Integrated approach for older adult friendly home staircase design

Mona Afifi [1]*, Belinda Parke [2], and Mohamed Al-Hussein [1]

[1] Department of Civil & Environmental Engineering, Alberta University, Alberta, Canada
[2] Faculty of Nursing, Alberta University, Alberta, Canada
** Corresponding author (mkafifi@ualberta.ca)*

Purpose The concept of designing or modifying home environments plays an important role in maintaining safety for older adults (65 and older). Poor staircase architectural design could contribute to increasing the risk of falling for older adults. The purpose of this research is to evaluate staircase architectural design by investigating the risk of falling associated with staircase elements and aiming to improve the surrounding environment for older adults living independently in their homes. This paper presents research which is built around the following hypotheses: 'Improving the architectural design of staircase could reduce the risk of falling for older adults'. **Method** This research provides an integrated evidence-based assessment that combines all aspects related to staircase architectural design, represented in the following 3 stages. Stage 1 constructs a hierarchy of four elements which represent the architectural design of the staircase as follows: (i) staircase geometrical design; (ii) handrail design; (iii) lighting; and (iv) step design. Each element is divided to a number of features; for instance, handrail design, if exists, is divided into five features: (i) handrail height; (ii) handrail cross-section; (iii) handrail surface texture; (iv) handrail extension; and (v) minimum handrail-wall clearance. Each feature is divided into a number of scenarios representing the different architectural design alternatives for that feature: e.g., variation on handrail heights. A rating factor that represents the degree by which the proposed scenario reduces the risk of falling for older adult, is assigned to each scenario. Stage 2 develops a rating system for the analyzing staircase elements and features which present the degree to which each element and its features reduce the risk of falling for older adults. In this stage, a mathematical model is developed to calculate the rating value for different staircase design scenarios. Stage 3 develops a decision tree analysis module called a design assessment tree (DAT) which represents a complete vision for different staircase design scenarios. A case study is presented in order to illustrate the effectiveness of the proposed methodology. **Results & Discussion** The result of the developed rating system is a rating number for different staircase design scenarios that represent the degree by which the proposed staircase architectural design reduces the risk of falling for older adults. Figure 1 illustrates the optimal design scenario for the geometrical design element, which is part of the developed DAT for the staircase assessment procedure. DAT works as a manual for architects to represent the staircase assessment for any proposed design, and to visualize the optimal design scenario comparing to other scenarios in the each branch.

***Keywords**: staircase design, older adult, risk of falling*

INTRODUCTION

Ascending and descending staircases have been reported as a difficult daily activity for older adults[1]. Statistically, one out of four older adults is expected to fall when climbing staircases in the home environment[2]. Falling for older adults might lead to injuries[2,3]. In addition to experiencing physical harm, older adults might experience loss of confidence or develop a fear of falling, which will impact their performance while ascending or descending staircases[2,4-6].

There is a wide variation of staircase configurations such as spiral staircases, straight staircases with landing, and U-shaped staircases. Each staircase configuration has been associated with different handrailing, lighting and step dimensions (riser and tread). The concept of modifying staircase configuration plays an important role in maintaining safety for older adults. Previous studies have investigated the cause of falling through ascending or descending staircases for older adults[1,2,6-9]. Other studies have recommended staircase modifications for handrail, lighting and step design to reduce the risk of falling[4,10-16].

This paper presents an evidence-based integrated framework that combines all aspects related to staircase architectural design to reduce the risk of falls in older people. A practical case study of staircase design is presented from the perspective of reducing the risk of falling for older adults to demonstrate the effectiveness of the proposed methodology.

First, the staircase is divided into a number of elements that represent its architectural design .Then; those elements are divided into a number of features that provide more detailed specifications. Each feature has different scenarios that represent the architectural design alternatives for that feature. A rating factor is calculated for each element and its associated features to represent how much it reduces the risk of falling for older adults based on previous evidence-based studies. The proposed methodology assesses the staircase design, while not the actual value or true meaning of the rating numbers presented. Design Assessment Tree (DAT) has been developed to represent a complete vision of different staircase design scenarios. DAT could work as a manual for architects to represent the staircase assessment for any proposed design, and to visualize the optimal design scenario compared to other scenarios in each branch.

STAIRCASE ELEMENTS AND FEATURES

The staircase is divided into four design elements: staircase geometrical design, handrail design, lighting, and step design elements. This categorization follows the logical divisions provided in the building code. Handrail, lighting and step specifications are provided in the building code as subdivisions of the staircase design specifications. In addition, staircase geometric design is considered to be a design element that presents the formation of the staircase as an independent design object, which can only be tracked by the geometrical design of the staircase. The staircase geometrical design element is divided into the staircase configuration and the number of steps per flight, represented as two subdivision features. Each element is divided into a number of features that define its architectural design, as illustrated in Figure 1.

