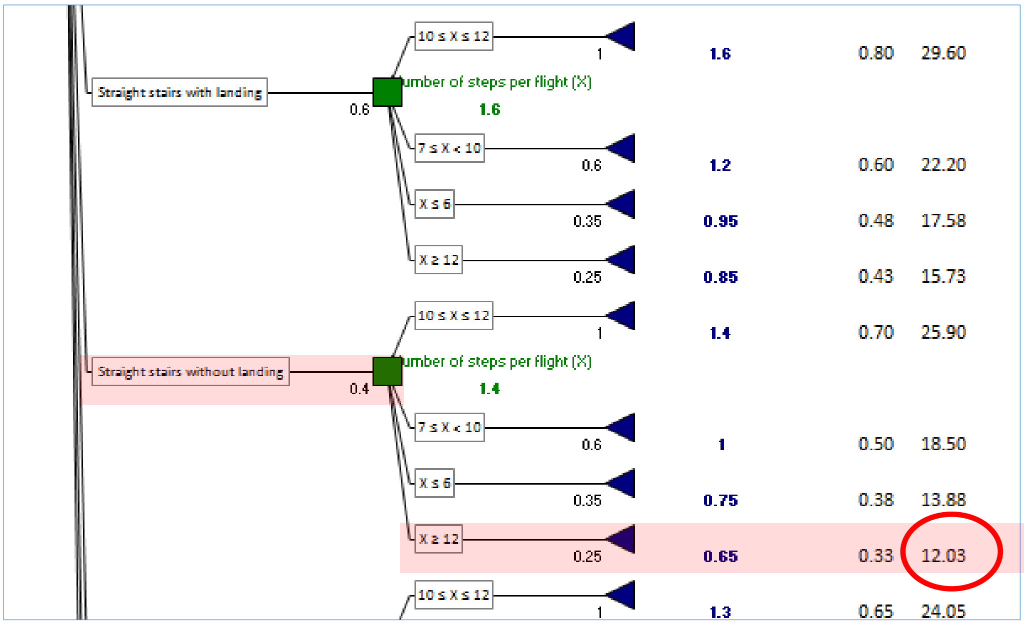
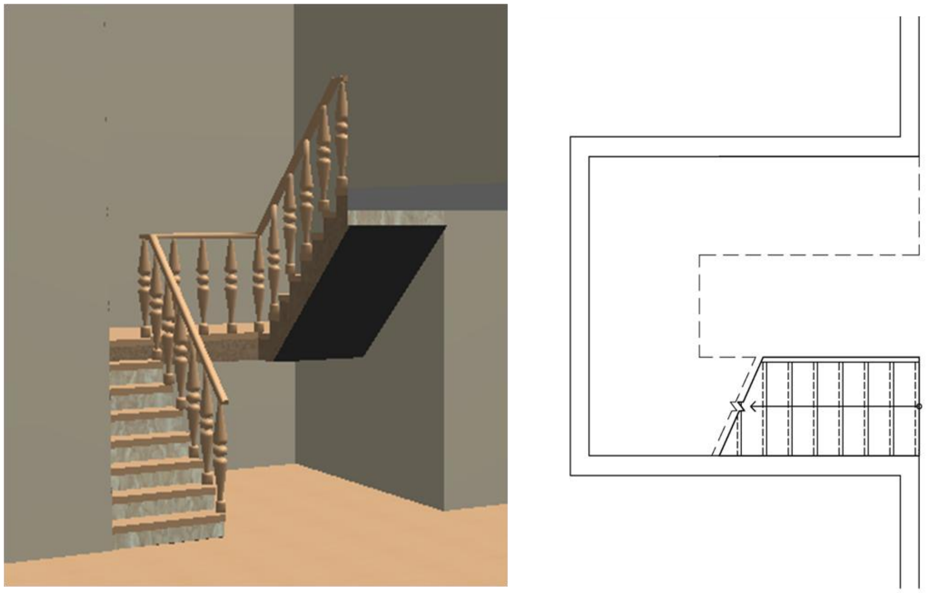


Figure 3.15 Staircase geometrical design rating number for the case study

3.6.2 U-shape staircases

The proposed staircase, illustrated in Figure 3.16, is for U-shape staircases with the following specifications: number of steps per flight = 8, handrail height = 900-mm and it exists in one side only, handrail cross-section shape is rectangle with smoothed edges, illumination level = 250-lux, lighting throughout staircases is consistent, light switch away from staircases path and two ways light switch, going dimension = 269-mm, riser height = 174-mm, nosing dimension = 40-mm.



(a) (b)

Figure 3.16 (a) Perspective of U-shape staircase and (b) plan for it

3.6.2.1 Staircase assessment using tables and calculations

The following Tables (3.32, 3.33, 3.34 and 3.35) illustrate: 1) the different features under each design element; 2) R values for all design features; and 3) tables used to get values of R.

Table 3.32: Features of staircase geometric design element (G)

Feature No	**Feature's name**	**Feature symbol**	**Proposed design**	**Rating factor (R)**	**Table used to get (R)**
1	Staircase geometry	G_g	U-shape staircase	1	Table 3.1
2	Number of steps per flight	G_s	$7 \geq (G_s=8 \text{ steps}) \geq 10$	0.6	Table 3.4

Table 3.33: Features of handrail design element (H)

Feature No	Feature's name	Feature symbol	Proposed design	Rating factor (R)	Table used to get (R)
1	Handrail existence	H_e	One handrail	0.7	Table 3.5
2	Handrail height	H_h	(H_h = 900) ≤ 910-mm	0.4	Table 3.6
3	Handrail cross-section shape	H_c	Other handrail shapes and dimensions	0.7	Table 3.7
4	Handrail surface texture	H_s	comfortable handrail surface texture (not too smooth or not too rough)	1	Table 3.8
5	Handrail extension	H_{ex}	No handrail extension	0.5	Table 3.9
6	Minimum Handrail-wall clearance	H_w	Smooth wall surface and handrail-wall clearance ≥ 57-mm	1	Table 3.10

Table 3.34: Features of lighting element (L)

Feature No	Feature's name	Feature symbol	Proposed design	Rating factor (R)	Table used to get (R)
1	illumination level	L_i	(L_i=250-lux) ≤ 300-lux	0.4	Table 3.11
2	consistency of lighting amount	L_c	Lighting throughout staircases is consistent	1	Table 3.12
3	light switches	L_s	Light switch away from staircases path and two ways light switch	1	Table 3.13

Table 3.35: Features of step design element (S)

Feature No	Feature's name	Feature symbol	Proposed design	Rating factor (R)	Table used to get (R)
1	Going (Tread without nosing) depth	S_g	(S_g= 269-mm) ≤ 280-mm	0.4	Table 3.15
2	Riser height	S_r	152≤ (S_r = 174-mm)≤190-mm	1	Table 3.16
3	nosing	S_n	(Nosing dimension=40-mm) ≥25-mm and not rounded	0.5	Table 3.17
4	steps finishing material	S_f	Finish material provide evened throughout the staircases and provide uniform slip-resistance	1	Table 3.18

The average rating factor ($\bar{R}$) for staircase geometrical design element (G) is calculated satisfying equation 3.6 as follows:

$$\bar{R}(G) = (1+0.6)/2 = 0.8 \quad \textbf{3.26}$$

The average rating factor ($\bar{R}$) for handrail design element (H) is calculated satisfying equation 3.7 as follows:

$$\bar{R}(H) = (0.7 + 0.4 + 0.7 + 1 + 0.5 + 1)/6 = 0.72 \quad \textbf{3.27}$$

The average rating factor ($\bar{R}$) for lighting element (L) is calculated satisfying equation 3.8 as follows:

$$\bar{R}(L) = (0.4 + 1 + 1)/3 = 0.8 \quad \textbf{3.28}$$

The average rating factor ($\bar{R}$) step design element (S) is calculated satisfying equation 3.9 as follows:

$$\bar{R}(S) = (0.4 + 1 + 0.5 + 1)/4 = 0.725 \quad \textbf{3.29}$$

The corrected rating number for staircase geometric design element (G) is calculated satisfying equation 3.11 as follows:

$$N_c(G) = \bar{R}\,(G)\; N(G) = 0.8*37 = 29.6 \quad \textbf{3.30}$$

The corrected rating number for the staircase geometrical design ($N_c(G)$) is 29.6; from Table 3.23, $N_c(G)$= 29.6 means that the risk of falling for older adults is strongly reduced by the design element (strong design).

The corrected rating number for handrail design element (H) is calculated satisfying equation 3.12 as follows:

$$N_c(H) = \bar{R}\,(H)\; N(H) = 0.72*27 = 19.35 \quad \textbf{3.31}$$

The corrected rating number for the handrail design ($N_c(H)$) is 19.35; from Table 3.1, $N_c(H)$=19.35 means that the risk of falling for older adults is moderately reduced by the design element (moderate design).

The corrected rating number for lighting element (L) is calculated satisfying equation 3.13 as follows:

$$N_c(L) = \bar{R}\,(L)\; N(L) = 0.8*21 = 16.8 \quad \textbf{3.32}$$

The corrected rating number for lighting element ($N_c(L)$) is 16.80; from Table 3.1, $N_c(L)=16.80$ means that the risk of falling for older adults is strongly reduced by the design element (strong design).

