Building Rating System: An instrument for Building Accessibility Measurement for Better Indoor Navigation by Blind People

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Abstract

Purpose - The purpose of this article is to create a Building Rating System (BRS) with its bottom-up design model that can be carried out manually and in the future automatically.
Design/methodology/approach - The BRS is built, based on the structure of Spatial Representation Framework (SRF) for indoor navigation by people with visual impairment which was validated with visually impaired people, and incorporated with building design standards and regulations from around the world. The BRS was afterwards validated by three groups of five experts in the related fields such as research & development, accessibility, and building & interior designs. Finally, the user evaluation was carried out as by three focus groups of three experts in risk assessment to verify the usability of the system.
Findings - This article provides the design and methodology of the BRS used for classifying the accessibility in buildings into 4 levels of classification for people with visual impairment navigating around the buildings. This system is evaluated with System Usability Scales (SUS) which is found to be in a "Good" level on average (72.2 SUS scores).
Research limitations/implications - Success Criteria used in the space classification is mainly created for people with visual impairment at this stage, other disabilities requirements must be taken into account for the next stage of the development.
Practical implications - The system can in the future be carried out automatically in the form of standalone software or plugins that can be integrated in buildings and interior design software to seek recommendations towards a creation of inclusive built environment.
Originality/value - This article presents a design architecture of BRS with its details, description and Success Criteria used in the space classification.

1 Introduction and Background

People with sight loss have encountered barriers to traveling independently inside buildings for a long time, especially the buildings full of unfamiliar features such as universities, hospitals, shopping malls, airports, and public spaces [1]. Inside the buildings, many problems and challenges are presented in the indoor environments, such as obstacles, noise, and other barriers, especially unpredictable objects like people to navigate around, which directly affect their daily activities and navigation [2].

However, many people with sight loss have identified unfamiliarity of spaces as the main reason for not visiting alone even thought many advanced technologies have been invented and come up with promising results, for instance, the indoor positioning systems (INS) and wearable computing devices [1]. However, this may not be the best solution since most of them are designed for sighted people. Learning new environments like hospitals, department stores, or large and complex buildings would be difficult due to the lack of accessibility information and navigational cues (e.g. landmarks) [3]. Therefore, it is very hard to decide which way to reach the destination in such complex and crowded environments [4]. In this case, they would take a long time to familiarize themselves with spaces and to construct a mental map.

Many people with sight loss are afraid of visiting the building alone since they do not know the features in spaces and buildings, which can injure them so they can end up in the hospital. This has resulted from the lack of inclusive design in the built environment. If the buildings are designed to meet the needs of people with sight loss, they would feel more confident to visit. Thus, to be able to know about a level of accessibility provided inside the building before making a visit to a building is essential and helpful. Towards the inclusive built environment, many building regulations and legislations have been declared and used in most developed countries (e.g. UK [5, 6], USA [7, 8], Singapore [9]), highlighting barrier-free, accessible and adaptable buildings and dwellings for all people regardless of disability.

To provide an access for all people a number of building designs standards are published giving recommendations on how to create built inclusive environments for all people. To check how a building performs in terms of access and each of use, involves site inspection throughout the building from a list of checklists and recommendations to be followed and indeed a time consuming inspection due to details and specifications given in the checklists and recommendations.

As a matter of fact, this research aimed to create the system that can assess the accessibility in a building which can be carried out manually and in the future automatically. Thus, a building rating system (BRS), an instrument for measuring a building accessibility is introduced in this paper. This paper presents the first stage of developing the BRS for measuring a building accessibility by focusing on people with sight loss. This system is novel based on its design, methodology (such as classification workflows), and the clear indicators for space-level, floor-level, and building-level classifications. The BRS has been developed based on the use of knowledge from the spatial representation framework (SRF) [1], saying that the spaces are composed of 11 components drawn from cognitive mapping of people with visual impairment. The SRF was validated with 30 visually impaired people and 15 experts who work closely with visually impaired people e.g. orientation and mobility (O&M) instructors and accessibility experts.

2 Building Accessibility Assessment

A system that enables people to rate the accessibility in buildings would be useful, assessing how well buildings and environments perform in terms of access and ease of use [10] plus giving suggestions and recommendations toward the creation and improvement of an inclusive built environment for all people.

As of now, assessing building accessibility for existing buildings and environments (aka *access audit*) and even assessing building construction proposals (aka *access appraisal*) for new developments, refurbishments, and alterations are still too difficult due to a number of reasons. For example, the complexity of the buildings which results in a number of auditing processes e.g. a large number of requirements/checklists [11] to be used to determine how well buildings and environments perform in terms of access and each of use [10]. Moreover, determining level of accessibility in buildings is also another reason. Both audit processes require thorough building inspection and review of the construction proposals for access audit and access appraisal, respectively.

Much research have been studied with different methodologies about how building accessibility can be systematically assessed. For example, Kim et al. [12] used virtual reality with wheelchair users' movement collecting 2D/3D images and assess the building accessibility using building design criteria, accordingly. Another example is that a conceptual framework for evaluating building accessibility [13], using formal methods presented by Church and Marston [14] in evaluation focusing on accessible paths for wheelchair users, in a structured and detailed way. Similarly, Wu et al. [11] developed a quantitative building accessibility assessment model, using the analytic hierarchy process (APA) to establish multi-attributes, also known as accessibility criteria hierarchy for physical features.