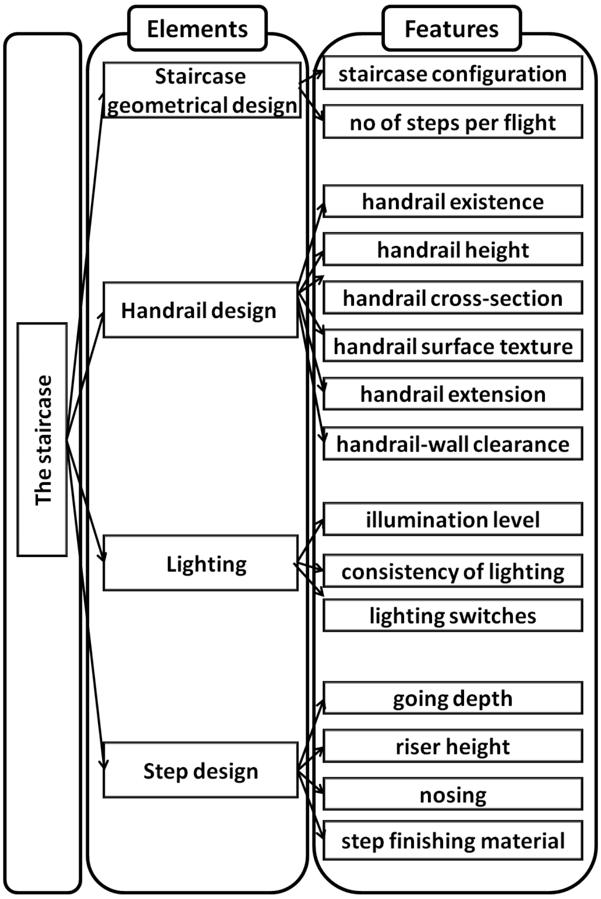


Fig.1. A flow chart for staircase elements and features

PROPOSED RATING SYSTEM

The developed rating system represents the degree by which the risk of falling for older adults is reduced. A rating factor (R) is assigned to different alternatives (scenarios). This rating factor is calculated based on an evidence-based comparison with alternative scenarios.

To set the comparison, a scale of numbers between 0.00 and 1.00 has been adopted to indicate how much each scenario may reduce the risk of falling for older adults. The rating factor 1.00 represents optimal risk reduction; the scaled numbers from 1.00 to I 0.00 represents the scaled reduction of the risk of falling for older adults, as illustrated in Table 1. The rating factor 0.0 means that the feature does not exist. For example, if the handrail does not exist, the rating factor of the “handrail existing” feature will be 0.00.

Table1. Explanations of rating factors

Rating Factor	*Explanation*
1.00	The risk of falling for older adults is optimally reduced by the selected scenario (Optimal design feature)
0.75	The risk of falling for older adults is strongly reduced by the selected scenario (Strong design feature)
0.50	The risk of falling for older adults is moderately reduced by the selected scenario (moderate design feature)
0.25	The risk of falling for older adults is increased by the selected scenario (weak design feature)
0.00	The design features does not exist (Highest risk of falling)