The corrected rating number for steps design element (S) is calculated satisfying equation 3.14 as follows:

$$N_c(S) = \bar{R}(S)\,N(S) = 0.725*15 = 10.88 \quad \textbf{3.33}$$

The corrected rating number for the step design ($N_c(S)$) is 10.88; from Table **3.26**, $N_c(S)=10.88$ means that the design element is under the strong design element (strong design).

The general rating number (N_{total}) for the whole staircase architectural design is calculating satisfying equation 3.16 as follows:

$$\begin{aligned} N_{total} &= N_c(G)+N_c(H)+N_c(L)+N_c(S) \\ &= 29.6+19.35+16.8+10.875 = 76.63 \end{aligned} \quad \textbf{3.34}$$

N_{total}, general rating number of the whole proposed staircase architectural design, is 76.63; from Table 3.27, $N_{total}=76.63$ means that the risk of falling for older adults is strongly reduced by the staircase design (strong staircase design).

3.6.2.2 Staircase assessment using DAT

The corrected rating numbers of different elements can be extracted directly from the DAT for each design scenario. The corrected rating number $N_c(G)$ can be extracted from DAT for staircase geometrical design, as illustrated in Figure 3.17 (the highlighted part). $N_c(G)$ value extracted from DAT is 29.6 which is the same as the value that has been calculated previously in equation 3.30 . Other corrected rating numbers (Nc(H), Nc(L) and Nc(S)), can be found using the same procedures used for $N_c(G)$, and their values are the same as the values that has been calculated previously using equations 3.31, 3.32 and 3.33, respectively. By satisfying equation 3.16, the general rating number of the whole staircase architectural design scenario (N_{total}) is the same as the value that has been previously calculated (N_{total}=76.63) by using equation 3.34.

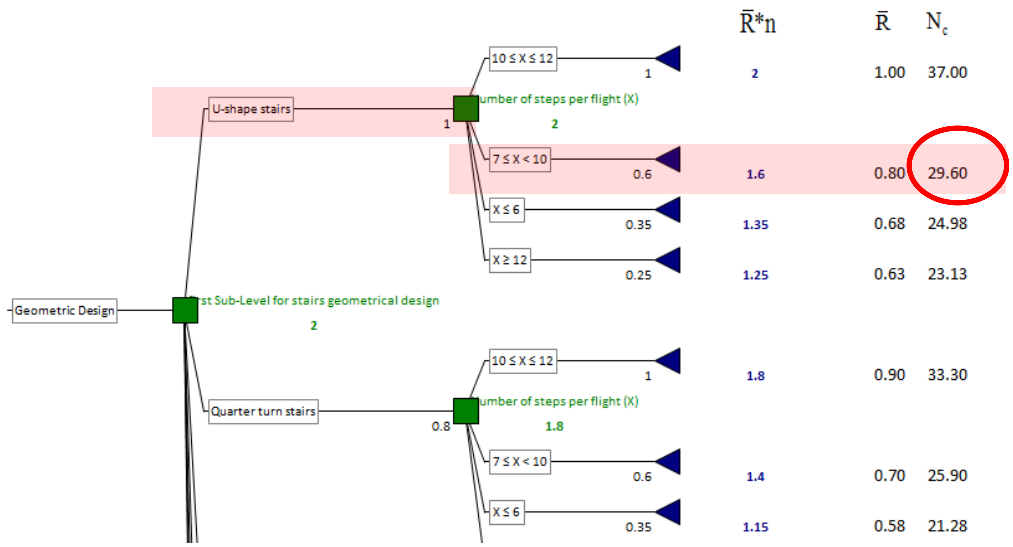
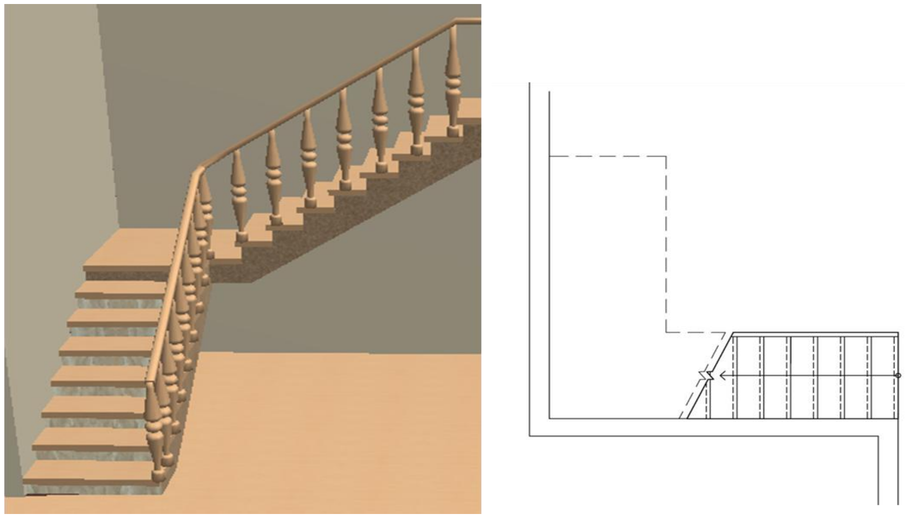


Figure 3.17 Staircase geometrical design rating number for the case study

3.6.3 Quarter turn staircases

The proposed staircase, illustrated in Figure 3.18 , is for quarter turn staircases with the following specifications: number of steps per flight = 8, handrail height = 900-mm and it exists in one side only, handrail cross-section shape is rectangle with smoothed edges, illumination level = 250-lux, lighting throughout staircases is consistent, light switch away from staircases path and two ways light switch, going dimension = 269-mm, riser height = 174-mm, nosing dimension = 40-mm.



(a) (b)

Figure 3.18 (a) Perspective of quarter turn staircase and (b) plan for it

3.6.3.1 Staircase assessment using tables and calculations

The following Tables (3.36, 3.37,3.38 and 3.39) illustrate: 1) the different features under each design element; 2) R values for all design features; and 3) tables used to get values of R.

Table 3.36: Features of staircase geometric design element (G)

Feature No	Feature's name	Feature symbol	Proposed design	Rating factor (R)	Table used to get (R)
1	Staircase geometry	G_g	Quarter turn staircase	0.8	Table 3.1
2	Number of steps per flight	G_s	$7 \geq (G_s=8 \text{ steps}) \geq 10$	0.6	Table 3.4

Table 3.37: Features of handrail design element (H)

Feature No	Feature's name	Feature symbol	Proposed design	Rating factor (R)	Table used to get (R)
1	Handrail existence	H_e	One handrail	0.7	Table 3.5
2	Handrail height	H_h	(H_h = 900) ≤ 910-mm	0.4	Table 3.6
3	Handrail cross-section shape	H_c	Other handrail shapes and dimensions	0.7	Table 3.7
4	Handrail surface texture	H_s	comfortable handrail surface texture (not too smooth or not too rough)	1	Table 3.8
5	Handrail extension	H_{ex}	No handrail extension	0.5	Table 3.9
6	Minimum Handrail-wall clearance	H_w	Smooth wall surface and handrail-wall clearance ≥ 57-mm	1	Table 3.10

Table3.38: Features of lighting element (L)

Feature No	Feature's name	Feature symbol	Proposed design	Rating factor (R)	Table used to get (R)
1	illumination level	L_i	(L_i=250-lux) ≤ 300-lux	0.4	Table 3.11
2	consistency of lighting amount	L_c	Lighting throughout staircases is consistent	1	Table 3.12
3	light switches	L_s	Light switch away from staircases path and two ways light switch	1	Table 3.13

Table 3.39: Features of step design element (S)

Feature No	Feature's name	Feature symbol	Proposed design	Rating factor (R)	Table used to get (R)
1	Going (Tread without nosing) depth	S_g	(S_g= 269-mm) ≤ 280-mm	0.4	Table 3.15
2	Riser height	S_r	152≤ (S_r = 174-mm)≤190-mm	1	Table 3.16
3	nosing	S_n	(Nosing dimension=40-mm) ≥25-mm and not rounded	0.5	Table 3.17
4	steps finishing material	S_f	Finish material provide evened throughout the staircases and provide uniform slip-resistance	1	Table 3.18

The average rating factor ($\bar{R}$) for staircase geometrical design element (G) is calculated satisfying equation 3.6 as follows:

$$\bar{R}(G) = \left(0.8 + 0.6\right)/2 = 0.7 \quad \textbf{3.35}$$

The average rating factor ($\bar{R}$) for handrail design element (H) is calculated satisfying equation 3.7 as follows:

$$\bar{R}(H) = \left(0.7 + 0.4 + 0.7 + 1 + 0.5 + 1\right)/6 = 0.72 \quad \textbf{3.36}$$

The average rating factor ($\bar{R}$) for lighting element (L) is calculated satisfying equation 3.8 as follows:

$$\bar{R}(L) = \left(0.4 + 1 + 1\right)/3 = 0.8 \quad \textbf{3.37}$$

The average rating factor ($\bar{R}$) step design element (S) is calculated satisfying equation 3.9 as follows:

$$\bar{R}(S) = (0.4 + 1 + 0.5 + 1)/4 = 0.725 \quad \textbf{3.38}$$

The corrected rating number for staircase geometric design element (G) is calculated satisfying equation 3.11 as follows:

$$N_c(G) = \bar{R}\ (G)\ N(G) = 0.7*37 = 25.9 \quad \textbf{3.39}$$

The corrected rating number for the staircase geometrical design (N_c(G)) is 25.9; from Table 3.23, N_c(G)= 25.9 means that The design element is under the strong design element.