To rate the accessibility in buildings, measuring accessibility in spaces is essential which will be used in rating accessibility of buildings overall. A number of studies have been proposed regarding the rating scales to be used in space with respect to the meeting of requirements. For example, 2 scales [10] of pass (all requirements are met) and fail (at least one fail); 3 scales [15] where 2 is *Fully comply*, 1 is *Partly comply*; and 0 is *Not comply/not provide*; and scales of 5 [16] where 1 is *Poor* (facility is not provided), *Satisfactory* (most requirements are not met), *Fair* (half requirements are met), *Good* (most requirements are met), and 5 is *Excellent* (all requirements are met), respectively. However, some studies have created their own their own rating scores, for example using relative accessibility (RA) scores [13, 14].

In terms of rating accessibility of the buildings, a percentage approach has usually been used for simplification and interpretation. All above-mentioned studies used percentages as a clear indicator [11, 12, 13, 14, 15] by first calculating space's accessibility score (with multiplying by the weighted importance [13]), summarizing scores of all spaces, and later normalizing the summary score into a percentage representing the accessibility of the buildings overall.

However, our study has shown that the use of percentage or averaging approaches are a bad practice since they cause a wrong measurement in rating the accessibility of buildings. Percentage and average may be too coarse to use especially in terms of safety. For example, the building may have a high percentage/average score but still have a few spaces that have zero or low accessibility scores such as horizontal circulation in Floor 1 (where the entrance is located). This means there is not any accessibility provided in any space of the floor since visually impaired people cannot access the building. Thus, our study presents a new rating scale, which is classified as categorical data, with clear indicators and meanings.

3 Methodology

To construct the BRS, the methodological triangulation method is used for confirmation and complementarity [17] towards a development of the BRS, consisting of reviews of building design standards and guidelines, expert validation, and user evaluation. The expert validation and review were carried out with face-to-face discussion individually with experts who at least have three-year experience in the required fields. The experts came from one of 3 groups, there were 5 experts in each group, such as Research and Development, Accessibility, and Building and Interior Design.

Group 1: *Research and Developments*, a group of five experts who are highly experienced in the field of research and developments (RDE). The experts were selected for their expertise with a computer science and/or engineering background over three years. This group was asked to validate and review the building rating system, especially focusing on the overview of the system towards feasibility in implementing and using this system in reality.

Group 2: *Accessibility*, a group of five experts who are highly experienced in the field of accessibility or assistive technology design for people with disabilities (AE). The experts were selected for their expertise with extensive understanding on helping people with disabilities (especially people with visual impairment). This group was asked to validate and review, focusing on the building rating scale (or Conformance A, AA, and AAA, in other words) and how to classify each space into a particular conformance level.

Group 3: *Building and Interior Design*, a group of five experts who are highly experienced in the field of building and interior design (BIE). The experts were selected for their expertise with extensive understanding in designing buildings and interiors and, especially designing inclusive built environments to meet the needs of people with disabilities. This group was asked to validate and review, focusing on the criteria and design specifications have been used in the space classification such as components and dimensions.

Finally, the user evaluation was done by site inspection with 3 focus groups of 3 three experts in building risk assessment using the System Usability Scales (SUS) to assess how system perform in terms of an ease of use [18].