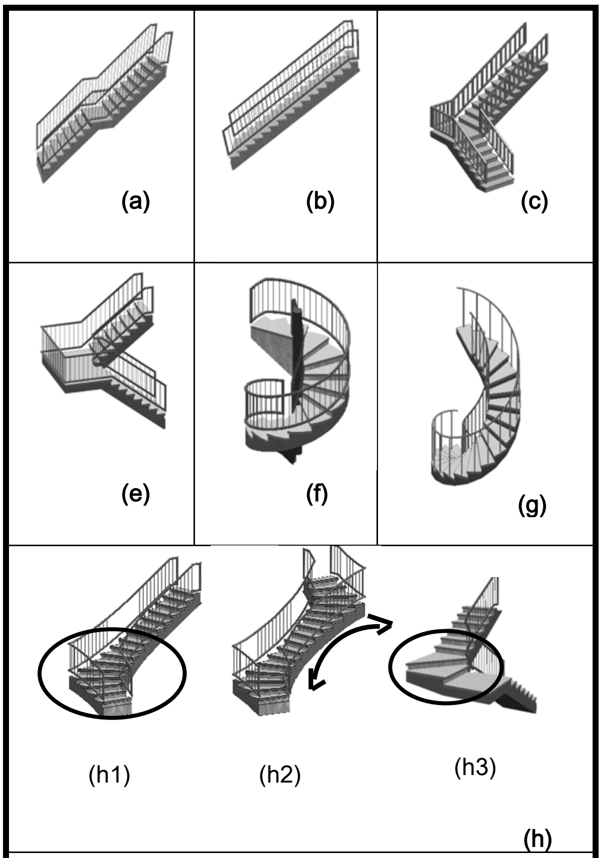
ELEMENT 1: STAIRCASE GEOMETRICAL DESIGN

From the perspective of investigating the risk of falling for older adults, staircase configuration[10, 13, 17-19]; and length of each flight[12, 13, 18] of the staircase are two important factors. Therefore, staircase geometrical design, as an element, can be divided into two main features that specify its architectural design: 1) staircase configuration which represents variation in staircase shapes (straight, circular or composite); and 2) number of steps per flight.

Feature 1: staircase configuration

This paper covers a wide range of staircase configurations including: 1) U-shape staircases; 2) Quarter turn staircases; 3) Straight staircases with landing; 4) Straight staircases without landing; 5) Helical staircases; 6) Spiral staircases; and 7) Composite staircases, illustrated in Figure 2, arranged from highest to lowest risk reduction in terms of falling for older adults. The optimal staircase design has been found to be the U-shaped staircase deign[18, 20], which has an associated rating factor of 1.00.

The composite staircase is defined as a mixed staircase configuration in one staircase connecting two floors. The worst staircase configuration is the composite staircase, as it causes an irregular gait pattern which increases the risk of falling for older adults[10, 18, 19, 21]. The composite staircase has an associated rating factor of 0.20. The remaining staircase configurations have a range of rating factors according to how much each staircase configuration reduces the risk of falling for older adults.



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

Fig.2. Staircase geometrical design: staircase configuration

Feature 2: number of steps per flight
Long flights (over 12 steps) or short flights (less than 6 steps) have been found to increase the risk falling[12, 13, 18]. There are four scenarios for the "number of steps per flight" feature: 1) 10 ≤ number of steps per flight ≤ 12, which is the optimal case and has an associated rating factor of 1.00; 2) 7 ≤ number of steps per flight < 10, which is an over moderate case with an assigned rating factor of 0.6; 3) number of steps per flight ≤ 6 ; and 4) number of steps per flight ≥ 12 which has the worst case scenarios with an associated rating factor of 0.25 indicating that they highly increase the risk of falling for older adults.

ELEMENT 2: HANDRAIL DESIGN
The handrail is an essential tool that assists older adults' movement while ascending and descending staircases[22]. Handrail design consists of six features: handrail existence, handrail height, handrail cross-section, handrail surface texture, handrail extension, and minimum handrail-wall clearance. These six features are chosen to represent the handrail design specifications that have been found to reduce the risk of falling for older adults. To express importance of each scenario compared to others, a suitable rating factor is assigned to each of the scenarios according to the potential reduction in the risk of falling for older adults.

Feature 1: handrail existence
Evidence suggests that as a person ages, the need for a handrail increases. Safety in ascending and descending a staircase is further enhanced when a handrail exists on both sides of the staircase[11, 22]. The scenarios for "handrail existence" are: 1) to have one handrail on each side of the staircase, which is the optimal design scenario with a rating factor of 1.00; 2) to have one handrail on one side of the staircase, which has an associated rating factor of 0.7 as a moderate case; and 3) to have no handrail on either side of the staircase with a rating factor of 0.00 as the feature does not exist.

Feature 2: handrail height
Handrail height is the vertical line from the top of the rail to the outside edge of the staircase, as illustrated in Figure 3(a). There are four scenarios for the "handrail height" feature[15, 18]: 1) 910 ≤ handrail height ≤ 970, which is considered the optimal handrail height, as it is the most preferred height by older adult users[15], and has an associated rating factor of 1.00; 2) handrail height ≤ 910; and 3) handrail height ≥ 1,000, both of these cases are the worst case scenarios with a rating factor of 0.4 as lower than moderate design; and 4) 970 ≤ handrail height ≤ 1,000, which is neither the optimal nor the worst case with an associated rating factor of 0.7 as an over moderate design.