The corrected rating number for handrail design element (H) is calculated satisfying equation 3.12 as follows:

$$N_c(H) = \bar{R}\ (H)\ N(H) = 0.72*27 = 19.35 \quad \textbf{3.40}$$

The corrected rating number for the handrail design (N_c(H)) is 19.35; from Table 3.1, N_c(H)=19.35 means that the risk of falling for older adults is moderately reduced by the design element (moderate design).

The corrected rating number for lighting element (L) is calculated satisfying equation 3.13 as follows:

$$N_c(L) = \bar{R}\ (L)\ N(L) = 0.8*21 = 16.8 \quad \textbf{3.41}$$

The corrected rating number for lighting element (N_c(L)) is 16.80; from Table 3.1, N_c(L)=16.80 means that the risk of falling for older adults is strongly reduced by the design element (strong design).

The corrected rating number for steps design element (S) is calculated satisfying equation 3.14 as follows:

$$N_c(S) = \bar{R}(S)\, N(S) = 0.725*15 = 10.88 \quad \textbf{3.42}$$

The corrected rating number for the step design ($N_c(S)$) is 10.88; from Table **3.26**, $N_c(S)=10.88$ means that the design element is under the strong design element (strong design).

The general rating number (N_{total}) for the whole staircase architectural design is calculating satisfying equation 3.16 as follows:

$$\begin{aligned} N_{total} &= N_c(G)+N_c(H)+N_c(L)+N_c(S) \\ &= 25.9+19.35+16.8+10.875 = 72.93 \end{aligned} \quad \textbf{3.43}$$

N_{total}, general rating number of the whole proposed staircase architectural design, is 72.93; from Table 3.27, $N_{total}=72.93$ means that the staircase design is slightly under the strong staircase design.

3.6.3.2 Staircase assessment using DAT

The corrected rating numbers of different elements can be extracted directly from the DAT for each design scenario. The corrected rating number $N_c(G)$ can be extracted from DAT for staircase geometrical design, as illustrated in Figure 3.19 (the highlighted part). $N_c(G)$ value extracted from DAT is 25.9 which is the same as the value that has been calculated previously in equation 3.39 . Other corrected rating numbers (Nc(H), Nc(L) and Nc(S)), can be found using the same procedures used for $N_c(G)$, and their values are the same as the values that has been calculated previously using equations 3.40, 3.41 and, 3.42, respectively. By using equation 3.16, the general rating number of the whole staircase architectural design scenario (N_{total}) is the same as the value that has been previously calculated ($N_{total}=72.93$) by using equation 3.43.

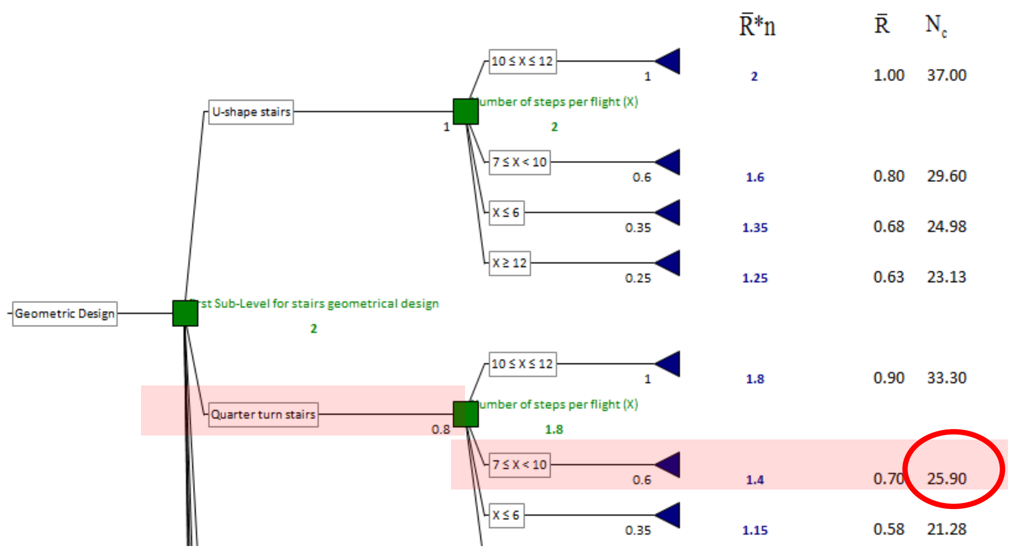


Figure 3.19 Staircase geometrical design rating number for the case study

3.6.4 Comparison between U-shaped staircases and quarter turn staircases

The previous case studies are used to track the effect of the staircase geometrical design element in the final assessment of the staircase. U-shaped staircases and quarter turn staircases are being assessed as two close staircase geometries by changing only the staircase geometry and keeping the handrail, lighting and step specifications the same, as illustrated in Table 3.40. The average rating factor for staircase geometrical design element $\bar{R}(G)$ for U-shaped staircases is 0.8, and for quarter turn staircases is 0.7; accordingly, the corrected rating number for staircase geometrical design element $N_c(G)$ for U-shaped staircases is 29.6, and for quarter turn staircases is 25.9. This affects the general rating number of the whole staircase architectural design (N_{total}) for U-shaped staircases to be 76.63 (which means: the risk of falling for older adults is strongly reduced by the staircase design), and for quarter turn staircases to be 72.93 (the staircase design is slightly under the strong staircase design). In conclusion, both U-shaped staircases and quarter turn staircases are considered to be “strong design”; however the U-shaped staircase design provides a better geometry than the quarter turn staircases, from the perspective of reducing the risk of falling for older adults. This makes the quarter turn stairs slightly under the strong design compared to the U-shaped staircases.

Table 3.40: Average rating factor for U-shapes and quarter turn staircase (S)

The average rating factor	U-shape staircases	Quarter turn staircases
$\bar{R}(G)$	0.8	0.7
$\bar{R}(H)$	0.716666667	0.716666667
$\bar{R}(L)$	0.8	0.8
$\bar{R}(S)$	0.725	0.725
$N_c(G)$	29.6	25.9
N_{total}	76.63	72.93

3.6.5 Sensitivity analysis

In this research, in order to compare the elements according to how much each of them reduces the risk of falling for older adults, a constant percentage of 25% is assumed to be the difference between the rating numbers of the four elements (staircase geometrical design, handrail design, lighting and step design elements). It's important to note that this research provides a framework for the staircase assessment through the proposed methodology, and that the purpose of this study is to give an integrated approach for that framework that's based on evidence-based studies.

In this section a sensitivity analysis is developed in order to examine the level of confidence in the previous assumption (25% difference between the rating numbers of the four elements). The sensitivity analysis is based on comparing two different types of staircase design geometry presented in the previous case studies; 1) the straight staircases without landing which has been found to be highly associated with a high risk of falling (Covinsky et al. 2009; Templer 1992b), 2) the U-shaped staircases which has been found to be one of the optimal staircase designs from the perspective of reducing the risk of falling (Svanstrom 1974;

Templer 1992b). As illustrated in Table 3.41, the general rating number (N_{total}) is being compared for the two staircase designs in four cases: 1) if the difference between the rating numbers of the four elements is zero, which means the weight for all the design elements is the same, or in other words, the four elements participate in reducing the risk of falling equally; 2) if the difference between the rating numbers of the four elements is 25%; 3) if the difference between the rating numbers of the four elements is 50%; 4) if the difference between the rating numbers of the four elements is 75%.

Table 3.41: General rating number at 0, 25%, 50%, and 75% difference

Average rating factor	Straight staircase without landing	U-shape staircase	0 difference	25% difference	50% difference	75% difference
$\bar{R}(G)$	0.33	0.8	**25**	**37**	**53.3**	**75.3**
$\bar{R}(H)$	0.72	0.72	**25**	**27**	**26.7**	**18.8**
$\bar{R}(L)$	0.8	0.8	**25**	**21**	**13.3**	**4.7**
$\bar{R}(S)$	0.73	0.73	**25**	**15**	**6.7**	**1.2**
Straight staircases without landing (N_{total})			**64.17**	**59.05**	**51.96**	**42.58**
U-shape staircases (N_{total})			**76.04**	**76.63**	**77.27**	**78.34**

The result of that sensitivity analysis can be presented by the comparison chart illustrated in Figure 3.20. In this chart, the general rating number $\mathbf{N_{total}}$ for straight staircases without landing has been found to be reduced by increasing the difference between the rating numbers of the four elements; this emphasizes the fact that this staircase design geometry is associated with a higher risk of falling. Also, the general rating number $\mathbf{N_{total}}$ for U-shaped staircases has been found to be increased by increasing the difference between the rating numbers of the four elements; this emphasizes the fact that the U-shaped staircase geometry reduced the risk of falling for older adults more than the staircases without landing, and gives a better assessment as the general rating number goes higher. However, looking closely at the weight of the average rating number for the 50% and 75% difference between the rating numbers of the four elements, the average rating number for the step design is 6.7 and 1.2 out of a total of 100 for the four design elements, which are very small numbers compared to the average rating number for the staircase geometrical design (53.3 and 75.3, respectively). From architecture perspective, step design is one of the effective elements in the staircase design, and the weight of 6.7 and 1.2 makes it irrelevant compared to the staircase geometrical design. Therefore, 50% and 75% difference between the rating numbers of the four elements will be excluded.