4 Building Rating System

4.1 Overview

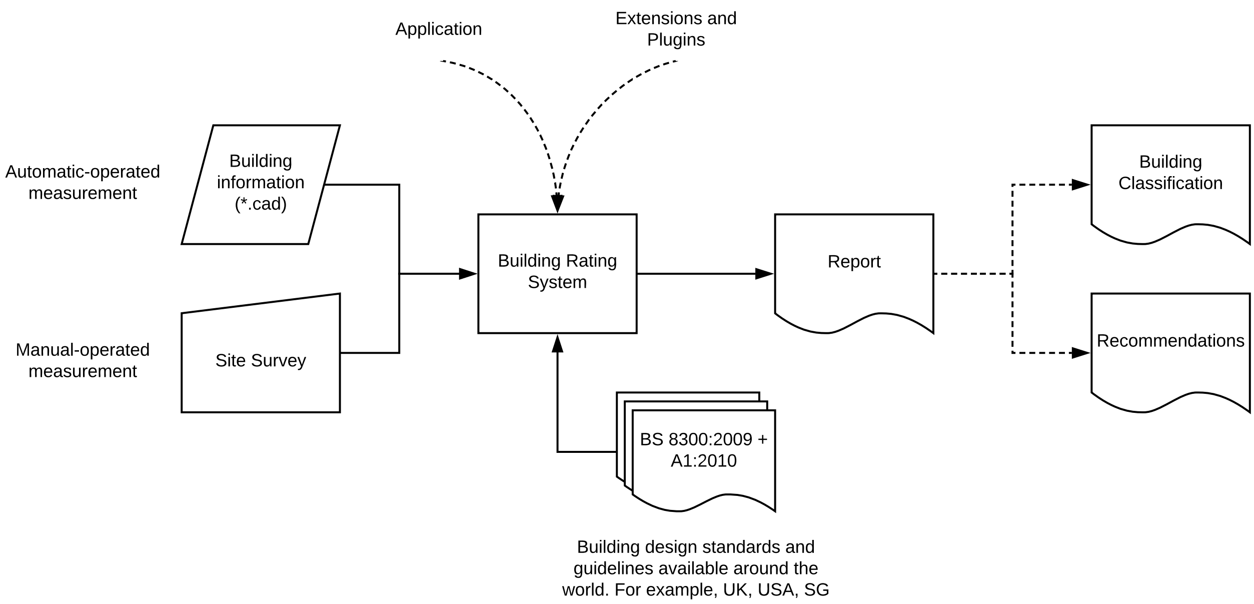


Figure 1: An Overview of Building Rating System

A building rating system is an application extended from the use of spatial representation framework (SRF). It is an instrument for measuring a level of accessibility provided in the buildings for people with visual impairment. The BRS can be carried out in both manually-operated and in the future automatically-operated measurements. To carry out the automatic measurement, the manual measurement must be in place, which is described in this paper.

To measure the building accessibility, many building design standards and guidelines available around the world (e.g. UK, USA, Canada, Singapore, and Australia) have been used and reviewed towards the construction of Success Criteria to be used in the space classification. At the end, the result is generated, consisting of building classification with details of each floor and spaces, and recommendations.

4.2 Design of Building Rating System

Currently, measuring the level of accessibility provided inside the buildings is still very difficult. For instance, the complexity of the building will result in a number of processes in the auditing process; there is not a set of success criteria to be used for an accessibility classification for building accessibility measurement. However, when it comes to auditing the environment, there is a set of checklists used to guide users in how to create the inclusive built environments [10].

Thus, this paper presents the building rating system, focusing on the accessibility for people with visual impairment, that can be carried out manually and in the future automatically

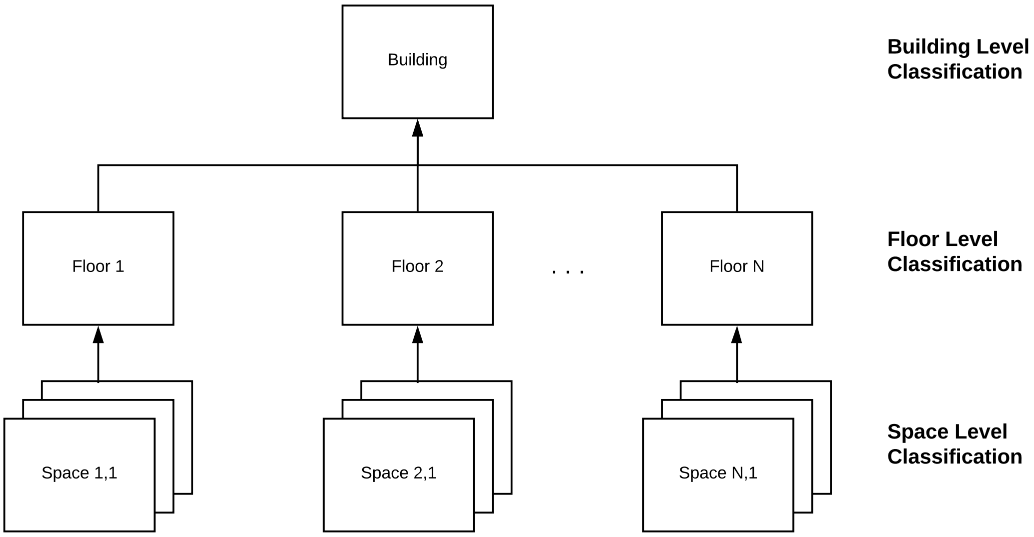


Figure 2: Bottom-up Design of the Building Rating System. The building accessibility assessment is started with the bottommost *Space Classification*, then *Floor Classification* using scores from the spaces' classification, and finally *Building Classification* using scores from the floors' classification

Due to complexity in designing the system, it is essentially to think of how the building is going to be rated and how its rating scores and interpretation are used. In fact, buildings are comprised of a number of spaces inside the building e.g. entrance, horizontal circulation, vertical circulation, WCs, etc. It is reasonably to classify the building into three levels i.e. *Building Level Classification*, *Floor Level Classification*, and *Space Level Classification* as shown in Figure 2. With the bottom-up design, measuring the level of accessibility for each space is a sensible starting point and can result in rating the level of accessibility of floors and later the building overall by a use of majority scoring method described in Section 4.5.

4.3 Conformances

Conformance refers to certification and confirmation that goods or services meet or satisfy the requirements, legislations, standards, or accepted practices [19]. In the BRS, the *requirements* are defined as Success Criteria, which will be used in the space classification. To meet the conformance, a space being measured must meet or satisfy the Success Criteria; thirteen types of spaces are used in the BRS (see Section 4.7).

In order to accommodate different situations that may require or allow greater levels of accessibility towards the building classification as shown in the big picture shown in Figure 2, the BRS has three levels of conformances (Conformance A, AA, and AAA) plus no conformance level, which are all classified as categorical data. Therefore, three levels of Success Criteria for all thirteen spaces must be given (see supplementary material in Appendix A). The WCAG 2.0 [19] also uses a similar rating scale for web pages.