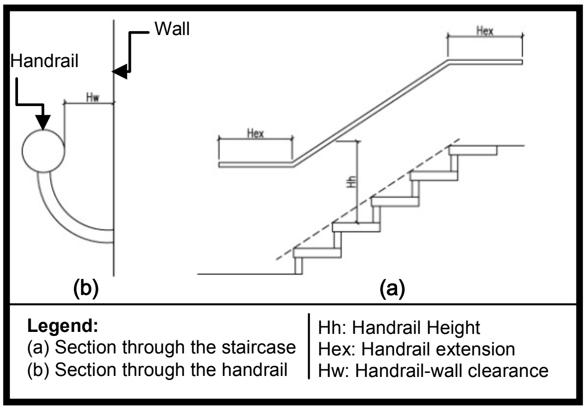


Fig.3. Schematic diagram for handrail specifications

Feature 3: handrail cross-section

By facilitating handrail graspability, the risk of falling could be reduced[14]. To facilitate graspability of the handrail a suitable handrail cross-section should be selected[14]. The "handrail cross-section" feature is considered to be a function of the handrail shape and the handrail cross-section dimension[14, 19]. The optimal scenario, based on the ability to grasp the handrail, is to have a circular handrail cross-section with a circumferences between 100-mm (32-mm diameter) and 160-mm (51-mm diameter), or to have an oval handrail cross-section with dimension of 50-mm in height and 37-mm in width[14]. These two scenarios have an associated rating factor of 1.00 representing the optimal case of the handrail cross-section. Other handrail shapes and dimensions are rated as over moderate designs as they have been found to have lower level of comfortability in most cases[14].

Feature 4: handrail surface texture

In order to facilitate handrail graspability, the surface texture needs to be not too smooth or not too rough[14, 18]. This case is considered as the first scenario of the "handrail surface texture" feature, and rated as 1.00 to represent the optimal scenario. The second scenario is to have too smooth handrail surface texture or too rough handrail surface texture. In that case the associated rating factor is 0.25 as it highly increases the risk of falling[14, 18].

Feature 5: handrail extension

Handrail extension, as illustrated in Figure 3(b), at the top and bottom of staircases has been found to be important in assessing older adult movement when ascending or descending the staircases[11]. There are four scenarios for the dimension of the "handrail extension" feature[11]: 1) 320 ≤ handrail extension on at least one handrail≤ 480, which is the optimal scenario and has an associated rating of 1.00; 2) handrail extension on at least one handrail ≥ 480, which is lower than the optimal case scenario with an associated rating factor of 0.8; 3) no handrail extension, which is associated with a rating factor of 0.5 as it moderately increases the risk of falling for older adults; and 4) handrail extension on at least one handrail≤ 320 is the worst scenario as it has been found that a short handrail extension increases the risk of falling more than no handrail extension[11], thus the associated rating factor is 0.4.

Feature 6: minimum handrail-wall clearance

The purpose of investigating the minimum handrail-wall clearance, illustrated in Figure 3(b), is to provide a sufficient space to grasp the handrail in case of a falling emergency. There are four scenarios for the "min handrail-wall clearance" feature[18, 23]: 1) a smooth wall surface and handrail-wall clearance≥ 57-mm; and 2) a rough wall surface and handrail-wall clearance ≥ 75-mm, both of these cases are the optimal cases which have a rating factor of 1.00; 3) a smooth wall surface and handrail-wall clearance < 57-mm; and 4) a rough wall surface and handrail-wall clearance < 75-mm, these two cases are the worst scenarios as they increase the risk of having finger injuries while moving the hand on the handrail and increase the risk of falling when ascending or descending the staircase[11], and thus have a rating factor of 0.4 indicating a lower than moderate design.

ELEMENT 3: LIGHTING

Poor vision is associated with increasing the risk of falling for older adults on staircases as they often require an increased lighting level[24, 25]. The lighting element is divided into three features that specify: 1) illumination level; 2) consistency of lighting; 3) light switch types and locations.

Feature 1: illumination level

Lighting for older adults has been recommended by Illuminating Engineering Society of North America-IESNA to be a minimum of 300-lux throughout the entire staircase[24]. The "Illumination level" feature is divided into two scenarios: 1) illumination level≥ 300-lux, which is the optimal scenario and has an associated rating factor of 1.00; and 2) illumination level ≤ 300-lux, which is the worst scenario and has an associated rating factor of 0.4.

Feature 2: consistency of lighting

Providing consistent lighting throughout the entire staircase is a very important factor that contributes to reducing the risk of falling for older adults[18, 24]. Providing inconsistent lighting may cause shaded areas on staircases which could cause confusion and might result in falls[18, 24]. Two scenarios are provided for the "consistency of lighting" feature: 1) consistent staircase lighting, which is the optimal scenario and has an associated rating factor of 1.00; 2) inconsistent staircase lighting, which is the worst scenario and has an associated rating factor of 0.4.