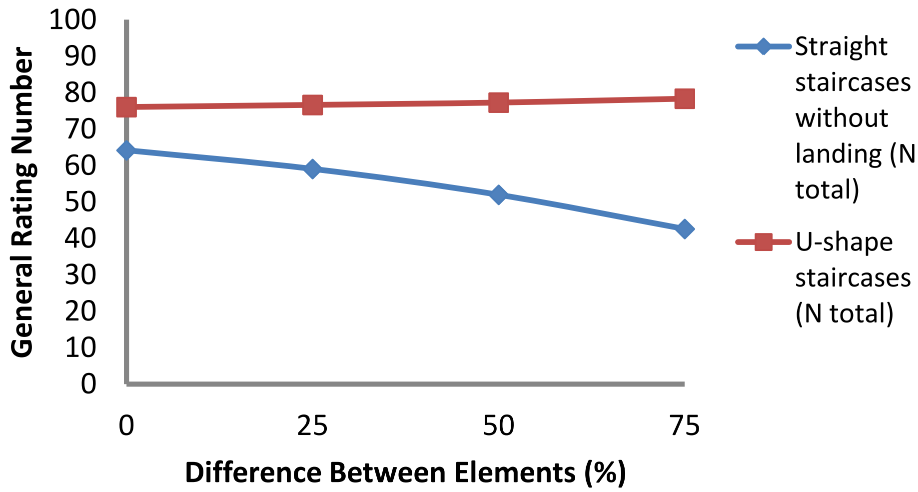


Figure 3.20 comparison between the general rating no of two staircase design

Looking to the general rating number (**N_{total}**) for 0 and 25% difference between the rating numbers of the four elements, the general rating numbers are very close in the case of U-shaped staircases (76.04 and 76.63). This gives the same result ,from Table 3.27, that the staircase design is a "strong design". In addition, the general rating numbers are close in the case of straight staircases without landing (64.16 and 59.05). This gives the same result, from Table 3.27, that the staircase design is a "moderate design". However, taking into consideration that the number 59.05 expresses a lower design assessment for the straight staircase without landing which emphasizes more the fact that this design is highly associated with the probability of increasing the risk of falling for older adults; therefore, the assumption of 25% is hypothetically the closest to emphasizing the fact that the U-shaped staircases are highly associated with reducing the risk of falling for older adults and the straight staircases are highly associated with increasing the risk of falling for older adults.

CHAPTER 4: CONCLUSION

4.1 Research Conclusion

This research proposes an innovative assessment for staircase architectural design which aims to reduce the risk of falling for older adults (65 years and older). The assessment has been developed by evidence-based analysis of the staircase elements. The staircase consists of four elements: 1) staircase geometrical design; 2) handrail design; 3) lighting; and 4) step design. The elements are followed by a number of features. Each design feature is evaluated according to its effect on reducing the risk of falling for older adults. The integrated staircase rating system will enable the designer to assess the proposed staircase's design aiming to reduce the risk of falling for older adults. Additionally the developed integrated staircase rating system can be used as a design tool to improve the staircase design through choosing alternative features. However, it should be noted that even with improving the staircase design older adults might experience falling.

A rating number (N) will be assigned to each element, representing the degree each element can effectively reduce the risk of falling for older adults on staircases. Each design feature is rated using rating factor (R). As each feature is assumed to affect its element independently, the average rating factor ($\overline{R}$) is calculated based on the R values of the design features under each element. From N and $\overline{R}$, a corrected rating number (N_c) is calculated for each element. This N_c enables the designer to rate each element in the staircase design. The summation of the elements' N_c values gives the total rating number that evaluates the whole staircase architectural design. A Design Assessment Tree (DAT) is developed, representing the four of the staircase elements and its associated features, which form the staircase design scenarios. Each element has its own developed DAT. The DAT enables the designer to extract directly the values of $\overline{R}$ and N_c for each element design scenario.

4.2 Research Contribution

- A staircase architectural design assessment has been developed which aims to reduce the risk of falling for older adults living independently in their homes. An evidence-based integrated architectural approach has been developed through constructing the staircase element analysis as part of improving the surrounding environment for older adults. The integrated architectural approach has been constructed through dividing the staircase into four elements: 1) staircase geometrical design; 2) handrail design; 3) lighting; and 4) step design.
- A complete rating system has been developed to assess the degree each design scenario reduces the risk of falling for older adults. The developed rating system is built based on groups of rating factors and numbers. A mathematical model is developed to evaluate each design element individually as well as the whole staircase design.
- A Design Assessment Tree has been developed containing different design scenarios for staircases as well as the rating number for each design scenario, which form a comprehensive vision of different design alternatives, and show the optimum design scenario for each element.

4.3 Proposed Future Research

In addition to staircase assessment, this research is providing a whole set of recommended alternatives for staircase design features. These recommended alternatives can optimally reduce the risk of falling for older adults, and can be used to develop a better staircase for older adults' users. Additionally, the developed integrated assessment rating system forms a foundation for future rating systems that will be developed for older adults' applications. The following are future development recommendations:

1. The proposed future research will expand, adopting the same integrated rating system, to include other house elements such as bathroom design, kitchen design and bedroom design assessment with the common aim of supporting older adults living independently in their communities.
2. The developed integrated assessment rating system and DAT can be used to develop an architectural assessment software program. This architectural assessment program can be incorporated into building information modeling (BIM). Furthermore, the developed rating system can be integrated with Computer-Aided Design (CAD) programs to provide an instant evaluation for the designed staircase to reduce the risk of falling for older adults.
3. A whole set of innovative solutions for staircase design features can be developed based on the proposed integrated evaluation system; such as: 1) installing an adjustable sensor-based handrail that is adjusted to a suitable height to reduce risk of falling for older adults and; 2) installing lighting sensors on the staircase to ensure constant lighting levels throughout the day.

REFERENCES

ACICR (2009). Seniors' Falls Injuries in Alberta. Edmonton, Alberta Centre for Injury Control & Research(ACICR). Government of Alberta. Health and Wellness.

Bakker, R. (1999). "Elderdesign: Home Modifications for Enhanced Safety and Self-Care." Care Manag J 1(1): 47-54.

Bangash, M. and Bangash, T. (1999). Staircases: Structural Analysis and Design. Rotterdam, A.A. Balkema.

Barlow, J. and Venables, T. (2004). "Will Technological Innovation Creat the True Lifetime Home?" Housing Studies 19(5): 795-810.

Bateni, H., Zecevic, A., et al. (2004). "Resolving Conflicts in Task Demands During Balance Recovery: Does Holding an Object Inhibit Compensatory Grasping?" Experimental Brain Research 157(1): 49-58.

Bayer, A. H. (2000). Fixing to Stay: A National Survey of Housing and Home Modification Issues. Washington, D.C., AARP.

BCNY. (2007) "New York State Building Code." from http://publicecodes.citation.com/st/ny/st/indes.htm.

Beneke, J. (1997). Stairs & Railings. Upper Saddle River, NJ, Creative Homeowner Press.

Butler-Jones, D. (2010). The Chief Public Health Officer's Report on the State of Public Health in Canada, 2010: Growing Older - Adding Life to Years 2010, Public Health Agency of Canada.

Byerts, T. O., Lawton, M. P., et al. (1982). Aging and the Environment: Theoretical Approaches. New York, Springer.

Cataneo, D. C. and Cataneo, A. J. M. (2007). "Accuracy of the Stair Climbing Test Using Maximal Oxygen Uptake as the Gold Standard." Jornal Brasileiro de Pneumologia: Publicacắo Oficial da Sociedade Brasileira de Pneumologia e Tisilogia 33(2): 128-133.

Cohen, J., LaRue, C. A., et al. (2009). "Stairway Falls: an Ergonomics Analysis of 80 Cases." Professional Safety 54(1): 27-32.

Covinsky, K. E., Lindquist, K., et al. (2009). "Pain, Functional Limitations, and Aging." Journal of the American Geriatrics Society 57(9): 1556-1561.

DCLG (2008). Lifetime Homes, Lifetime Neighbourhoods: A National Strategy for Housing in an Ageing Society. London, DCLG (Department for Communities and Local Government).

Demiris, G., Rantz, M. J., et al. (2004). "Older Adults' Attitudes Towards and Perceptions of 'Smart Home' Technologies: a Pilot Study." Informatics for Health and Social Care 29(2): 87-94.

Donald, L. P. and Bulpitt, C. J. (1999). "The Prognosis of Falls in Elderly People Living at Home." Age and Ageing 28: 121 - 125.

Edwards, P. and Mawani, A. (2006). "Healthy Aging in Canada: A New Vision, A Vital Investment From Evidence to Action. A Background Paper Prepared for the Federal, Provincial and Territorial Committee of Officials (Seniors)."

Enochs, R., Cato, A., et al. (1993). "Principles for forging a national health plan." J Health Care Poor Underserved 4(3): 344-348.

Ghafouri, M., McIlroy, W., et al. (2004). "Initiation of Rapid Reach-and-Grasp Balance Reactions: is a Pre-Formed Visuospatial Map Used in Controlling the Initial Arm Trajectory?" Experimental Brain Research 155(4): 532-536.

Gitlin, L. N. (2009). Environmental Adaptations for Older Adults and Their Families in the Home and Community. International Handbook of Occupational Therapy Interventions**:** 53-62.