For achieving each conformance in the BRS, Success Criteria for each conformance are designed based on the use of MoSCoW prioritization approach [20], where *Must-Have*, *Should-Have*, and *Could-Have* are used to define success criterion for Conformance A, AA, and AAA, respectively.

The success criteria to be used in the BRS are organized based on the impact on the design and improvement of spaces and building for better independent indoor navigations by people with visual impairment and accessibility. This means that the higher level of conformance the higher the level of accessibility is provided to people with visual impairment, and the more constraints in designing of spaces is required.

However, according to the field study of SRF, the findings have shown that the most important thing in the indoor navigation is safety. People with visual impairment are afraid of visiting somewhere where they do not know the features installed or cannot access the facilities provided in the spaces and buildings. As a result, there are three level of conformance as described with their requirements shown in Table 1.

Table 1: Conformance Level - Definitions and Requirements

Conformance	**Requirements**	**Definitions**
No Conformance	-	No conformance level, providing no accessibility in the space due to the failure of meeting the minimum level requirement. In this level, people with visual impairment are not advised to visit this space, unless assisted while inside the building.
A	Space must satisfy all the Must-Have success criteria. OR The Level A conforming alternate version is provided.	A minimum level, providing an ability to navigate the space without any hazard to people with visual impairment. In this level, people with visual impairment are likely to need assistance to perform some activities, otherwise perform activity with caution
AA	Space must satisfy all the Level A and the Should-Have success criteria. OR The Level AA conforming alternate version is provided.	A sufficient level of accessibility, providing features in addition to improving the independent navigation by people with visual impairment. In this level, people with visual impairment may need assistance to perform some activities. Note that this level is used as a general policy that all buildings must apply.
AAA	Space must satisfy all the Level A, Level AA, and all the Could-Have success criteria. OR The level AAA conforming alternate version is provided.	An enhanced level, providing features in addition to enabling an ability to access all of the facilities provided in the space to people with visual impairment. In this level, people with visual impairment are unlikely to need any assistance to perform the activities.

4.4 Space Classification

As shown in Table 1, to conform to the maximum conformance (Conformance AAA), the space must meet and satisfy all requirements of Conformance A, AA and AAA. In other words, if the space fails at least one requirement in Conformance A, the space shall be classified as no conformance as shown in a flow diagram in Figure 3. However, in some spaces Conformance AAA can be given regardless of the flow diagram if an alternate version of conformance is provided, see an example in the supplementary material in Appendix A, Section "A.5: Vertical circulation - Ramp".

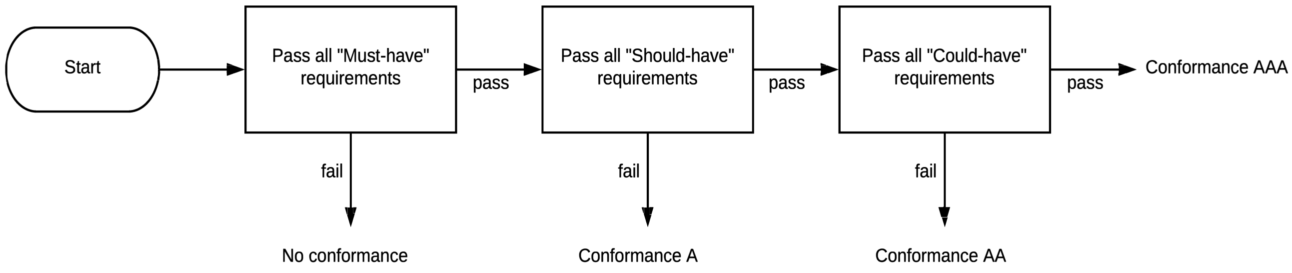


Figure 3: Determination of Space Classification in each space

4.5 Floor and Building Classifications

Having mentioned in Section 4.2, a space level is the bottommost level, where many spaces can be combined into a bigger space (e.g. floors and a building). The floor classification is therefore determined by the majority scores where the most conformances acquired from space classification is chosen as a level of accessibility overall. Similarly with a building classification, using the same method where a building accessibility is determined by as same as the majority scores where the most conformances acquired from floors classification is chosen.

In cases where a tie happens in the floor and building classification, a special rule shall be deployed where the conformance levels are converted to a score such as 0: No Conformance (N), 1: Conformance A, 2: Conformance AA, and 3: Conformance AAA. Afterwards, using an average scoring approach are in order as shown in Table 2.