Feature 3: light switch types and locations

In order to reduce the risk of falling, light switches need to be placed away from the staircase path and should be two-way [18, 19]. Four scenarios are provided for the “light switches” feature. The first scenario is light switch away from staircase path and two-way light switch, which is the optimal case and has an associated rating factor of 1.00. The second and third scenarios are: 1) light switch through staircase path and two-way light switch, and 2) light switch away from staircase path and one-way light switch, both scenarios are slightly over the moderate case with associated rating factor of 0.6. The last scenario is light switch through staircase path and one-way light switch, which is the worst case with an associated rating factor of 0.4.

ELEMENT 4: STEP DESIGN

The step design element considers step design specifications, which are: 1) going depth; riser height; nosing shape and dimensions; and step finishing material (see Figure 4). In this paper, the selected step design specification is based on the most preferred step dimensions provided in previous evidence-based studies for different age groups, including older adults[16, 18].

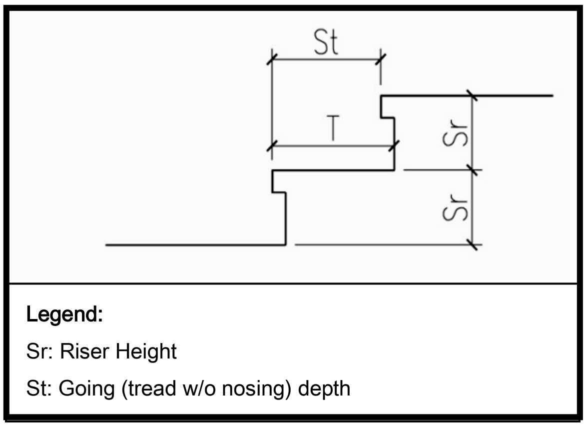


Fig.4. Schematic diagram for step specifications

Feature 1: going depth

The going depth represents the depth of the tread without nosing (see Figure 4). For the “minimum going depth dimension” feature, there are three scenarios[16, 18]: 1) 280 ≤ going depth ≤ 330, which is the optimal scenario and has an associated rating factor of 1.00; 2) going depth ≤ 280; and 3) going depth ≥ 330. The latter two scenarios are the worst case and have an associated rating factor of 0.4.

Feature 2: riser height

Three scenarios are provided for the “minimum riser height dimension” feature[16, 18]: 1) 152 ≤ riser height dimension ≤ 190 which is the optimal scenario and has an associated rating factor of 1.00; 2) riser height dimension ≤ 152; and 3) riser height dimension ≥ 190. The latter two scenarios are the worst case and have an associated rating factor of 0.4.

Feature 3: nosing

Safer staircase design can be achieved by optimizing the staircase nosing[18, 26]. The optimal scenario for the “nosing design” feature is to be rounded with nosing depth between 15-mm and 25-mm[18, 26]. The worst case scenario is not to be rounded with nosing depth outside of the range of the optimal scenario. The worst case has an associated rating factor of 0.25 as it is highly associated with increasing the risk of falling for older adults[26]. Intermediate cases such as satisfying the optimal nosing dimension, but not satisfying the optimal shape also have intermediate rating factors.

Feature 4: step finishing material

Finishing step material represents the texture, pattern and color of the finishing material of each staircase step. The optimal case scenario for the “finishing step material” feature is to have cohesive finishing material with uniform slip-resistance for the staircase steps[18, 26], which has an associated rating factor of 1.00. The worst case scenario is to have non-cohesive finishing material and non-uniform slip-resistance for staircase steps. In this case, the associated rating factor is assigned to be 0.4.

ASSESSMENT CALCULATIONS

One scenario is selected to represent the proposed staircase design. Based on the rating factor (R) that is assigned to each scenario for each feature, an average rating factor ( ) is calculated for each element, representing the selected scenario of each feature. This average rating factor represents how much the proposed features for each element reduces the risk of falling for older adults. The average rating factor must satisfy Equation 1.

$$\bar{R}(Y)=\left(\sum R(X)\right)/n \qquad \textbf{(1)}$$

Where:

(Y) = average rating factor ( ) for element Y;
R(X) = rating factor (R) for feature X;
Y = index for element symbol;
X = index for feature symbol; and
n = the total number of features for element Y (n=2 for staircase geometrical design (G), n=6 for handrail design element (H), n=3 for lighting element (L), and n=4 for step design element (S)).

A rating number (N) is generated to represent and rank the importance of each of the four elements. The summation of the four rating numbers is 100. This paper proposes an equal rating number (N) for the four staircase elements (25 each). The corrected rating number $N_c(Y)$, is calculated by multiplying the rating number by the average rating factor of each element, which represents how much each element, relative to the other elements, reduces the risk of falling for older adults. The corrected rating number $N_c(Y)$ for each of the four elements must satisfy Equation 2.

$$N_c(Y) = \bar{R}(Y)\,N(Y) \qquad \textbf{(2)}$$

Where:

- **$N_c(Y)$** = corrected rating number for element Y;
- **(Y)** = average rating factor ( ) for element Y;
- **N(Y)** = rating number (N) for design element Y;
- **Y** = index for element symbol.