Haslam, R. and Stubbs, D. (2006). Understanding and Preventing Falls. Boca Raton, Fla. ; London, Taylor & Francis.

Health-Canada (2002). Healthy Aging: Prevention of Unintentional Injuries Among Seniors. Ottawa: Minister of Public Works and Government Services, Division of Aging and Seniors.

Helmy, A. I. (2004). The Pyramid Essnce. Cairo, Egypt Dar El-Fanar Elmasrya

Hill, L., Haslam, R., et al. (1999). Safety of Older People on Stairs Behavioural Factors, A report prepared for The Department of Trade and Industry.

Loughborough, Health & Safety Ergonomics Unit, Department of Human Sciences, Loughborough University.

Horstman, T. R. and Fanning, D. E. (2004). High Traction Flooring Laminate, Patent Application Publication.

House, C. and House, S. (2008). Houses in the Sun: Light, Movement, Embrace: House + House. Mulgrave, Vic., Images Pub.

HRSDC. (2011) "Human Resources and Skills Development Canada, Indicators of Well-being in Canada, Canadians in Context - Aging Population " Retrieved August 2nd, 2011, from http://www4.hrsdc.gc.ca/.3ndic.1t.4r@-eng.jsp?iid=33.

IESNA (2007). Recommended Practice for Lighting and the Visual Environment for Senior Living IESNA(Illuminating Engineering Society of North America).

Irvine, C. H., Snook, S. H., et al. (1990). "Stairway Risers and Treads: Acceptable and Preferred Dimensions." Applied Ergonomics 21(3): 215-225.

Ishihara, K., Nagamachi, M., et al. (2002). "Handrails for the Elderly: A Survey of the Need for Handrails and Experiments to Determine the Optimal Size of Staircase Handrails." Gerontechnology 1(3): 175-189.

Kannus, P., Parkkari, J., et al. (1999). "Fall-Induced Injuries and Deaths Among Older Adults." American Medical Association 281(20): 1895-1899.

Lanspery, S. and Hyde, J. (1997). Staying Put: Adapting the Places Instead of the People. Amityville, N.Y., Baywood Pub.

Lawton, M. P. (1986). Environment and Aging. Albany, N.Y., Center for the Study of Aging.

Lawton, M. P., Windley, P. G., et al. (1982). Aging and the Environment: Theoretical Approaches. New York, Springer.

Lee, H.-J. and Chou, L.-S. (2007). "Balance Control During Stair Negotiation in Older Adults." Journal of Biomechanics 40(11): 2530-2536.

Lord, S. R. and Dayhew, J. (2001). "Visual Risk Factors for Falls in Older People." Journal of the American Geriatrics Society 49(5): 508-515.

Lord, S. R., Sherrington, C., et al. (2001). Falls in Older People: Risk Factors and Strategies for Prevention. Cambridge ; New York, Cambridge University Press.

Lorentsen, O. (1995). "National Structures in the Delivery of Rehabilitation Technology Services." Int J Technol Assess Health Care 11(2): 174-186.

Maki, B. E. (1988a). Influence of Handrail Height and Stairway Slope on the Ability of Young and Elderly Users to Generate Stabilizing Forces and Moments. Ottawa, Editiorial Office, Division of Electrical Engineering,National Research Council of Canada.

Maki, B. E. (1988b). Influence of Handrail Shape, Size and Surface Texture on the Ability of Young and Elderly Users to Generate Stabilizing Forces and Moment. Ottawa, Editiorial Office, Division of Electrical Engineering,National Research Council of Canada.

Maki, B. E. and McIlroy, W. E. (2006). "Control of Rapid Limb Movements for Balance Recovery: Age-Related Changes and Implications for Fall Prevention." Age and Ageing 35(2): 12-18.

Martel, L., Belanger, A., et al. (2005). Healthy Today, Healthy Tomorrow? Findings from the National Population Health Survey. Ottawa, Statistics Canada Catalogue.

Miyasike-daSilva, V., Allard, F., et al. (2011). "Where Do We Look When We Walk on Stairs? Gaze Behaviour on Stairs, Transitions, and Handrails." Experimental Brain Research 209(1): 73-83.

NRC (2006). Alberta Building Code 2006. Ottawa, National Research Council of Canada, Alberta.

Oh-Park, M., Xue, X., et al. (2011). "Transient Versus Persistent Fear of Falling in Community-Dwelling Older Adults: Incidence and Risk Factors." Journal of the American Geriatrics Society 59(7): 1225-1231.

Ostroff, E. and Preiser, W. F. E. (2001). Universal design handbook. New York, McGraw-Hill.

Pauls, J., L (1982). Recommendation for Improving the Safety of Stairs Ottawa, Division of building research, National Research Council of Canada.

Pynoos, J., Caraviello, R., et al. (2009). "LifeLong Housing: The Anchor in Aging-Friendly Communities." Journal of the American Society on Aging 33(2).

Robertson, H. (1952). Modern Architectural Design. London,, Architectural Press.

Rogers, M. E., Rogers, N. L., et al. (2004). "Reducing the Risk for Falls in the Homes of Older Adults." Journal of Housing For the Elderly 18(2): 29 - 39.

Roth, L. M. (2007). Understanding Architecture: Its Elements, History, and Meaning. Boulder, Colo., Westview Press.

Rowe, M. A. and Fehrenbach, N. (2004). "Injuries Sustained by Community-Dwelling Individuals with Dementia." Clin Nurs Res 13(2): 98-110, discussion 111-116.

Roys, M. S. (2001). Serious Stair Injuries Can be Prevented by Improved Stair Design.

Rudy, T. E., Weiner, D. K., et al. (2007). "The Impact of Chronic Low Back Pain on Older Adults: A Comparative Study of Patients and Controls." Pain 131(3): 293-301.

Saaty, T. L. (2008). "Decision making with the analytic hierarchy process." International Journal of Services Sciences 1(1): 83-98.

SCC (2008). Barrier-Free Design Guide, Based on the Alberta Building Code 2006. Design for independence and Dignity for Everyone, Vision, Hearing, Communication, Mobility, Cognition. Safety Code Council. Edmonton.

Scott, V., Pearce, M., et al. (2005). Technical Report: Injury Resulting from Falls Among Canadians Age 65 and over (on the Analysis of Data from the Canadian Community Health Survey, Cycle 2.1, as Presented in: Report on Seniors' Falls in Canada). Victoria, BC Public Health Agency of Canada.

Scott, V., Wagar, L., et al. (2010). Falls & Related Injuries amoung Older Canadians: Fall-related Hospitalizations & Intervention Initiatives. Victoria, BC: Victoria Scott Consulting, Prepared on behalf of the Public Health Agency of Canada, Division of Aging and Seniors.

Statistics-Canada. (2009) "Activity-limiting Injuries, 2009." Retrieved 10 Jan, 2012, from http://www.statcan.gc.ca/.

Stefanov, D. H., Bien, Z., et al. (2004). "The Smart House for Older Persons and Persons with Physical Disabilities: Structure, Technology Arrangements, and Perspectives." IEEE Trans Neural Syst Rehabil Eng 12(2): 228-250.

Svanstrom, L. (1974). "Falls on Stairs: an Epidemiological Accident Study." Scandinavian journal of social medicine 2(3): 113-120.

Templer, J. A. (1992a). The Staircase: History and Theories. Cambridge, Mass., MIT Press.

Templer, J. A. (1992b). The Staircase: Studies of Hazards, Falls, and Safer Design. Cambridge, Mass., MIT Press.

Tinetti, M. E. (2003). "Clinical Practice. Preventing Falls in Elderly Persons." N Engl J Med 348(1): 42-49.

Turcotte, M. and Schellenberg, G. (2007). A portrait of seniors in Canada, 2006 / by Martin Turcotte and Grant Schellenberg. Ottawa :, Statistics Canada, Social and Aboriginal Statistics Division.

van Weely, S. F. E., van Denderen, C. J., et al. (2009). "Reproducibility of Performance Measures of Physical Function Based on the BASFI, in Ankylosing Spondylitis." Rheumatology 48(10): 1254-1260.

VandenBussche, J., Gallagher, K. M., et al. (2011). "Foot Placement in Oblique Stair Descent." Proceedings of the Human Factors and Ergonomics Society Annual Meeting 55(1): 1765-1768.

Vander-Burg, G. (2008). Findings Report, Demographic Planning Commission. Edmonton Alberta Seniors and Community Supports.

Vellas, B. J., Wayne, S. J., et al. (1997). "Fear of Falling and Restriction of Mobility in Elderly Fallers." Age Ageing 26(3): 189-193.

Verghese, J., Wang, C., et al. (2008). "Self-Reported Difficulty in Climbing Up or Down Stairs in Nondisabled Elderly." Archives of Physical Medicine and Rehabilitation 89(1): 100-104.

Voermans, N. C., Snijders, A. H., et al. (2007). "Why Old People Fall (and How to Stop Them)." Practical Neurology 7(3): 158-171.

Warren, S., Craft, R. L., et al. (1999). Designing Smart Health Care Technology into the Home of the Future.

Watanabe, L. (2009) "Independence Technology Discontinues the iBOT ", from http://www.mobilitymgmt.com/Articles/2009/02/01/Independence-Technology-Discontinues-the-iBOT.aspx.

Wild, D., Nayak, U. S. L., et al. (1981). "Description, Classification and Prevention of Falls in Old People at Home." Rheumatology 20(3): 153-159.