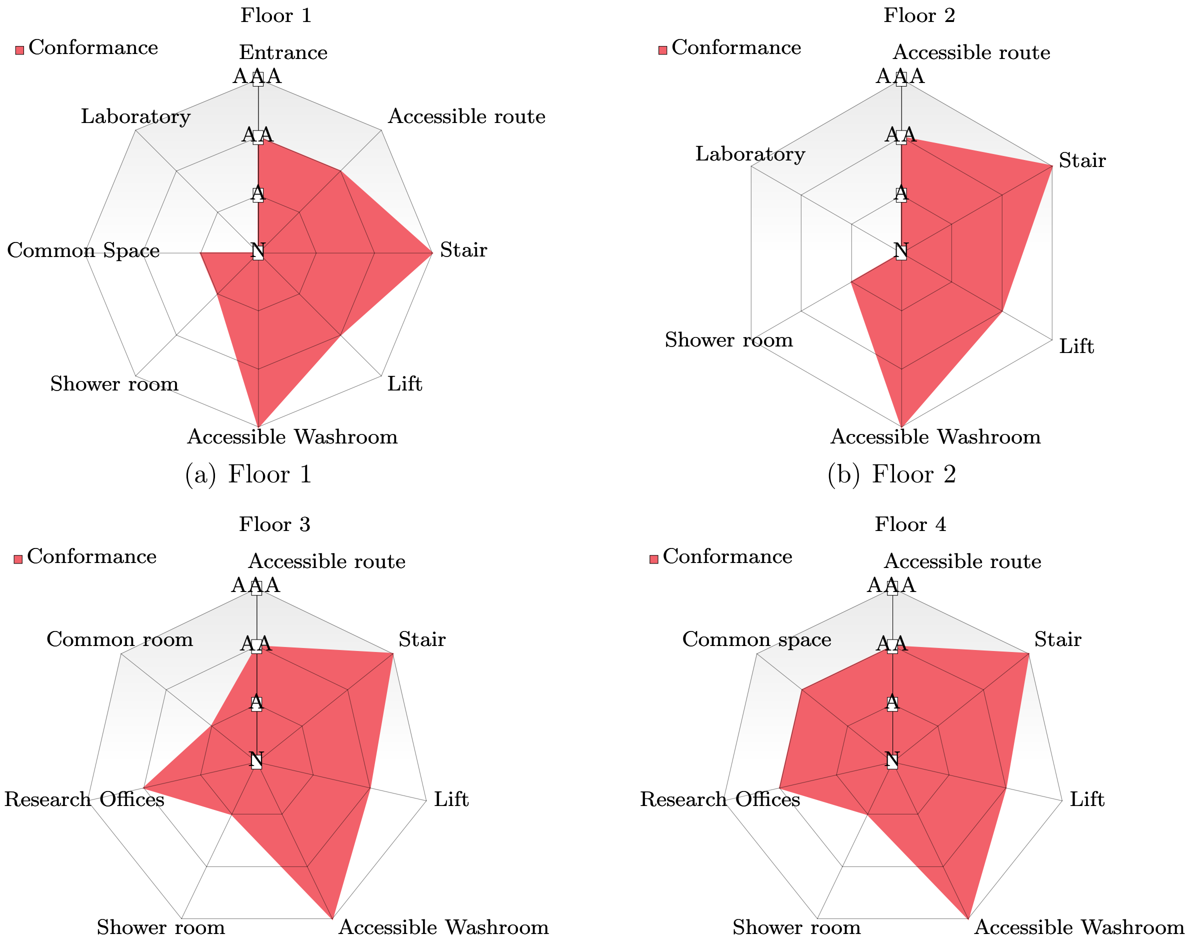
Table 2: Average scoring approach used in cases of a tie.

Tie Combination	**Average scoring approach**	**Classification**
2 in a tie		
N + A	(0+1)/2 = 0.5	A*
N + AA	(0+2)/2 = 1	A
N + AAA	(0+3)/2 = 1.5	A
A + AA	(1+2)/2 = 1.5	A
A + AAA	(1+3)/2 = 2	AA
AA + AAA	(2+3)/2 = 2.5	AA
3 in a tie		
N + A + AA	(0+1+2)/3 = 1	A
N + A + AAA	(0+1+3)/3 = 1.33	A
N + AA +AAA	(0+2+3)/3 = 1.66	A
A + AA + AAA	(1+2+3)/3 = 2	AA
4 in a tie		
N + A + AA + AAA	(0+1+2+3)/4 = 1.5	A

* Even though the average score is 0.5 (below 1: Conformance A), it is still above 0 (No Conformance), meaning that there still has accessibility. Thus, a minimum level of conformance shall be given in this case.

4.6 Results and Interpretation

Once the building (all spaces) is measured, the results will be reported in the form of spider (radar) charts, representing the level of accessibility at one particular floor achieved for each category of spaces in four scales, consisting of N: No Conformance, A: Conformance A, AA: Conformance AA, and AAA: Conformance AAA. The example of space classification can be seen in Figure 4.



(a) Floor 1

(b) Floor 2

(c) Floor 3

(d) Floor 4

Figure 4: Example of the space classification in Building 53 (Mountbatten), University of Southampton.

Table 3: Floor and Buildings Classifications - Majority scoring approach.

	N	A	AA	AAA	Classification
Floor 1	1	2	3	2	AA
Floor 2	1	1	2*	2	AA
Floor 3	0	2	3	2	AA
Floor 4	0	1	4	2	AA
			Building Classification		**AA**

* Conformance AA is selected due to the special rule applied in cases of "AA + AAA" is in a tile as shown in Table 2.

From Figure 4 and Table 3, the building is measured by the use of the space classification where Conformance AA are given for all floors which building classification is apparently determined as

Conformance AA due to four ratings of Conformance AA which is the majority. This means that the building conforms with the Conformance AA, a general policy that all building must conform to. With this result, people with visual impairment may ask for an assistance when navigating around this building.