The summation of the four corrected rating numbers represents how much the proposed staircase design reduces the risk of falling for older adults. Thus, in the perfect hypothetical case, the staircase rating must equal 100. The total rating for staircase design is calculated satisfying Equation 3.

$$N_{total} = \sum N_c(X) \qquad \textbf{(3)}$$

Where:

- **N_{total}** = total rating number of the proposed staircase architectural design;
- **Nc(X)** = corrected rating number for staircase element (X).

A scale is developed to categorize the total rating of the staircase from the perspective of reducing the risk of falling for older adults. A total rating from (100 to 90) represents the optimal staircase design; (90 to 65) represents strong staircase design; (65 to 40) represents moderate staircase design; (40 to 15) represents a weak staircase design; and (15 to 0) represents the staircase design associated with the highest risk of falling.

DESIGN ASSESSMENT TREE (DAT)

The Design Assessment Tree (DAT) is a decision tree that has only decision nodes. DAT works as a manual for architects to represent a complete vision for staircase assessment for any proposed design. In addition, DAT allows the architect to visualize the optimal design scenario compared to other scenarios in each branch. Each individual branch in the DAT carries the rating factor (R) of each scenario. There are two columns at the end of each DAT branch, as illustrated in Figure 5: the first column lists the average rating factor for each design scenario, calculated by satisfying Equation 1; the second column displays the corrected rating number Nc(Y) for each design scenario, calculated by satisfying Equation 2. DAT is developed for each element independently.

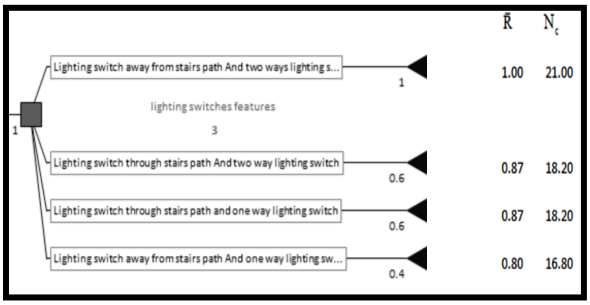


Fig.5. part of the DAT for lighting switches feature illustrates the associated $\bar{R}$ and Nc for each scenario

CASE EXAMPLE

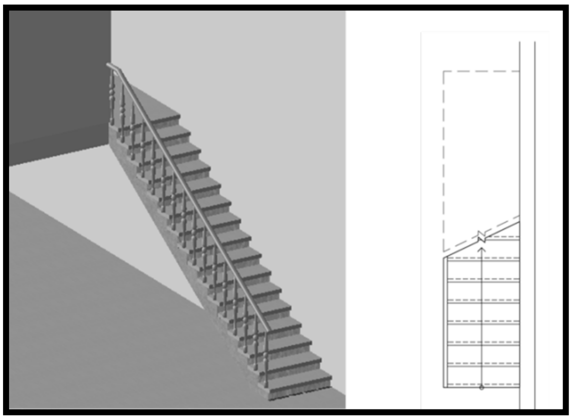


Fig.6. Perspective/plan: straight staircases w/o landing

To illustrate the effectiveness of the proposed staircase assessment, the case example of straight staircase without landing is presented, as shown in Figure 6. The proposed staircase consists of 16 steps per flight; with a handrail height of 900-mm and it exists in one side of the staircase. The handrail cross-section shape is rectangular with smoothed edges. The illumination level = 250-lux and the lighting throughout the staircase is consistent. The light switch is away from the staircase path and is a two-way switch. Tables 2, 3, 4 and 5 illustrate the actual scenarios for each feature based on the proposed staircase design, and provide the associated rating factors.

Table2. Features of staircase geometrical design

Feature no	***Feature's name***	***Proposed scenario***	***Rating factor(R***
Feature 1	Staircase configuration	Straight staircases without landing	0.4
Feature 2	Step no/ flight	(G_s=16 steps) ≥ 12	0.25

Table3. Features of handrail design

Feature No	***Feature's name***	***Proposed scenario***	***Rating factor(R)***
Feature 1	Handrail existence	One handrail	0.7
Feature 2	Handrail height	(Hh = 900) ≤ 910-mm	0.4
Feature 3	Handrail cross-section	Other handrail shapes and dimensions	0.7
Feature 4	Handrail surface texture	Comfortable handrail surface texture (not too smooth or not too rough)	1
Feature 5	Handrail extension	No handrail extension	0.5
Feature 6	Minimum Handrail-wall clearance	Smooth wall surface and handrail-wall clearance ≥ 57-mm	1