Williams, R. and RHS (1995). The Garden Designer. London, Frances Lincoln.

Zietz, D. and Hollands, M. (2009). "Gaze Behavior of Young and Older Adults During Stair Walking." Journal of Motor Behavior 41(4): 357-366.

Zietz, D., Johannsen, L., et al. (2011). "Stepping Characteristics and Centre of Mass Control During Stair Descent: Effects of Age, Fall Risk and Visual Factors." Gait & Posture 34(2): 279-284.

APPENDIX (A)

The following table is a description of the evidence-based studies that support the design features for the four staircase elements: 1) staircase geometrical design (G); 2) handrail design (H); 3) lighting (L); and 4) step design (S). The table illustrates the aim of each study, the participant setting, and the type of the study. For example, "Balance control during stair negotiation in older adults" by Lee and Chou (2007) has been used to assign the staircase geometry feature and the number of steps per flight feature. It should also be noted that "IESNA (Illuminating Engineering Society of North America): recommended practice for lighting and the visual environment for senior living" has been used to assign the illumination level feature in the lighting element, and "Alberta Building Code 2006" has been used to assign the nosing feature. The rest of the design features have been assigned based on the studies presented in the following table.

Type of information extracted from this research	Author & Year	Title	Reference type	Aim of study / Participant setting	Type of study method	Comments
Feature (G_g): staircase geometry / Feature (G_s): number of steps per flight	Lee and Chou 2007	Balance control during stair negotiation in older adults	Journal: Journal of Biomechanics	Comparing the center of mass and center of pressure inclination angles for 12 healthy older adults and 14 healthy young adults, in order to detect the gait instability while ascending and descending 3 steps of staircases.	Quantitative	Experiment-al study
Feature (G_g): staircase geometry / Feature (G_s): number of steps per flight	Wild et al. 1981	Description, classification and prevention of falls in old people at home	Journal: Rheumatology and Rehabilitation	Investigating the cause of falling for older adults based on 125 older adult participants who reported the detailed causes of falling in their home environment.	Qualitative	Descriptive study
Feature (G_g): staircase geometry	Svanstrom 1974	Falls on Stairs: an Epidemiological Accident Study	Journal: Scandinavian Journal of Public Health	Aiming to prevent falling on staircases. The study is based on a survey of 273 people who experienced injuries while ascending and descending the staircases who come to a specific hospital in Malmo during one year.	Qualitative	The study is based on epidemiolo-gical survey of staircase accidents

Feature (G_g): staircase geometry	Covinsky et al. 2009	Pain, Functional Limitations, and Aging	Journal: journal of American Geriatrics Society	Examining the relationship between functional limitation and pain for people aged 50 and older. 18,531 participants in the 2004 Health and Retirement Study (HRSDC). Climbing the staircases is part of the study to evaluate the ability to climb several flights and/or one flight.	Qualitative	opinion survey
Feature (G_s): number of steps per flight	Miyasike-daSilva et al. 2011	Where do we look when we walk on stairs? Gaze behaviour on stairs, transitions, and handrails	Journal: experimental brain research	Investigating gaze behaviour, using an eye tracker, while ascending and descending the staircases for 1) the transition steps, 2) the handrail, and 3) the first attempt to climb unfamiliar steps. Eleven participants between 23-38 years old.	Quantitative	Experiment -al study
Feature (G_g): staircase geometry / Feature (G_s): number of steps per flight / Feature (L_c): consistency of lighting amount / Feature (L_s): lighting switches / Feature (Enochs et al.): minimum handrail-wall clearance / Feature (S_f): steps finishing material	Templer 1992b	The Staircase: Studies of Hazards, Falls, and Safer Design	book: MIT Press	Investigating the risk of falling. This book is based on a number of previous studies that focused mainly on investigating the risk of falling associated with the staircase design, in addition to studying the behaviour on the staircases through the movement pattern of different groups of people, such as older adults.	Qualitative	
Feature (H_e): handrail existence / Feature (H_{ex}): handrail extension	Ishihara et al. 2002	Handrails for the elderly: A survey of the need for handrails and experiments to determine the optimal size of staircase handrails.	Journal: Gerontechnolog y	Investigating the necessity for the handrail and its optimal specifications. The study is based on a questionnaire to over 2,800 older adults (60 years and older) who live independently.	Qualitative	opinion survey
Feature (H_e): handrail existence	Hill et al. 1999	Safety of Older People on Stairs Behavioural Factors, A report prepared for The Department of Trade and Industry.	Report: Department of Human Sciences, Loughborough University	Investigating the behaviour of older adults on and around the staircases from a safety perspective. This report is based on interviewing a total number of 157 older adult (65-96 years) participants in their own environment.	Qualitative	opinion survey
Feature (H_h): handrail height / Feature (H_c): handrail cross-section	Maki 1988a	Influence of Handrail Height and Stairway Slope on the Ability of Young and Elderly Users to Generate Stabilizing Forces and Moments	Book: National Research Council of Canada	Investigating the influence of various handrail heights with two slopes (41^o and 49^o) on the level of safety for 20 young participants and 20 older adult participants (aged 59 and older), aiming to develop better handrail standards.	Quantitative	Experiment -al study

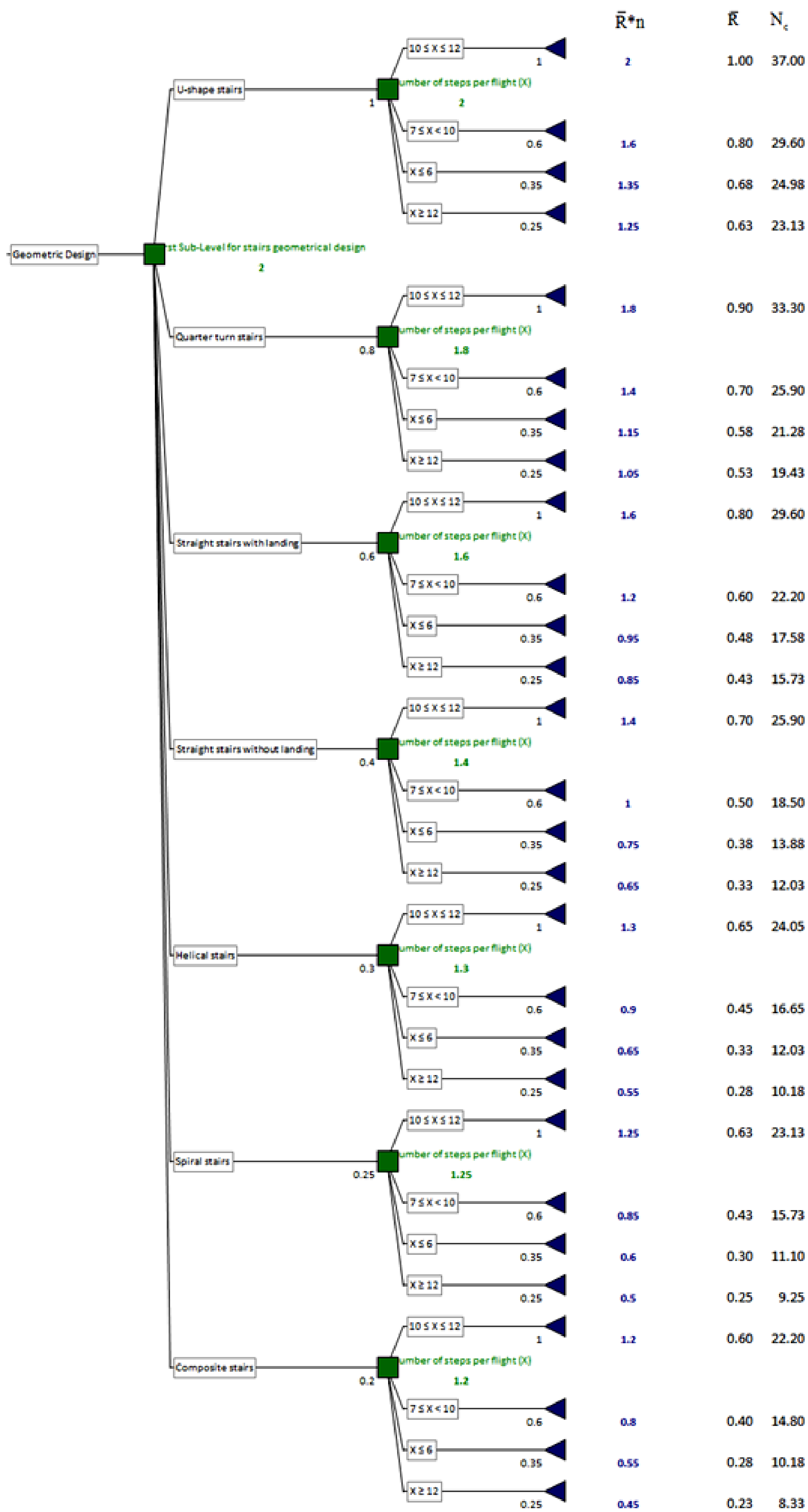
Feature (H_s): handrail surface texture	Maki 1988b	Influence of Handrail Shape, Size and Surface Texture on the Ability of Young and Elderly Users to Generate Stabilizing Forces and Moment	Book: National Research Council of Canada	Investigating the influence of handrail Shape, Size and Surface Texture on the staircase users to generate stabilizing forces and moments. Three different handrail shapes (circular, horizontal rectangle and square with different circumferences), along with four other commonly-used shapes (oval, decorative, and two different dimensions of long vertical rectangle) were tested on 20 young and 20 older adult participants.	Quantitative	experimental study
Feature (S_g): going depth / Feature (S_r): riser height	Irvine et al. 1990	Stairway risers and treads: acceptable and preferred dimensions	Journal: Applied Ergonomics	Determining the optimal dimension for the stairs' riser and tread through 19 sets of staircases with different riser and tread dimensions, based on the most preferred and acceptable staircases for different age groups (from 19 to 69 years)	Qualitative	opinion survey