4.7 Success Criteria

Success Criteria are requirements used in the space classification, measuring the building accessibility overall. Thirteen types of space are considered to be measured in the BRS with each space classified into one of the three levels of conformance (Conformance A, AA, and AAA). This means that there will be thirty-nine success criterion needed towards the building accessibility measurement such as *Entrances*, *Foyer*, *Passageways and Corridors*, *Stairs*, *Ramps*, *Lifts*, *Ambulant Disable WCs*, *Accessible Washroom*, *Bathrooms and shower rooms*, *Bedrooms*, *General space* (e.g. office, living room, refreshment room), *Utility spaces* (e.g. kitchen, laundry, and storage room), and *Hall and Stadium* (e.g. lecture room, conference room, auditorium, and stadium).

Determining the success criterion to be included for each conformance for each space inevitably requires an understanding of an inclusive built environment design for buildings to meet the needs of people with visual impairment. A number of building design standards, guidelines, and regulations have therefore been studied and reviewed such as UK , USA, Canada, Singapore, Australia.

All success criteria will be first used in the manually operated audit as a pass/fail checklist for measuring the level of accessibility. In the auditing process, there will be four options that users can select, which will affect the score at the end of the process, such as *Pass*: a feature met the Success Criteria; *Fail*: a feature failed the Success Criteria; *Can't Tell*: a feature cannot be measured due to technical difficulties, which will require further (visual) inspections indicated by (*) asterisk in the spider chart. Note that the option of *Can't Tell* shall not be provided in the *Must-Have* Success Criteria.; *Not Applicable*: a feature is not present, which is ignored in the accessibility measurement.

5 Expert Validation and Review

Three groups of five experts in research and development (RDE), accessibility (AE), and building and interior design (BIE) were recruited, of which 5 experts have worked with people with visual impairment; 7 experts with general disabilities; and 1 expert with Cerebral palsy; while there were 2 experts in the field of research and development that have not yet worked with disabled people.

In this part, all responses from 15 experts will be quantified in the form of 5-scales expert agreement, using a coding system shown in Table 4, and later statistically analyzed (as shown in Table 5) with the details given in the face-to-face discussion.

Table 4: Agreement scale - a coding system for quantifying qualitative data used in the expert validation and review.

Scale	Coding	Criteria and Descriptions
1	Strongly disagree	*Disagree*; Proposed element is not sensible and workable in practice. The proposed element needs to be redesigned, accordingly.
2	Disagree	*Somewhat disagree*; Some part of a proposed element does not seem to be sensible and workable in practice. Suggestions are either made with what to be concerned and fixed for the proposed element.
3	Neutral	*Neither agree or disagree*
4	Agree	*Agree but there is a room for improvements*; The proposed element seems to be sensible and workable in practice. Suggestions are either made for improving the proposed element.
5	Strongly agree	*Agree*; The proposed element is well-designed, sensible and workable in practice.

Table 5: Experts' agreement with a statistical test on the design of BRS and its components proposed in this study. The proposed element is considered as agree if the agreement scale is more than 3.

Category	# of experts who agree	Mean	Sig. (2-tailled)
Building Rating System			
Design of the building rating system	13	4.000	< 0.001
Conformance	10	3.667	0.027
Space Classification	10	3.667	0.027
Floor and Building classifications	3	2.400	0.033
Results and Interpretation	3	2.400	0.033
Success Criteria: Entrance			
Conformance A	9	3.4667	0.048
Conformance AA	10	3.6667	< 0.001
Conformance AAA	9	3.5333	0.006
Success Criteria: Foyer			
Conformance A	10	3.6667	< 0.001
Conformance AA	10	3.6667	< 0.001
Conformance AAA	10	3.6667	< 0.001
Success Criteria: Horizontal Circulation (Passageways and Corridors)			
Conformance A	10	3.6667	< 0.001
Conformance AA	10	3.6667	< 0.001
Conformance AAA	10	3.6667	< 0.001
Success Criteria: Vertical Circulation - Stairs			
Conformance A	10	3.6667	< 0.001
Conformance AA	10	3.6667	< 0.001
Conformance AAA	10	3.6667	< 0.001
Success Criteria: Vertical Circulation - Ramps			
Conformance A	9	3.5333	0.006
Conformance AA	10	3.6667	< 0.001

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Category	# of experts who agree	Mean	Sig. (2-tailled)
Conformance AAA	10	3.6667	< 0.001
Success Criteria: Vertical Circulation - Lifts			
Conformance A	9	3.5333	0.006
Conformance AA	10	3.6667	< 0.001
Conformance AAA	10	3.5333	0.006
Success Criteria: Ambulant Disabled WCs			
Conformance A	10	3.6667	< 0.001
Conformance AA	10	3.6667	< 0.001
Conformance AAA	10	3.6667	< 0.001
Success Criteria: Accessible Washroom			
Conformance A	10	3.6667	< 0.001
Conformance AA	10	3.6667	< 0.001
Conformance AAA	10	3.6667	< 0.001
Success Criteria: Bathrooms and Shower rooms			
Conformance A	9	3.4667	0.048
Conformance AA	9	3.5333	0.006
Conformance AAA	10	3.6667	< 0.001
Success Criteria: Bedrooms			
Conformance A	10	3.6667	< 0.001
Conformance AA	8	3.4000	0.054
Conformance AAA	10	3.6667	< 0.001
Success Criteria: General spaces			
Conformance A	10	3.6667	< 0.001
Conformance AA	10	3.6667	< 0.001
Conformance AAA	10	3.6667	< 0.001
Success Criteria: Utility Spaces			
Conformance A	8	3.4000	0.054
Conformance AA	10	3.6667	< 0.001
Conformance AAA	10	3.6667	< 0.001
Success Criteria: Hall and Stadium			
Conformance A	10	3.6667	< 0.001
Conformance AA	10	3.6667	< 0.001
Conformance AAA	10	3.6667	< 0.001

Based on the statistical results shown in Table 5, most of components in the BRS and Success Criteria were successfully validated, while some were not due to the ambiguous design and impractical functionality. For instance, Floor and Building Classification that was designed with a use of averaging and percentage approaches to calculate the floor and building accessibility.

Many experts pointed out that the averaging/percentage approach is too coarse, biased, and not accurate to be used especially in terms of safety measurement. For example, the building may have a high average/percentage score but still have a few spaces that have no conformance. Furthermore, some spaces may be more critical than others such as main entrance or restrooms. On the other hand, two experts proposed another approach with the use of an overlapping score method, where the floor and building classifications are determined by using overlapping scores for each space (floor classification) and floor (building classification). Considering that, the overlapping score method is not as good as the averaging score method. Similarly, if one floor falls into No Conformance level, the building classification will apparently fall into No Conformance as well. Therefore, a majority of building areas fall in each accessibility level so (0, A, AA, AAA) is used instead of the average and percentage scoring approaches.

6 User evaluation

The user evaluation was carried out with three focus groups of three experts in risk assessment as to verify the usability of the system. The process involved site inspections where the Building 53 (Mountbatten) at the University of Southampton was selected. Prior to the focus groups, the experts were asked to assess the accessibility for many types of space as shown below. After that, the experts were then asked to give opinions based on user experience in using the BRS. In terms of usability evaluation, System Usability Scales (SUS) was used, where all responses were converted into a five-point scale that ranging from 1-*Strongly Disagree* to 5-*Strongly Agree* [35, 36]. The results of the usability analysis can be broken down into (1) overview and (2) details as shown in Table 6 and Table 7, respectively.

- Main Foyer (Wide-open area)
- Seminar Room (Large, and movable space)
- Zepler Student Laboratory (Large, and fix space)
- Office (Small space)
- WCs - Accessible washroom
- WCs - Public toilets
- Horizontal Circulation (e.g. passageways and corridors)
- Vertical Circulation - Stairs
- Vertical Circulation - Lifts.

In Table 6, the results have shown that the overall usability of the BRS was 72.2 SUS score, as classified as *Good* in the adjective rating scale [35], while the acquired SUS scores varied from 30.0 (*Awful*) to 92.5 (*Best Imaginable*). By the adjective rating scales, 4 out of 9 experts have agreed the usability of the BRS is in *Ok* level, while others said 2 for *Best Imaginable* and *Good*, and 1 for *Awful*. These indicators have shown that the BRS may not perform the best at this stage, and there must be room for improvement which leads to a question-by-question in-depth analysis in Table 7.

Table 6: SUS Scores for the BRS performed in the user evaluation, where SUS scores is interpreted into Adjective Ratings. 1: *Strongly Disagree*, 2: *Disagree*, 3: *Neutral*, 4: *Agree*, and 5: *Strongly Agree*

	Risk Assessor								
SUS Question	**R1**	**R2**	**R3**	**R4**	**R5**	**R6**	**R7**	**R8**	**R9**
1. I think that I would like to use the BRS frequently when doing a risk assessment for space designs.	5	4	4	4	5	4	5	5	2
2. I found the BRS unnecessarily complex.	1	1	2	2	1	2	1	1	4
3. I thought the BRS was easy to use.	5	5	4	5	5	4	4	5	2
4. I think that I would need the support of a technical person to be able to use this system.	4	4	4	3	2	1	5	4	5
5. I found the various functions in the BRS were well integrated.	4	4	4	5	4	4	4	5	3

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SUS Questions	Risk Assessor								
	R1	R2	R3	R4	R5	R6	R7	R8	R9
6. I thought there was too much inconsistency in this system.	2	2	2	1	2	2	2	1	3
7. I imagine that most people would learn to use this system very quickly.	4	5	5	4	5	5	3	5	1
8. I found the BRS very awkward to use.	3	3	3	1	1	2	3	1	4
9. I felt very confident using the BRS.	4	4	5	4	5	4	3	5	3
10. I needed to learn a lot of things before I could get going with this system.	4	4	4	2	1	2	2	1	3
Sum	36	36	37	31	31	30	32	33	30
SUS Score	70.0	70.0	67.5	82.5	92.5	80.0	65.0	92.5	30.0

Min Score	30.0 (Awful)	**Adjective Rating** [35, 36]	
Max Score	92.5 (Best)	90.1 - 100	Best Imaginable
Average Score	72.2 (Good)	85.5 - 90.1	Excellent
		71.4 - 85.5	Good
Acquired Adjective Ratings	Best × 2	50.9 - 71.4	Ok
	Good × 2	35.7 - 50.9	Poor
	Ok × 4	20.3 - 35.7	Awful
	Awful × 1	0 - 20.3	Worst Imaginable

Table 7: Actual mean score for each items acquired in the BRS usability test goes against the benchmarks for average and good scores for the 10 SUS items, including one-sample t-test.

SUS Question	Actual Score (N=9)		Benchmark [37]	
	Mean	Sig. (2-tailed)	Average Score	Good Score
1. I think that I would like to use the BRS frequently when doing a risk assessment for space designs.	4.22^{g*}	0.005	≥ 3.39	≥ 3.80
2. I found the BRS unnecessarily complex.	1.67^{g*}	0.004	≤ 2.44	≤ 1.85
3. I thought the BRS was easy to use.	4.33^{g*}	0.004	≥ 3.67	≥ 4.24
4. I think that I would need the support of a technical person to be able to use this system.	3.56	0.247	≤ 1.85	≤ 1.51
5. I found the various functions in the BRS were well integrated.	4.11^{g*}	0.001	≥ 3.55	≥ 3.96
6. I thought there was too much inconsistency in this system.	1.89^{a*}	0.001	≤ 2.20	≤ 1.77
7. I imagine that most people would learn to use this system very quickly.	4.11^{a*}	0.040	≥ 3.71	≥ 4.19
8. I found the BRS very awkward to use.	2.33	0.111	≤ 2.25	≤ 1.66
9. I felt very confident using the BRS.	4.11^{a*}	0.003	≥ 3.72	≥ 4.25

... Continued on next page

SUS Question	Actual Score (N=9)		Benchmark [37]	
	Mean	**Sig. (2-tailed)**	**Average Score**	**Good Score**
10. I needed to learn a lot of things before I could get going with this system.	2.56	0.312	≤ 2.09	≤ 1.64

[g] Actual SUS mean score has surpassed a benchmark of good score
[a] Actual SUS mean score has surpassed a benchmark of average score
[*] Actual SUS mean score is found to statistically significant ($p < 0.05$)

In detail, the question-by-question (in-depth) analysis was performed and shown in Table 7. Means of each item are statistically tested and compared against the benchmark by Lewis and Sauro [37], who provided the average and good scores that each item should achieve. Based on the analysis, the BRS has performed very well in terms of ease of use and its design/workflow as shown in item 1-3 and 5, whose means have achieved the good score while item 6-7 achieved the average score.

On the other hand, some improvements are taken into account as in item 4, 8 and 10. The findings from 3 focus groups showed that the metrics/requirements used in the Success Criteria are architectural jargon which are too technical but always used in the building design standards and guidelines around the world. To create the BRS for all people, some terminology might be changed to make it easier to understand. With this reason, however, the experts have asked a technical person to guide them in the beginning. Based on the observation, the experts were grasping using the BRS when they understand a big picture of the system. Otherwise a user manual or training must be provided prior to the use the BRS.

7 Conclusion

People with sight loss have encountered barriers to traveling independently inside buildings for a long time, especially the buildings full of unfamiliar features. Learning new environments like hospitals, department stores, or large and complex buildings would be difficult due to the lack of accessibility information and navigational cues. Many people with sight loss are therefore afraid of visiting the building alone since they do not know the features in spaces and buildings. Thus, to be able to know about a level of accessibility provided inside the building before making a visit to a building is essential and helpful.

This research proposed the "Building Rating System: An instrument for Building Accessibility Measurement for Better Indoor Navigation by Blind People" based on the spatial representation framework for better indoor navigation by blind people [1]. The system is mainly designed, and can be carried out manually and in the future automatically, with the bottom-up design starting from the space classification, floor classification, and building classification (the topmost) indicating a building accessibility overall. To measure the accessibility of building, Success Criteria were designed for 13 types of space with 3-levels of conformance (Conformance *A*, *AA*, *AAA*) and also *No Conformance* used as accessibility indicators. The building rating system was validated and reviewed by 3 groups of 5 experts who work in the related fields to confirm the validity of the system, and later evaluated by 9 of building risk assessors, who have experience in building and space inspections, as 3 focus groups of 3 risk assessors. The results have suggested that the building rating system has acquired a good level (72.2 SUS score) on average.

A Supplementary Material

The supplementary material for this article can be found online at ePrint, the University of Southampton [38] or https://www.dropbox.com/s/xzvz2a5z9p8c8et/Supplementary.pdf

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Biography

Watthanasak Jeamwatthanachai, also known as Hall. Hall is a researcher at the National Electronics and Computer Technology Center (NECTEC). He is also a PhD candidate in the Cyber Physical System (CPS) research group. He has been researching on the topic of Human-Computer Interaction and Informatics, specializing in Spatial Representation for better indoor navigation by people with visual impairment. His research is focusing on how to create maps that can be visualized in 3D geography with full detail of information that meets the need of people with sight loss. The motivation is to help people with sight loss to have a freedom in navigation indoors. He is also interested in expanding and utilizing the 3D map into other research areas of autonomous systems, indoor position systems, new enabling technologies and other indoor-based systems.