Table4. Features of lighting

Feature No	***Feature's name***	***Proposed scenario***	***Rating factor(R)***
Feature 1	Illumination level	(Li=250-lux) ≤ 300-lux	0.4
Feature 2	Consistence lighting amount	Lighting throughout staircases is consistent	1
Feature 3	Light switches	Light switch away from staircases path and two- way light switch	1

Table5. Features of step design

Feature No	***Feature's name***	***Proposed scenario***	***Rating factor(R)***
Feature 1	*Going depth*	*(Sg= 269-mm) ≤ 280-mm*	*0.4*
Feature 2	*Riser height*	*152≤ (Sr = 174-mm)≤190-mm*	*1*
Feature 3	*Nosing*	*(Nosing dimension=40-mm) ≥25-mm and not rounded*	*0.5*
Feature 4	*Step finishing material*	*Finish material provide evened throughout the stairs and provide uniform slip-resistance*	*1*

The average rating factor ( ) for the staircase geometrical design element (G), handrail design (H), lighting (L) and step design (S) is calculated satisfying Equation 1 as follows:

$$\bar{R}\,(G) = (0.4 + 0.25)/2 = 0.325$$

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

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

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

The corrected rating number for the staircase geometric design element (G) handrail design (H), lighting (L), and step design (S) is calculated satisfying Equation 2 as follows:

$$N_c(G) = \bar{R}\ (G)\ N(G) = 0.325*25 = 8.13$$

$$N_c(H) = \bar{R}\ (H)\ N(H) = 0.72*25 = 18$$

$$N_c(L) = \bar{R}\ (L)\ N(L) = 0.8*25 = 20$$

$$N_c(S) = \bar{R}\ (S)\ N(S) = 0.725*25 = 18.13$$

The total rating for the proposed straight staircase without landing is obtained by satisfying Equation 3. The total rating for the proposed staircase design (64.26) indicates that the proposed straight staircase without landing has a moderate staircase design.

$$N_{total} = 8.13 + 18 + 20 + 18.13 = 64.26$$

The same results can be obtained by selecting DAT branches that express the proposed scenarios. The total rating of the staircase can be optimized by selecting better scenarios for different design features from the developed DAT. For example, as illustrated in Figure 6, the number of steps per flight can be optimized by selecting the optimal scenario, with an associated rating factor of 1.00, which is to have between 10 to 12 steps per flight. Also, the effect of choosing a certain scenario on the average rating factor ( ) can be tracked. Therefore, the architect might decide to add a landing in the middle of the staircase to satisfy the optimal number of steps per flight; in that case, the average rating factor will be optimized from 0.33 to 0.7. This process can be applied to different features of the four elements to optimize the whole staircase design. The advantage of using DAT for optimization is that rating factor for the different scenarios of each feature are visually easier to extract and compare.

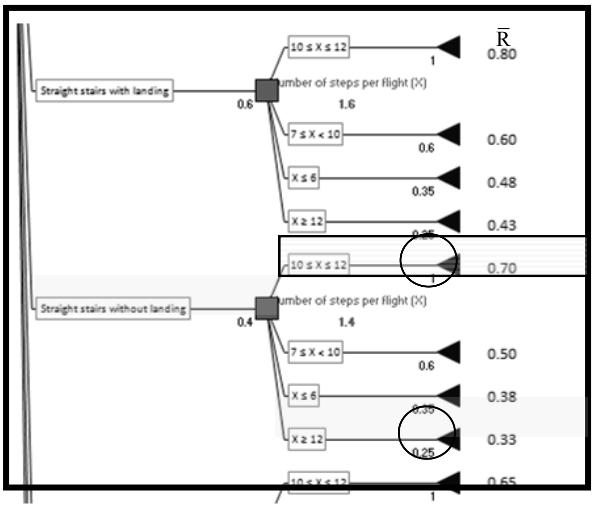


Fig.6. scenarios for number of steps per flight and its associated rating factors

CONCLUSION

This paper proposes an integrated assessment for staircase architectural design which aims to reduce the risk of falling for older adults. The assessment considers all the features of staircase design that could be improved through different scenarios. The assessment has been developed by evidence-based analysis of the staircase elements (staircase geometrical design, handrail design, lighting, step design). The proposed integrated staircase rating system enables architects to assess the proposed staircase design with the aim of reducing the risk of falling for older adults. Additionally, the developed integrated staircase rating system and DAT can be used as a design tool to improve staircase design through choosing alternative scenarios for different design features. A case example is analyzed to demonstrate the use of the proposed staircase assessment.

References

1. Turcotte, "A portrait of seniors in Canada, 2006 / by Martin Turcotte and Grant Schellenberg", *Ottawa, Statistics Canada, Social and Aboriginal Statistics Division*, 2007
2. Scott, Pearce, et al., "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*, 2005
3. ACICR, "Seniors' Falls Injuries in Alberta", *Alberta Centre for Injury Control & Research(ACICR). Government of Alberta. Health and Wellness, Edmonton*, 2009
4. Zietz, Johannsen, et al., "Stepping Characteristics and Centre of Mass Control During Stair Descent: Effects of Age, Fall Risk and Visual Factors", *Gait & Posture*, Vol. 34(2), pp. 279-284, 2011
5. Vellas, Wayne, et al., "Fear of Falling and Restriction of Mobility in Elderly Fallers", *Age Ageing*, Vol. 26(3), pp. 189-93, 1997
6. Oh-Park, Xue, et al., "Transient Versus Persistent Fear of Falling in Community-Dwelling Older Adults: Incidence and Risk Factors", *Journal of the American Geriatrics Society*, Vol. 59(7), pp. 1225-1231, 2011
7. Tinetti, "Clinical Practice. Preventing Falls in Elderly Persons", *N Engl J Med*, Vol. 348(1), pp. 42-9, 2003
8. Verghese, Wang, et al., "Self-Reported Difficulty in Climbing Up or Down Stairs in Nondisabled Elderly", *Archives of Physical Medicine and Rehabilitation*, Vol. 89(1), pp. 100-104, 2008
9. Kannus, Parkkari, et al., "Fall-Induced Injuries and Deaths Among Older Adults", *American Medical Association*, Vol. 281(20), pp. 1895-1899, 1999
10. Lord(b), Sherrington, et al., "Falls in Older People: Risk Factors and Strategies for Prevention", *Cambridge ; New York, Cambridge University Press*, 2001
11. Ishihara, Nagamachi, et al., "Handrails for the Elderly: A Survey of the Need for Handrails and Experiments to Determine the Optimal Size of Staircase Handrails", *Gerontechnology*, Vol. 1(3), pp. 175-189, 2002
12. Miyasike-daSilva, Allard, et al., "Where Do We Look When We Walk on Stairs? Gaze Behaviour on Stairs, Transitions, and Handrails", *Experimental Brain Research*, Vol. 209(1), pp. 73-83, 2011
13. Wild, Nayak, et al., "Description, Classification and Prevention of Falls in Old People at Home", *Rheumatology*, Vol. 20(3), pp. 153-159, 1981
14. Maki, "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*, 1988b
15. Maki, "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*, 1988a
16. Irvine, Snook, et al., "Stairway Risers and Treads: Acceptable and Preferred Dimensions", *Applied Ergonomics*, Vol. 21(3), pp. 215-225, 1990
17. Lee and Chou, "Balance Control During Stair Negotiation in Older Adults", *Journal of Biomechanics*, Vol. 40(11), pp. 2530-2536, 2007
18. Templer, "The Staircase: Studies of Hazards, Falls, and Safer Design", *Cambridge, Mass., MIT Press*, 1992
19. Haslam and Stubbs, "Understanding and Preventing Falls", *Boca Raton, Fla. ; London, Taylor & Francis*, 2006
20. Svanstrom, "Falls on Stairs: an Epidemiological Accident Study", *Scandinavian journal of social medicine*, Vol. 2(3), pp. 113-20, 1974
21. VandenBussche, Gallagher, et al., "Foot Placement in Oblique Stair Descent", *Proceedings of the Human Factors and Ergonomics Society Annual Meeting*, Vol. 55(1), pp. 1765-1768, 2011
22. Hill, Haslam, et al., "Safety of Older People on Stairs Behavioural Factors, A report prepared for The Department of Trade and Industry.", *Health & Safety Ergonomics Unit, Department of Human Sciences, Loughborough University, Loughborough*, 1999
23. SCC, "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*, 2008
24. IESNA, "Recommended Practice for Lighting and the Visual Environment for Senior Living ", *ed. A.I.R.-.-. IESNA Lighting for the Elderly and Partially Sighted Committee, IESNA(Illuminating Engineering Society of North America)*, 2007
25. Lord(a) and Dayhew, "Visual Risk Factors for Falls in Older People", *Journal of the American Geriatrics*

Society, Vol. 49(5), pp. 508-515, 2001

26. Pauls, "Recommendation for Improving the Safety of Stairs "*, Division of building research, National Research Council of Canada, Ottawa*, 1982