APPENDIX (B)

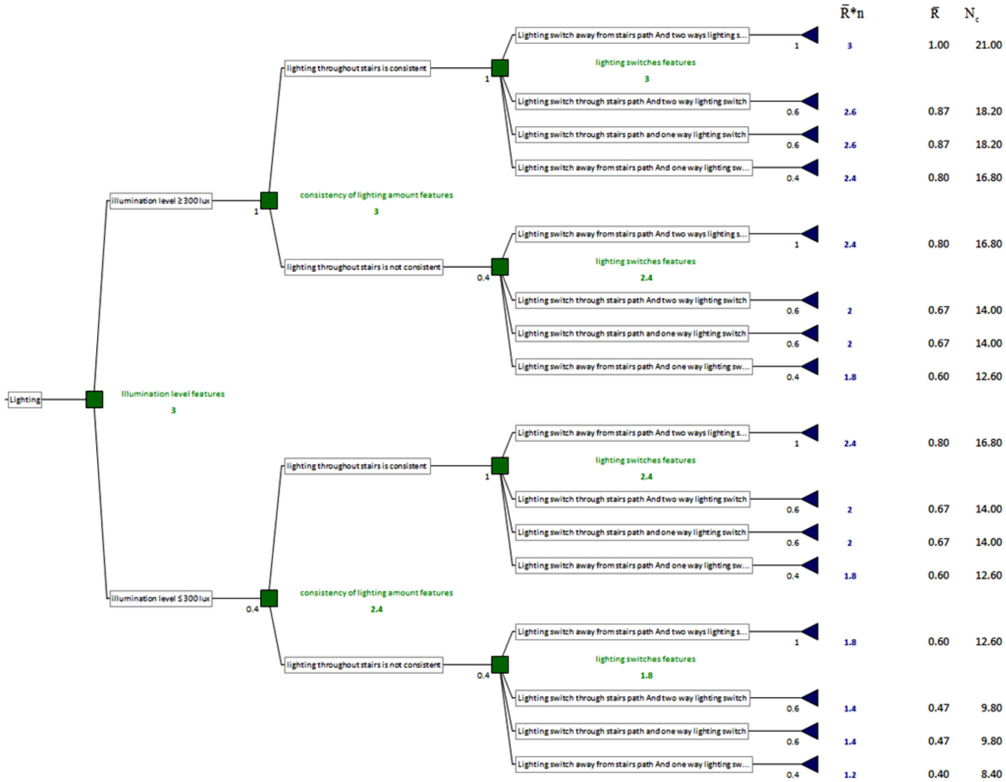
The Decision Assessment Tree (DAT) spreadsheet:

The Decision Assessment Tree (DAT) directly shows the rating numbers for proposed staircase design scenarios, using “PrecisionTree” software that performs the decision analysis under Microsoft Excel. There is a DAT that has been developed for each element in the staircase design. Each DAT visualizes all possible staircase design scenarios for each element. As an example, for the staircase geometrical design element, the branches in its DAT express the different scenarios for each design feature (for example, for the feature of “Number of steps per flight”, the four different scenarios have been presented by four branches). In addition, the rating factor for each scenario is represented by the “value” of the branch. All the nodes in the DAT of each element are decision nodes; therefore, no probability is associated to any node.

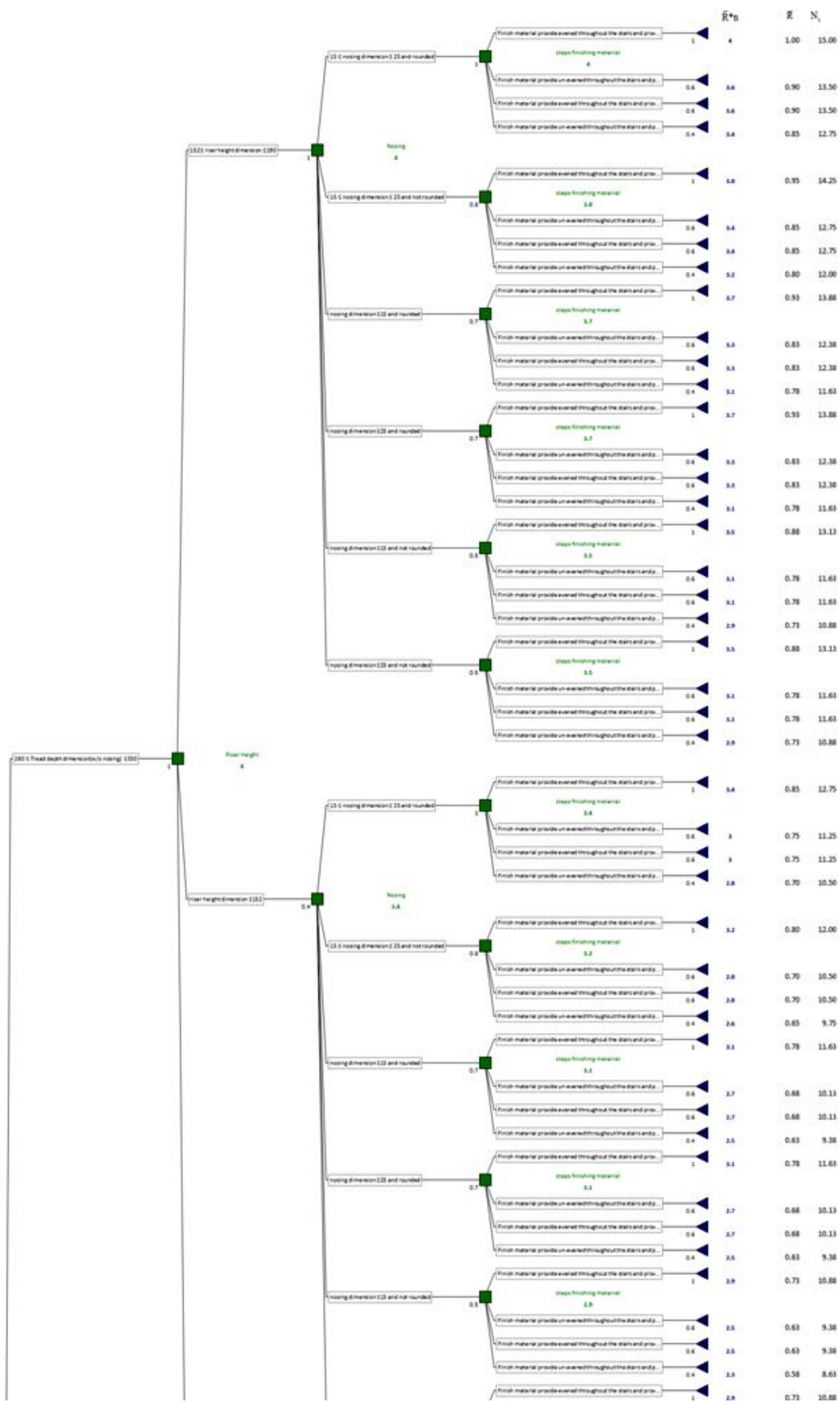
Staircase geometrical design DAT:

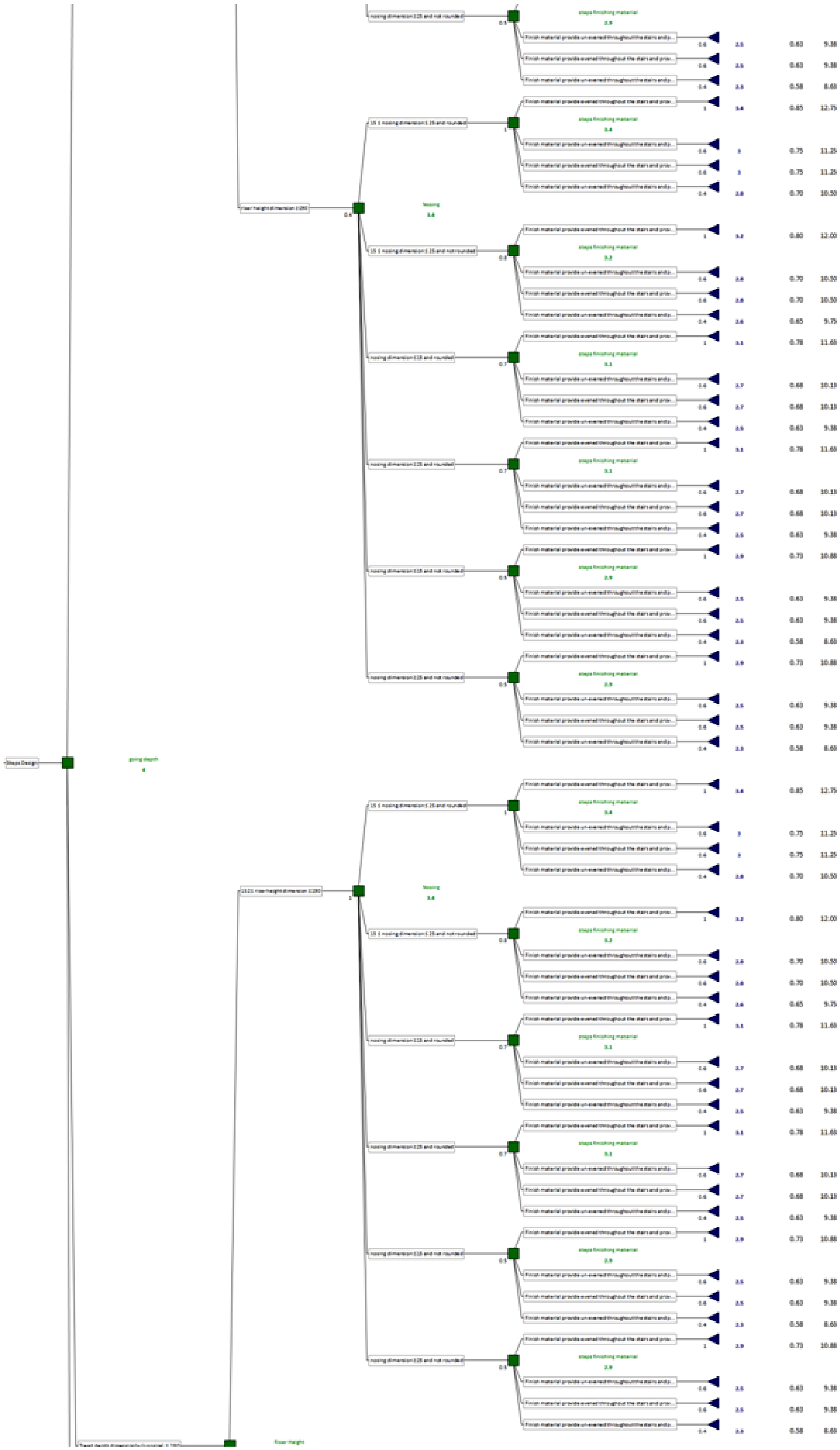


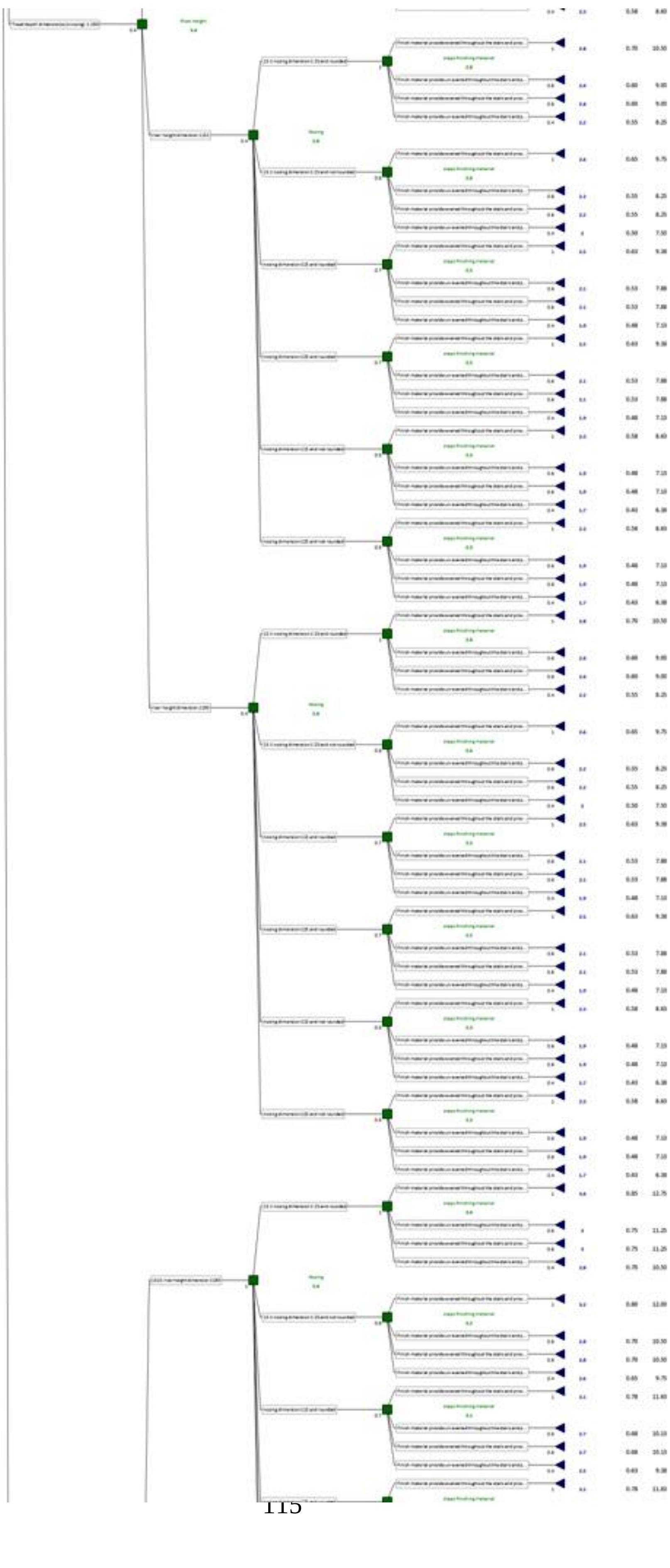
Staircase Lighting DAT:

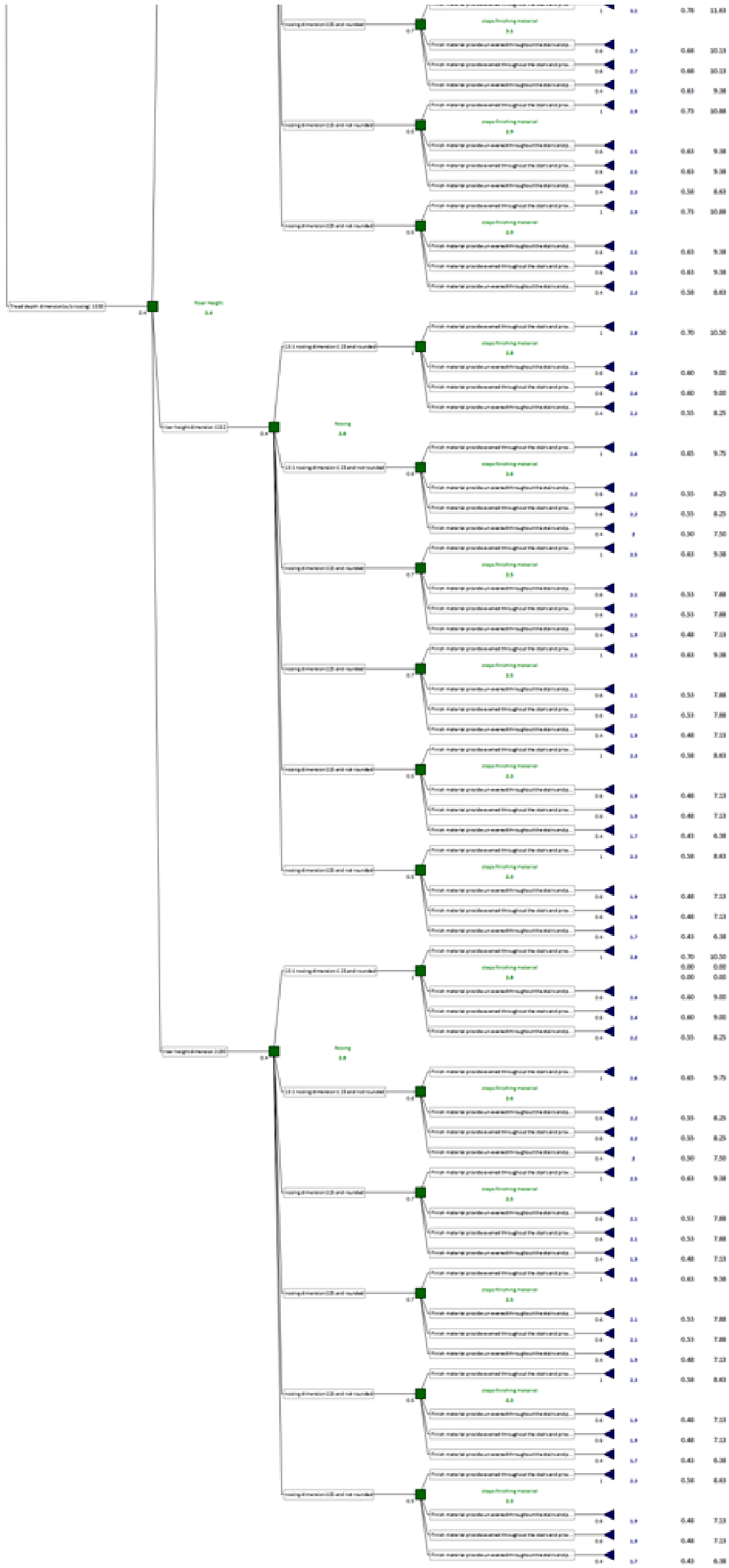


Staircase Step Design DAT:









Handrail Design DAT: