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Enquiries about this publication can be sent to:

Australian Building Codes Board
GPO Box 2013
CANBERRA ACT 2601
Phone: 1300 134 631
Email: ncc@abcb.gov.au
Web: abcb.gov.au

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Preface

The Inter-Government Agreement (IGA) that governs the Australian Building Codes Board (ABCB) places a strong emphasis on reducing reliance on regulation, including consideration of non-regulatory alternatives such as non-mandatory handbooks and protocols.

This Handbook is one of a series produced by the ABCB developed in response to comments and concerns expressed by government, industry and the community that relate to the built environment. The topics of Handbooks expand on areas of existing regulation or relate to topics which have, for a variety of reasons, been deemed inappropriate for regulation. They provide non-mandatory advice and guidance.

The Access Verification Methods Handbook assists in understanding DV2 and DV3 of NCC Volume One. It addresses issues in generic terms, and is not a document that sets out specific compliance advice for developing solutions using DV2 and DV3. It is expected that this Handbook will be used to guide solutions relevant to specific situations in accordance with the generic principles and criteria contained herein.

In NCC 2019, DV2 and DV3 provide performance-based pathways for practitioners to demonstrate that a building is compliant with the relevant access *Performance Requirements* of the NCC using a Verification Method as the Assessment Method. The *Verification Methods* have been introduced to improve the flexibility of designers to demonstrate compliance with the *Performance Requirements* of the NCC.

Contents

REMINDER

This Handbook is not mandatory or regulatory in nature and compliance with it will not necessarily discharge a user's legal obligations. The Handbook should only be read and used subject to, and in conjunction with, the general disclaimer at page i.

The Handbook also needs to be read in conjunction with the relevant legislation of the appropriate State or Territory. It is written in generic terms and it is not intended that the content of the Handbook counteract or conflict with the legislative requirements, any references in legal documents, any handbooks issued by the Administration or any directives by the Appropriate Authority.

1 Background

The NCC is a performance-based code containing all *Performance Requirements* for the construction of buildings. To comply with the NCC, a solution must achieve compliance with the Governing Requirements and the *Performance Requirements*. The Governing Requirements contain requirements about how the *Performance Requirements* must be met. A building, plumbing or drainage solution will comply with the NCC if it satisfies the *Performance Requirements*, which are the mandatory requirements of the NCC.

This document was developed to provide guidance to practitioners seeking to demonstrate compliance with the *Performance Requirements* using the *Verification Methods* DV2 and DV3.

1.1 Scope

The Handbook is structured to first provide the reader with an overall introduction to the concept of the two *Verification Methods* and then going on to provide further guidance on implementing these *Verification Methods*.

Further reading on this topic can be found with the references located in the body of this document and in Appendix D.

1.2 Design and approval of Performance Solutions

The design and approval processes for solutions using the Access *Verification Methods* (DV2 and DV3) is expected to be similar to that adopted for demonstrating compliance of other NCC *Performance Solutions*. Since the design approval process for *Performance Solutions* varies between the responsible State and Territory governments it is likely to also be the case with designs incorporating the Access *Verification Methods* and requirements should be checked for the relevant jurisdiction.

Notwithstanding the quantified input and acceptance criteria, other qualitative aspects of DV2 and DV3, which are discussed in this document, require assessment and analysis throughout the design and approval process. The advice of an appropriately qualified person should be sought to undertake this assessment and analysis where required, and may be aided by the early and significant involvement from regulatory authorities, peer reviewer(s) and / or a technical panel as appropriate to the State or Territory jurisdiction.

1.3 Supplementary information

This handbook provides an overview of the use of *Verification Methods* DV2 and DV3. Some information that may be relevant to the use of the *Verification Methods*, such as certain inputs and sources of data, is not within the scope of this handbook.

Some of this information will be provided as supplementary information on the ABCB website (abcb.gov.au) to allow for ongoing development / amendment in response to feedback from users.

1.4 Using this document

General information about complying with the NCC and responsibilities for building and plumbing regulation is provided in Appendix A of this document.

Acronyms used in this document are provided in Appendix B.

Italicised terms are defined terms used in this document. They align with the defined terms in the NCC. See Schedule 3 of the NCC for further information.

Additional information about other legislative requirements is provided in Appendix C.

Further reading on accessible features and buildings is also provided in Appendix D.

Different styles are used in this document. Examples of these styles are provided below:

NCC extracts

Examples

Alerts

Reminders

2 Complying with the Access Performance Requirements

The NCC *Performance Requirements* prescribe the minimum necessary technical requirements for buildings, building elements, and plumbing and drainage systems. They must be met to demonstrate compliance with the NCC.

The *Performance Requirements* that may be satisfied using DV2 (for the purpose of access) are DP1, DP2, DP6, EP3.4 and FP2.1. For the purposes of ramps, DV3 may be used to satisfy DP2. Note that DV2 and DV3 are not the only methods of demonstrating compliance with the *Performance Requirements*.

Other *Performance Requirements* not covered by DV2 and DV3 may need to be considered in order to comply with NCC Volume One A.2.2(3) and A2.4(3). It is necessary to understand the inter-relationships between other requirements and the requirements relevant within DV2 and DV3 to ensure no design conflicts arise.

2.1 NCC Compliance pathways

Compliance with the NCC is achieved by complying with the Governing Requirements of the NCC and relevant *Performance Requirements*. There are three options available to demonstrate compliance with the *Performance Requirements*:

- a *Performance Solution*,
- a *DTS Solution*, or
- a combination of a *Performance Solution* and a *DTS Solution*.

Within the *Performance Solution* pathway, some options available are:

1. Direct application of the *Performance Requirements*, and
2. *Verification Methods*.

Table 2.1 outlines where these options can be used to show compliance with *Performance Requirements* DP1, DP2, DP6, EP3.4 and FP2.1.

Table 2.1 Options for demonstrating compliance

Performance Requirement	Direct application of Performance Requirements (Performance Solution)	DV2 (Performance Solution)	DV3 (Performance Solution)	DTS Provisions (DTS Solution)
DP1	Y	Y	N	Y
DP2 (General)	Y	Y	N	Y
DP2 (Ramps)	Y	Y	Y	Y
DP6	Y	Y	N	Y
EP3.4	Y	Y	N	Y
FP2.1	Y	Y	N	Y

See Appendix A for further information on demonstrating compliance with the NCC.

2.2 Access Performance Requirements

The *Performance Requirements* related to DV2 and DV3 are reproduced below.

DP1 Access for people with a disability

Access must be provided, to the degree necessary, to enable—

(a) people to—
   (i) approach the building from the road boundary and from any *accessible* carparking spaces associated with the building; and
   (ii) approach the building from any *accessible* associated building; and
   (iii) access work and public spaces, accommodation and facilities for personal hygiene; and
(b) identification of *accessways* at appropriate locations which are easy to find.

Limitation:

DP1 does not apply to a Class 4 part of a building.

DP2 Safe movement to and within a building

So that people can move safely to and within a building, it must have—

(a) walking surfaces with safe gradients; and

(b) any doors installed to avoid the risk of occupants—

  (i) having their egress impeded; or

  (ii) being trapped in the building; and

(c) any stairways and ramps with—

  (i) slip-resistant walking surfaces on—

    (A) ramps; and

    (B) stairway treads or near the edge of the nosing; and

  (ii) suitable handrails where necessary to assist and provide stability to people using the stairway or ramp; and

  (iii) suitable landings to avoid undue fatigue; and

  (iv) landings where a door opens from or onto the stairway or ramp so that the door does not create an obstruction; and

  (v) in the case of a stairway, suitable safe passage in relation to the nature, volume and frequency of likely usage.

DP6 Paths of travel to exits

So that occupants can safely evacuate the building, paths of travel to *exits* must have dimensions appropriate to—

(a) the number, mobility and other *characteristics* of occupants; and

(b) the function or use of the building.

Limitation:

DP6 does not apply to the internal parts of a *sole-occupancy unit* in a Class 2 or 3 building or Class 4 part of a building.

EP3.4 Lift access for people with a disability

When a passenger lift is provided in a building *required* to be *accessible*, it must be suitable for use by people with a disability.

FP2.1 Personal hygiene facilities

Suitable sanitary facilities for personal hygiene must be provided in a convenient location within or associated with a building, to the degree necessary, appropriate to—

(a) the function or use of the building; and
(b) the number and gender of the occupants; and
(c) the disability or other particular needs of the occupants.

3 Development of Access Performance Solutions

This section outlines the process of developing a *Performance Solution* using the *Verification Methods* DV2 and DV3.

3.1 Performance-based design brief (PBDB)

A PBDB is a documented process that defines the scope of work for the access *Performance Solution*. Its purpose is to set down the basis on which analysis of the proposed building and its *Performance Solution* will be undertaken, as agreed by the relevant stakeholders.

A PBDB allows all relevant stakeholders to be involved in the development of a *Performance Solution*, and to share their specific knowledge and perspectives with the design team.

When developing a *Performance Solution*, a PBDB should be undertaken involving all relevant stakeholders to the building design.

Relevant stakeholders vary from design to design. Often relevant stakeholders include: the access consultant, architect, developer, client, engineers and the building surveyor / certifier. Note that some state legislation prevents the building surveyor / certifier from being involved in the design process. If this is not the case, care is required to ensure they are not involved in design decisions that they will be certifying; as this would constitute a conflict of interest.

Alert

Building surveyor and building certifier are used synonymously throughout the country depending on which jurisdiction you are located in.

Relevant stakeholders can be determined by conducting a simple analysis as to who should be involved in the PBDB process. This analysis should identify stakeholders with a high interest in the design process.

While full agreement on all aspects of the PBDB is the preferred outcome, it is acknowledged that in some instances this may not be possible. If full agreement cannot be achieved through the PBDB process, dissenting views should be appropriately recorded so that it can be considered by the appropriate authority when determining compliance and as part of the approvals process.

3.2 Access design strategy

The PBDB should cover the access design strategy for the building, outlining the features that will be incorporated into the building to achieve the required outcome.

For example, the designer of a low-rise Class 9b art gallery may choose to investigate alternative options for providing ramps in their building that may not necessarily comply with the DTS provisions. The strategy to accomplish this may be to incline some of the floors and demonstrate that the proposed solution provides equivalent safety and amenity as a DTS compliant solution. To further optimise the design, the strategy may aim to optimise the accessibility of the locations of amenities, entrances and accessible sanitary facilities.

3.3 Performance-based design report (PBDR)

Once the analysis has been completed, a final report should be prepared that includes the information from the agreed PBDB, all the modelling and analysis, and all other information required to clearly demonstrate that the building complies with the *Performance Requirements*. Further details on preparing a PBDR are provided in Section 6.

3.4 Practitioner conduct

When preparing a *Performance Solution*, practitioners should exercise their duties in an appropriate manner. Key principles include:

1 Acting in the public interest

In undertaking their duties, including meeting the needs of their client, a practitioner should exercise their discretionary powers in ways that safeguard the public interest.

2 Independence

In performing their professional duties, a building surveyor / certifier should be objective, impartial and free from any conflict of interest. Other practitioners should ensure any conflicts of interest are disclosed to all relevant parties.

3 Competence

A practitioner should not undertake professional work that they are not competent to perform. See Section 3.5 for further details of the peer review process.

3.5 Peer review

The appointment of a peer reviewer should be considered at the PBDB stage where a building and its *Performance Solution* are complex. This includes those that have innovative designs, or challenging aspects of modelling or analysis which fall outside the competence and expertise of the building surveyor / certifier.

The peer reviewer should have suitable qualifications and experience which give them a level of competence in order to evaluate the *Performance Solution* proposed.

The peer review is potentially the most complex kind of review both technically and ethically. The peer review should consider the following:

- whether the completed work has met its objectives;
- other options that could have been included in the preliminary design;
- whether the evaluation of options is rigorous and fair;
- the validity of the assumptions;
- the validity of the conclusions;
- the process for completion of the construction work;
- the validity of the recommendations;
- the objectives set out for the work;
- adherence to relevant regulations and codes of practice;
- the fitness-for-purpose of the work.

The peer review may also consider elements of the design process, such as resources, value engineering, concept design, risk reviews and design methodology. Note that allowing a peer reviewer to have input into the scope of the work, the design process, project planning and the completed work review can lead to a better outcome for the project.

While the work is in progress, the peer reviewer can review inputs at specified points to aid the design process and avoid problems such as poor evaluation of options and incorrect assumptions.

4 DV2: Access to and within a building

4.1 Overview

Verification Method DV2 provides a structure which designers may use to complete a *Performance Solution* that demonstrates compliance with *Performance Requirements* DP1, DP2, DP6, EP3.4 and/or FP2.1.

Access solutions are multi-faceted and dependent on the needs of the user groups of the building which may vary markedly from case to case. DV2 is therefore flexible and enables consideration of solutions to meet occupant needs. DV2 allows the minimum acceptable criteria based on the unique *characteristics* of a building and its occupants to establish whether a building solution provides accessibility equivalent to the minimum requirements of a DTS compliant building.

The basic process of DV2 is:

1. Develop a PBDB to determine the metrics (measurable acceptance criteria) that can be used to measure the levels of safety and amenity that are provided by the *Performance Requirements*.

2. Design a reference access solution for the building that meets the DTS requirements and benchmark the level to which the building performs against the measurable acceptance criteria.

3. Measure the level to which the proposed access solution performs against the measurable acceptance criteria. If the proposed solution performs equal to or better than the reference solution when as measured by the measurable acceptance criteria, the proposed access solution is verified against the relevant *Performance Requirements* of the NCC.

4.2 DV2 Verification Method

DV2 Access to and within a building

Compliance with DP1, DP2, DP6, EP3.4 and/or FP2.1, for access, is verified when it is determined that the proposed building provides an equivalent level of access as a reference building when using the following process:

(a) A performance-based design brief is completed to define the following:
  (i) The occupant profile and *characteristics* based on the type and use of the building.
  (ii) The appropriate method for determining the level of access.
  (iii) The appropriate modelling method and tool.
  (iv) The measurable acceptance criteria.

(b) Using the appropriate method, the level of access *required* is determined by first modelling a reference building using the relevant *Deemed-to-Satisfy Provisions* of Parts D, E and F and the occupant profile and *characteristics* to determine the—
  (i) needs of the occupants that the reference building addresses; and
  (ii) facilities required to be accessed by each occupant profile; and
  (iii) baseline measurable acceptance criteria.

(c) The proposed building and access solution must be modelled using a modelling method and approach consistent with that used for the reference building, and the same critical features including the following:
  (i) Occupant profile and *characteristics*.
  (ii) Building location and orientation.
  (iii) Locations of all entrances and *exits*.
  (iv) Locations of facilities important to the solution, including sanitary facilities, lifts, stairwells, etc.
  (v) The number and range of facilities.

(d) The proposed solution’s level of access is assessed by modelling occupant performance using *characteristics*, whereby the proposed building provides for equivalent access appropriate to the needs of each occupant profile.

4.3 Developing the PBDB

A PBDB process (Section 3.1) is critical to determining the overall framework of the DV2 access solution and defining the inputs and features that must be considered, such as:

- The occupant profile and *characteristics* based on the type and use of the building.
- The appropriate method for determining the level of access.
- The appropriate modelling method and tool.
- The measurable acceptance criteria.

4.3.1 Occupant profile and characteristics

Relevant occupant *characteristics* are those which define how an occupant will interact with a building, including but not limited to: occupant movement speeds, turning ability, reach capability, perception of luminance contrast and hearing threshold. The occupant profile is the number and proportions of occupants that are expected to have each *characteristic*. The profile will be influenced by the classification and function of the building.

The occupant disability groups, and their associated *characteristics*, may be derived from ABS 4450.0 2016 which is based on the model developed by the Washington Group, World Health Organisation as a means of assembling population disability data. The disability groupings are:

1. Vision
2. Hearing
3. Walking, including stair and ramp traversal
4. Memory / cognitive
5. Activities of daily living
6. Communication (including understanding).

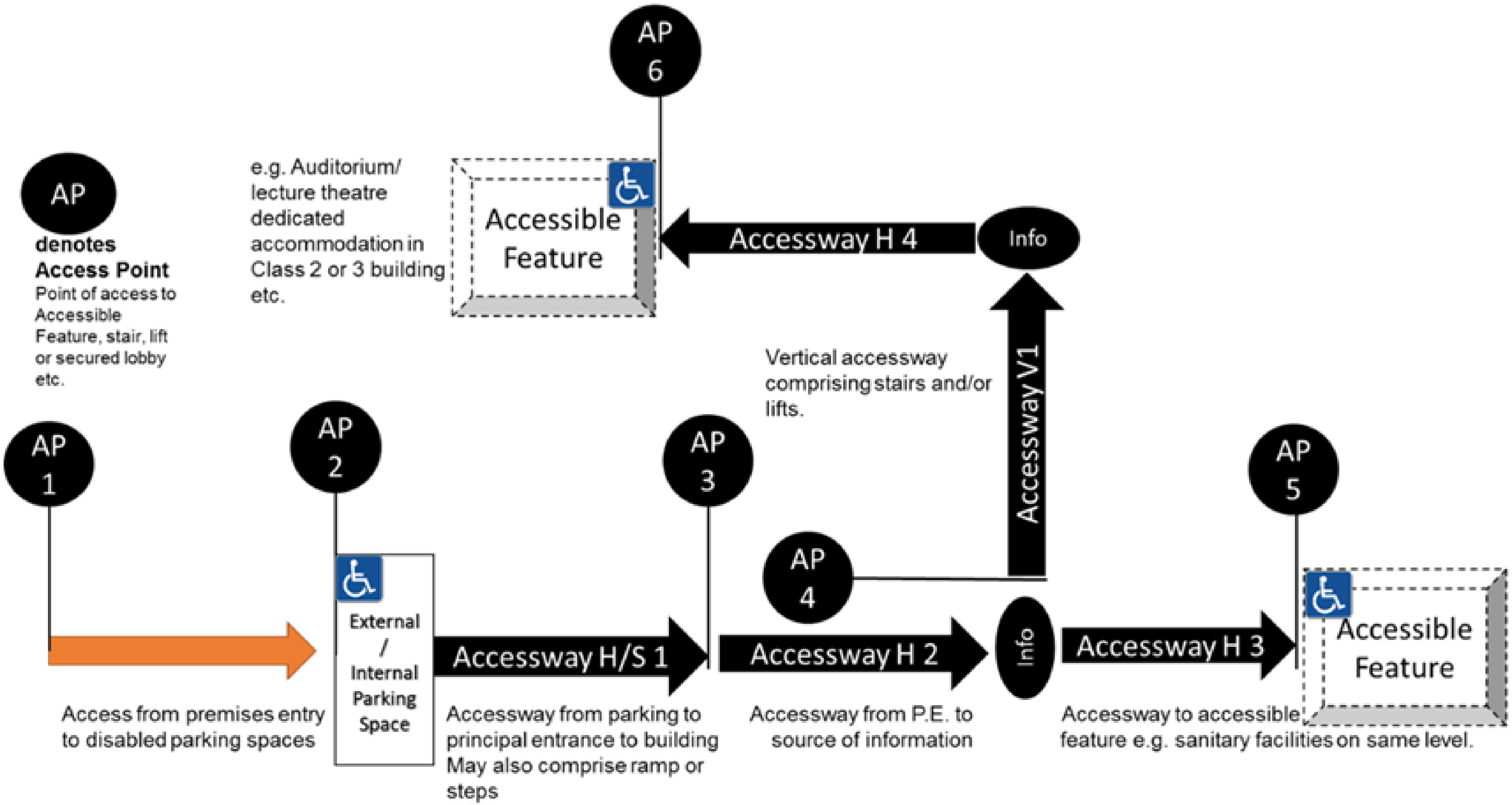
It is suggested that a representative occupant is developed for each of these groupings (also referred to as a persona). When determining the occupant profile, special attention needs to be paid to the impacts of ageing which typically increases the level of disability.

The final occupant profile may not include all the groupings mentioned above, depending on the classification and use of the building. The profile should be fully documented, and include occupant needs the building will accommodate to be addressed by the reference and proposed building models.

4.3.2 Method of assessing access

Figure 4.1 reflects diagrammatically a framework that may be used to assess the level of access in a building. The PBDB should use a similar framework to explain its access strategy.

Figure 4.1 Example accessway and accessible features model (access to and within a building)



For the purpose of the accessway and accessible features model of Figure 4.1:

- Accessible feature denotes a part of a building that is required to be accessible such as designated sanitary accommodation, accessible adult change facilities (AACF), auditoriums, conference rooms and meeting rooms.
- Accessway H/S1 denotes a horizontal accessway (usually external) between an external accessible car parking space or dedicated car park and the principal entrance. The “S” denotes a change in level in the accessway where the levels are interconnected via a ramp or stair.
- Accessway H denotes an internal horizontal accessway usually comprising a corridor, passage, or designated path through an open area marked in some manner e.g. via tactile ground surface indicators or shorelines (see AS 1428.1 – 2009.)
- Accessway V denotes a vertical accessway usually comprising accessible stairs, ramps and/or passenger lifts.
- Info denotes signs or notices providing information on accessible facilities.

4.3.3 Analysis methods

Table 4.1 outlines possible analysis methods for different activities that may form a part of the DV2 *Performance Solution*.

Table 4.1: Task types and basis of analysis for each element of accessibility framework

Task / Activity	Accessway: Flat Open Path	Accessway: Corridor	Accessway: Ramp	Accessway: Stair	Accessway: Lift	Access Point: Principal Entrance	Access Point: Enclosed Accessway	Access Point: Entry Accessible Feature	Accessible Feature: Disabled Parking Space	Accessible Feature: Conference Room / Auditorium	Accessible Feature: Sanitary Facility	Accommodation Suite / Accessible Feature: SOU	Accessible Feature: Other
Navigate	Y	Y	N	N	N	N	N	N	N	N	N	Y	Y
Identify and locate	N	N	N	N	Y	Y	N	N	Y	Y	Y	Y	Y
Safely traverse /climb	N	Y	Y	N	N	N	N	N	N	N	N	Y	Y
Manoeuvre	N	N	N	N	Y	N	N	Y	Y	N	N	Y	Y
Reach (including switches and controls)	N	N	N	N	Y	N	N	N	N	N	Y	Y	Y
Open/ Grasp	N	N	N	N	N	Y	Y	Y	N	N	Y	Y	N
Transfer	N	N	N	N	N	N	N	N	Y	N	Y	Y	Y
Seated	N	N	N	N	N	N	N	N	N	Y	N	N	Y
Participate	N	N	N	N	N	N	N	N	N	Y	N	N	Y

Other data sources may be used to inform the analysis, these include

- Ancillary Codes of Practice such as AS 1428.2 or ISO 21542-2011.
- Peer reviewed evidence based studies.
- Validated digital human models such as Sammie or Veritas.
- Laboratory measured data.

The methods of assessing an access solution must result in an output that is able to be measured by the measurable acceptance criteria.

4.3.4 Measurable acceptance criteria

The measurable acceptance criteria are the key metrics that are suitable to determine the performance of an access solution.

Example

The method of measurement can be via a dimensional check, for example, the width of a doorway permitting access by a wheelchair where the wheelchair footprint may be known with a representative persona user. A similar criterion may be used in determining the width of an accessway for passing.

The acceptance criteria should enable a proposed access model to be assessed against a reference access model on a pass/fail basis. Acceptance criteria need to be clearly documented in the PBDB and agreed by stakeholders in the form of a schedule. Measurable acceptance criteria may relate to:

- safe traversal of accessway and manoeuvring through doorways.
- navigation of accessways.
- identifying and locating accessible features, including signage and *exits*.
- reaching, opening and grasping of fixtures, doors, controls and switches.
- clearances and space for manoeuvring.
- visual contrast.

4.3.5 Equity and dignity

Occupant equity and dignity should be considered by the stakeholders in the development of the PBDB. Stakeholders may, for example, set up an Equity and Dignity Scoring Model. In this model it is the role of the stakeholders to define the scoring criteria for each access element. If used in a DV2 approach, the PBDB stakeholders would use the model to score the building features of the reference access solution and use this to assess whether the proposed access solution adequately addresses equity and dignity of occupants and document in the PBDR.

4.4 Comparing the reference and proposed access solutions

4.4.1 Occupant needs

Occupant needs must be considered in accordance with the occupant *characteristics* and profile determined during the creation of the PBDB. Needs relate to the ‘design interventions’ that are required to make the building more accessible and usable by occupants including those with a disability.

An occupant characterisation schedule may be developed to document the connection of the design responses to the measurable acceptance criteria nominated in the PBDB.

4.4.2 Reference access solution

A reference access solution within a reference building is required to be designed to determine the benchmark criteria that must be met by the proposed access solution. The reference building must be designed using the *DTS Provisions* that are relevant to the *Performance Requirements* the solution will address.

The accessible facilities required by the *DTS Provisions* must be included in the model for the reference building and access solution. These include, but are not necessarily limited to:

- Facilities to be accessed in accordance with D3.1, D3.2, D3.3 and D3.5

- Signage in accordance with D3.6
- Hearing augmentation in accordance with D3.7
- Tactile ground surface indicators in accordance with D3.8
- Wheelchair seating spaces in accordance with D3.9
- Special access to swimming pools in accordance with D3.10
- Marking of glazing on accessways in accordance with D3.11
- The standard, number and location of passenger lifts in accordance with E3.6
- Accessible sanitary facilities in accordance with Part F2.

Drawings reflecting these aspects of the access solution may be prepared to document the reference building and access solution.

4.4.3 Features required to be consistent between the proposed and reference access solutions

For the comparison between the access solutions to be meaningful, DV2(c), requires the reference building model and the proposed solution use consistent:

(a) modelling method and approach
(b) occupant population profile and *characteristics*
(c) building location and orientation
(d) locations of all entrances and *exits*
(e) locations of facilities important to the solution, including sanitary facilities, lifts, stairwells, etc.
(f) number and range of facilities.

4.4.4 Comparison of the proposed and reference access solutions using the measurable acceptance criteria

The performance of the reference building and proposed access solutions should be assessed using the same modelling method documented in the PBDR.

Performance of the reference buildings and proposed solution are assessed by comparing the measurable acceptance criteria defined in the PBDB. The level to which the reference access solution meets the measurable acceptance criteria is used as a baseline to which the performance of the proposed access solution is compared.

An Equity and Dignity Scoring Model may be applied as a means of determining the level of accessibility achieved by the reference and proposed access solutions.

5 DV3: Ramp gradient, crossfall, surface profile and slip resistance for ramps used by wheelchairs

5.1 Overview

DV3 provides designers with a pathway to demonstrate the compliance of ramps with *Performance Requirement* DP2. There are four specific requirements which must be checked for any ramp considered under this method, as well as a single overarching maximum gradient. Each ramp needs to be checked for these requirements individually in accordance with its own particular criteria.

A ramp must be designed to ensure that it can be used safely and equitably. This is determined through an assessment of its design against DV3 which assesses:

- The pushing force required during ascent and braking force during descent of a ramp must be appropriate for its users.
- The time taken for an ascent must be reasonable for the capabilities of its users.
- The crossfall, surface profile and slip resistance must be appropriate to the gradient of the ramp to ensure user safety.
- Finally, as an overarching limitation, the gradient must not be steeper than 1:8.

The physical parameters nominated in the NCC or this Handbook may be varied to better suit the particular building and *characteristics* of the building occupants at the discretion of the designer and the appropriate authority. Such an approach is consistent with that use of *Performance Solutions* under the NCC and it is suggested that variations be based on peer reviewed and evidence-based research and consider equity and dignity explicitly.

Alert

DV3 has been developed for the design of ramps to be used by wheelchair users and may be inappropriate for sensitive pedestrians.

5.2 DV3 Verification Method

DV3 Ramp gradient, crossfall, surface profile and slip resistance for ramps used by wheelchairs

(a) Compliance with *Performance Requirement* DP2, in regards to the gradient, crossfall, surface profile and slip resistance of a ramp for the use of wheelchairs, is verified when—

(i) the ramp has a gradient that is not steeper than 1:8; and

(ii) the pushing force required to accelerate a wheelchair and user during ascent is in accordance with **(a)**; and

(iii) the required braking force for a wheelchair and user during descent is in accordance with **(b)**; and

(iv) the projected ascent time is in accordance with **(c)**; and

(v) the ramp crossfall, surface profile and slip resistance is in accordance with **(d)**.

(b) The pushing force during ascent must be in accordance with the formula:

$$\boldsymbol{F_p > mg \sin \alpha + C_{\pi 1} N_1 + C_{\pi 2} N_2}$$

where—

F_p = the maximum pushing force during ascent, equal to 40 N for ramps required to be usable by the general public; and

m = the design mass of the wheelchair and wheelchair user, equal to 127 kg for ramps required to be usable by the general public; and

g = the gravitational constant, equal to 9.8 m/s^2; and

α = the angle of incline of the ramp; and

$C_{\pi 1}, C_{\pi 2}$ = the coefficient of rolling resistance between the wheelchair wheel and ramp surface, for the rear wheels and front wheels respectively; and

N_1, N_2 = the normal force between the wheelchair wheels and ramp surface, for the rear wheels and front wheels respectively.

(c) The braking force during descent must be less than 9 N when calculated in accordance with the formula:

$$F_b = mg \sin\alpha - C_{\pi 1}N_1 - C_{\pi 2}N_2$$

where—

F_b = the braking force during descent; and

m = the design mass of the wheelchair and wheelchair user, equal to 127 kg for ramps required to be usable by the general public; and

g = the gravitational constant, equal to 9.8 m/s^2; and

α = the angle of incline of the ramp; and

$C_{\pi 1}, C_{\pi 2}$ = the coefficient of rolling resistance between the wheelchair wheel and ramp surface, for the rear wheels and front wheels respectively; and

N_1, N_2 = the normal force between the wheelchair wheels and ramp surface, for the rear wheels and front wheels respectively.

(d) The time taken to ascend the ramp must be less than 17 s when calculated in accordance with the formula:

$$T = \frac{Lm}{t(F_p - mg \sin\alpha - C_{\pi 1}N_1 - C_{\pi 2}N_2)}$$

where—

T = the time taken to ascend the ramp in seconds; and

L = the length of ramp in meters; and

m = the design mass of the wheelchair and wheelchair user, equal to 127 kg for ramps required to be usable by the general public; and

t = the time taken for the wheelchair to achieve maximum velocity, equal to 0.8 s; and

F_p = the maximum pushing force during ascent, equal to 40 N for ramps required to be usable by the general public; and

g = the gravitational constant, equal to 9.8 m/s^2; and

α = the angle of incline of the ramp; and

$C_{\pi 1}, C_{\pi 2}$ = the coefficient of rolling resistance between the wheelchair wheel and ramp surface, for the rear wheels and front wheels respectively; and

N_1, N_2 = the normal force between the wheelchair wheels and ramp surface, for the rear wheels and front wheels respectively.

(e) The crossfall must be no steeper than, the surface profile must be no rougher than, and the slip resistance must be no less than, the values nominated in Table DV3 for the gradient of the ramp.

Table DV3: Ramp crossfall, surface profile and slip resistance

Gradient	Crossfall	Surface profile (mm)	Slip resistance
1:14	1:40	2	P4/R11
1:12	1:50	2	P5/R12
1:10	1:100	1	P5/R12
1:8	1:100	0.5	P5/R12

5.3 Input data for DV3

5.3.1 Wheelchair data

In order to accurately determine the forces acting upon the wheelchair, a wheelchair model is required. The A90 manual wheelchair referred to in AS 1428.1-2009 has all the necessary data for manoeuvring modelling and analysis but does not have the other details that would normally be available with wheelchair specifications from the various manufacturers or suppliers.

As there is no A90 power wheelchair (PWC) model, an equivalent model should be selected. If required, manual wheelchair (MWC) and PWC footprints can be made in accordance with B.6.2 of ISO21542-2011.

5.3.2 Occupant characteristics and inputs

The following inputs are applied in the equations of DV3:

- a maximum pushing force allowed during ascent, nominally 40 N for the general public
- a maximum braking force to bring the wheelchair to a complete stop during descent, nominally 9 N for the general public
- the maximum time to ascend a ramp, nominally 17 s
- the time taken to reach full velocity, nominally 0.8 s
- the mass of a manual wheelchair user and chair, nominally 127 kg
- the gravitational constant g is 9.8 m/sec.

The intent of DV3 is to allow designers to design ramps appropriately for their users. As such, the physical parameters may be varied in accordance with the *characteristics* of those users where validated. For example, an aged care facility might use particular wheelchairs with a different weight and/or distribution of force. Ramps used as part of a wheelchair sports facility could be designed to require a greater force for ascent, due to the greater strength of their persona.

Variations to the inputs for DV3 should be documented in a PBDB and agreed by the appropriate authority, as part of the *Performance Solution*. It is suggested that such variations be based upon peer reviewed and evidence-based research.

5.3.3 Pushing force during ascent

The maximum gradient for ascent is determined through the calculation of the required pushing force using the equation from DV3(a):

The force that the wheelchair user can apply to the wheelchair drive wheels needs to be sufficient to successfully traverse the ramp in question.

The inputs required for the equation are:

- α, the inclined gradient of the ramp in degrees for which the sine is calculated e.g. sin 7.13° = 0.125
- m is the mass of a manual wheelchair user and chair, nominally 127 kg

- $C_{\pi 1}$ and $C_{\pi 2}$ are the rolling resistances for rear and front wheels respectively
- N_1 and N_2 are the normal forces though the front and rear wheels, for an A90 wheelchair, forces should be distributed with 38.9% for N_1 (rear wheels) and 61.1% for N_2 (caster wheels)
- The gravitational constant g is 9.8 m/s^2

Example

The following example values of $C_{\pi 1}$ and $C_{\pi 2}$ are taken from Table 3 of Sauret et al (2012):

For a rear pneumatic wheel with a pressure of 448 kPa, diameter of 610 mm and track width of 35 mm, $C_{\pi 1}$ is:

Carpet low pile: 4.84 X 10^{-3}

Carpet with high pile: 6.07 X 10^{-3}

Hard and smooth: 1.28 X 10^{-3}

For a solid caster wheel with a diameter of 101 mm and track width of 35 mm, $C_{\pi 2}$ is:

Carpet low pile: 3.54 X 10^{-3}

Carpet with high pile: 4.5 X 10^{-3}

Hard and smooth: 0.36 X 10^{-3}

Solve the equation for F_p and ensure that it is not greater than the allowable pushing force (nominally 40 N). If the pushing force is exceeded then retry with a lesser gradient.

5.3.4 Braking force during descent

The required braking force during descent is determined through DV3(b).

The stability of the wheelchair and the user is paramount. The highest risk of destabilising is in descent. The braking system for the manual wheelchair requires the application of the braking force (F_b) via the hand. The limit for the proposed user is 9 N in accordance with the test set out in ISO 7176, however, as above this may be varied where validated by expected occupant *characteristics* and accepted by the relevant authority.

The inputs for the equation in DV2(b) are:

- α, the inclined gradient of the ramp in degrees for which the sine is calculated e.g. sin 7.13° = 0.125
- m is the mass of a manual wheelchair user and chair, nominally 127 kg
- $C_{\pi 1}$ and $C_{\pi 2}$ are the rolling resistances for rear and front wheels respectively
- N_1 and N_2 are the normal forces though the front and rear wheels, for an A90 wheelchair, forces should be distributed with 38.9% for N_1 (rear wheels) and 61.1% for N_2 (caster wheels)
- The gravitational constant g is 9.8 m/s^2.

Example

The following example values of $C_{\pi 1}$ and $C_{\pi 2}$ are taken from Table 3 of Sauret et al (2012):

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Carpet low pile: 4.84 X 10^{-3}

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For a solid caster wheel with a diameter of 101 mm and track width of 35 mm, $C_{\pi 2}$ is:

Carpet low pile: 3.54 X 10^{-3}

Carpet with high pile: 4.5 X 10^{-3}

Hard and smooth: 0.36 X 10^{-3}

Solve the equation for F_b and ensure that it is not greater than the allowable braking force (nominally 9 N). If the braking force is exceeded then retry with a lesser gradient.

5.3.5 Ascent time

The time taken to ascend a ramp is calculated through DV3(c).

DV3(c) is used to ensure that the time taken to traverse the sloping section of ramp appropriate to the gradient being tested does not exceed 17 s.

The inputs for Equation 3 are:

- α, the inclined gradient of the ramp in degrees for which the sine is calculated e.g. sin 7.13° = 0.125
- m is the mass of a manual wheelchair user and chair, nominally 127 kg
- $C_{\pi 1}$ and $C_{\pi 2}$ are the rolling resistances for rear and front wheels respectively
- N_1 and N_2 are the normal forces though the front and rear wheels, for an A90 wheelchair, forces are distributed with 38.9% for N_1 (rear wheels) and 61.1% for N_2 (caster wheels), although this may vary with the gradient of the ramp
- The gravitational constant g is 9.8 m/s^2
- L, the length of the ramp in metres. This should be the length between landings, as a landing allows a user to rest.
- The time taken for the wheelchair to reach top speed, t, nominally 0.8 s.
- The maximum pushing force during ascent, F_p.

Solve the equation for T and ensure that it is not greater than the minimum ascent time (nominally 17 s). If the nominal ascent time is exceeded then retry with a lesser gradient and length. The resultant velocity should also be checked.

5.3.6 Crossfall, surface profile and slip resistance

In addition to the computed requirements, Table DV3 within DV3(e) sets out particular requirements for:

- **Crossfall** – as crossfall increases so do the force demands upon each wheel in order to keep the manual wheelchair heading in a uniform direction. The F_p

calculation assumes the application of an even pushing force being exerted on each rear wheel.

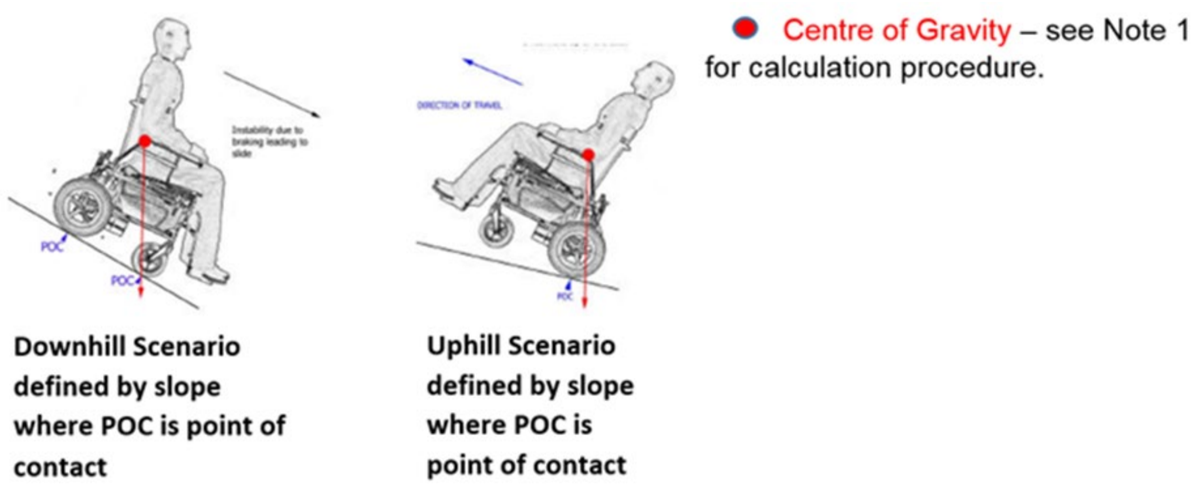
- **Surface profile** – to minimise resonance, especially for powered wheelchair users.
- **Slip resistance** – because a powered wheelchair can stall and start to slide on hard and very smooth surfaces if they have a low slip resistance classification (for example, P3 or less). It is for this reason that ramps with gradients steeper than 1:14 are required to have a P5 slip resistance rating.

The surface profile is specified for each specific gradient and therefore needs an appropriate test or measurement method for onsite checking.

5.3.7 Tipping check for PWCs

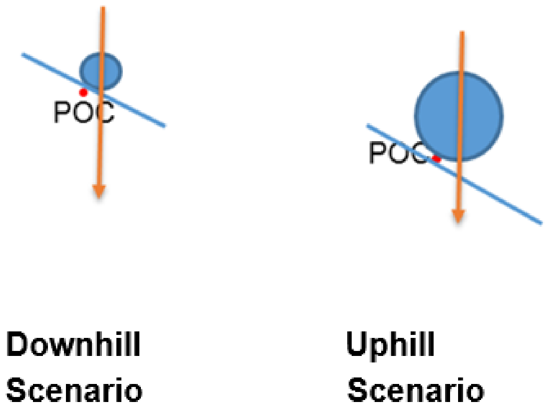
It is suggested that a graphical stability check be carried using a PWC model an example of which is below in Figure 5.1.

Figure 5.1: Graphical checking of stability for PWC appropriate to gradient being assessed



Note 1: Using the PWC model, draw in the vertical component of the force representing the distribution of the mass of the PWC and the user as shown in Figure 5.1.

Figure 5.2: Enlarged downhill and uphill scenarios



If the centre of gravity is outside of the point of contact (POC), as shown in Figure 5.1 and Figure 5.2, the wheelchair is at risk of tipping and therefore the ramp is not suitable.

6 Reporting – PBDR

A final report should clearly demonstrate that compliance with the relevant NCC *Performance Requirements*, as agreed in the performance-based design brief, has been achieved. The content of a typical final report might include:

- An overview of the PBDB, including:
    - Scope of the project
    - Relevant stakeholders
    - Applicable NCC *Performance Requirements*
    - Applicable NCC *DTS Provisions* relating to the identified *Performance Requirements*
    - Approaches and methods of analysis
    - Any assumptions that were made
    - Acceptance criteria and safety factors agreed to by stakeholders.
- Overview and outline of the analysis, modelling and/or testing carried out:
    - Method of analysis used
    - Calculations and outcomes
    - The sensitivities, redundancies and uncertainty studies carried out
    - Variations to the required inputs and validation
    - The results obtained and relevance to the PBDB.
- Evaluation of results including:
    - Comparison of results with acceptance criteria
    - Any further sensitivity studies undertaken
    - Any peer review or expert judgement applied and its justification.
- Conclusion:
    - Specifications of the final design that are deemed to be acceptable
    - The NCC *Performance Requirements* that were met
    - All limitations to the design and any conditions of use.

APPENDICES

Appendix A Compliance with the NCC

A.1 Responsibilities for regulation of building and plumbing in Australia

Under the Australian Constitution, State and Territory governments are responsible for regulation of building, plumbing and development / planning in their respective State or Territory.

The NCC is an initiative of the Council of Australian Governments and is produced and maintained by the ABCB on behalf of the Australian Government and each State and Territory government. The NCC provides a uniform set of technical provisions for the design and construction of buildings and other structures, and plumbing and drainage systems throughout Australia. It allows for variations in climate and geological or geographic conditions.

The NCC is given legal effect by building and plumbing regulatory legislation in each State and Territory. This legislation consists of an Act of Parliament and subordinate legislation (e.g. Building Regulations) which empowers the regulation of certain aspects of buildings and structures, and contains the administrative provisions necessary to give effect to the legislation.

Each State's and Territory's legislation adopts the NCC subject to the variation or deletion of some of its provisions, or the addition of extra provisions. These variations, deletions and additions are generally signposted within the relevant section of the NCC, and located within appendices to the NCC. Notwithstanding this, any provision of the NCC may be overridden by, or subject to, State or Territory legislation. The NCC must therefore be read in conjunction with that legislation.

A.2 Demonstrating compliance with the NCC

Compliance with the NCC is achieved by complying with the Governing Requirements of the NCC and relevant *Performance Requirements*.

The Governing Requirements are a set of governing rules outlining how the NCC must be used and the process that must be followed.

The *Performance Requirements* prescribe the minimum necessary requirements for buildings, building elements, and plumbing and drainage systems. They must be met to demonstrate compliance with the NCC.

Three options are available to demonstrate compliance with the *Performance Requirements*:

- a *Performance Solution*,
- a *Deemed-to-Satisfy Solution*, or
- a combination of a *Performance Solution* and a *Deemed-to-Satisfy Solution*.

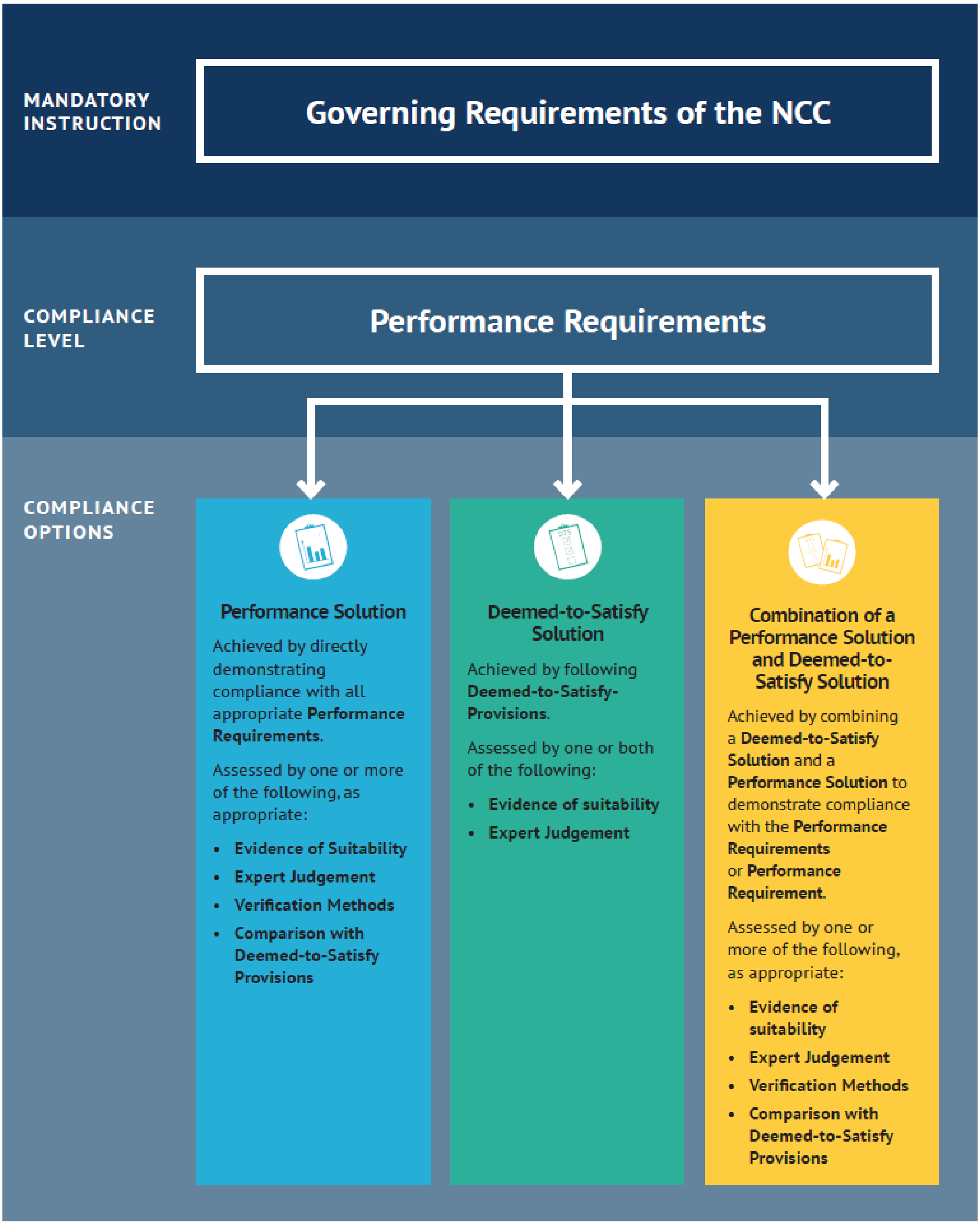
All compliance options must be assessed using one or a combination of the following Assessment Methods, as appropriate:

- Evidence of Suitability
- Expert Judgement
- *Verification Methods*
- Comparison with DTS Provisions.

A figure showing hierarchy of the NCC and its compliance options is provided in Figure A.1. It should be read in conjunction with the NCC.

To access the NCC or for further general information regarding demonstrating compliance with the NCC visit the ABCB website (abcb.gov.au).

Figure A.1 Demonstrating compliance with the NCC



Appendix B Acronyms

The following table, Table B.1 contains acronyms used in this document.

Table B.1 Acronyms

Acronym	Meaning
ABCB	Australian Building Codes Board
ABS	Australian Bureau of Statistics
AP	Access Point
AS	Australian Standard
BCA	Building Code of Australia
DDA	Disability Discrimination Act
DTS	Deemed-to-Satisfy
IGA	Inter-government agreement
ISO	International Standardization Organisation
NCC	National Construction Code
MWC	Manual Wheelchair
PBDB	Performance-Based Design Brief
PBDR	Performance-Based Design Report
POC	Point Of Contact
PWC	Power Wheelchair
WHS	Workplace Health & Safety

Appendix C Acts, Regulations and design responsibilities

C.1 Disability Discrimination Act – Disability (Access to Premise – Buildings) 2010

For disability related issues, the NCC isn't the only piece of legislation which is required to be complied with for building.

The Australian Government's Disability Discrimination Act 1992 (DDA) has been in effect since March 1993. The DDA prohibits discrimination against people with disability or their associates in a range of areas including transport, education, employment, accommodation and premises used by the public.

The DDA is complaints-based (as opposed to compliance-based) legislation. It does not include legislative or regulatory guidance as to the specific steps that must be taken to ensure compliance with the general duties in relation to access to premises.

Concern with the lack of certainty regarding practical compliance obligations under the DDA led to amendments to Section 31 of the DDA, which came into effect in April 2000, to allow the Australian Government's Attorney-General to formulate Disability Standards in relation to access to premises. Contravention of any Disability Standards formulated under the DDA is unlawful under Section 32 of the DDA. Section 34 of the DDA effectively provides that compliance with a relevant Disability Standard is sufficient to satisfy the DDA duty not to discriminate in relation to the subject area covered by the Standards.

The need to review the BCA access provisions as part of the development of Disability Standards in relation to access to premises stemmed from:

- recognition that the technical requirements of the BCA at that time were not considered to meet the intent and objectives of the DDA; and
- the potential for inconsistencies between two legislative requirements in relation to access for people with disability to buildings, being the DDA and, through State and Territory building law, the BCA.

The ABCB was requested by the Australian Government to develop proposals for a revised BCA, to enable it to form part of draft Premises Standards. Once the Premises Standards had been formulated, the BCA would be amended so that the technical details of each document mirror each other. Therefore, compliance with State and Territory building law and the access provisions of the BCA would mean compliance with the Premises Standards and hence the DDA.

The Premises Standard provide clarity in developing building solutions which are equitable and dignified (two of the key aims of the DDA) for all occupants. The Premises Standard in replicating the BCA is also performance-based. The Standards state that:

- they are not intended to limit the way in which a relevant building may otherwise satisfy the applicable *Performance Requirements*; and
- a relevant building is taken to comply with the Access Code if the building provides a level of access that is not less than the level that the building would have provided if it had complied with the provisions.

Designers and practitioners should seek expert advice for project specific information on, particularly when undertaking *Performance Solutions* which relate to the disability access provisions.

C.2 Other Applicable Acts, Regulations and design responsibilities

There is other legislation (both Commonwealth, and State and Territory) which may impact on building approval and design.

For instance, the NCC does not regulate matters such as the roles and responsibilities of building and plumbing practitioners. These fall under the jurisdiction of the States and Territories.

State and Territory building and plumbing legislation is not nationally consistent in relation to these matters with significant variations with respect to:

- registration of practitioners

- mandatory requirements for inspections during construction.

The design and approval of building and plumbing and drainage solutions will need to consider these variations.

In addition to the relevant legislation, Workplace Health and Safety (WHS) legislation is also applicable which requires safe design principles to be applied.

A Code of Practice on the safe design of structures has been published by Safe Work Australia (2012) which provides guidance to persons conducting a business or undertaking work in regard to structures that will be used, or could reasonably be expected to be used, as a workplace. It is prudent to apply these requirements generally to most building classes since they represent a workplace for people undertaking building work, maintenance, inspections at various times during the building life.

The Code of Practice defines safe design as:

> “the integration of control measures early in the design process to eliminate or, if this is not reasonably practicable, minimise risks to health and safety throughout the life of the structure being designed”.

It indicates that safe design begins at the start of the design process when making decisions about:

- the design and its intended purpose
- materials to be used
- possible methods of construction, maintenance, operation, demolition or dismantling and disposal
- what legislation, codes of practice and standards need to be considered and complied with.

The Code of Practice also provides clear guidance on who has health and safety duties in relation to the design of structures and lists the following practitioners:

- architects, building designers, engineers, building surveyors / certifiers, interior designers, landscape architects, town planners and all other design practitioners contributing to, or having overall responsibility for, any part of the design

- building service designers, engineering firms or others designing services that are part of the structure such as ventilation, electrical systems and permanent fire extinguisher installations
- contractors carrying out design work as part of their contribution to a project (for example, an engineering contractor providing design, procurement and construction management services)
- temporary works engineers, including those designing formwork, falsework, scaffolding and sheet piling
- persons who specify how structural alteration, demolition or dismantling work is to be carried out.

In addition, WHS legislation places the primary responsibility for safety during the construction phase on the builder.

From the above it is clear that the design team in conjunction with owners / operators and the builder have a responsibility to document designs, specify and implement procedures that will minimise risks to health and safety throughout the life of the structure being designed.

A key element of safe design is consultation to identify risks, develop practical mitigation measures and to assign responsibilities to individuals / organisations for ensuring the mitigation measures are satisfactorily implemented.

This approach should be undertaken whichever NCC compliance pathway is adopted.

Some matters specific to health and safety are summarised below, but this list is not comprehensive.

- The NCC and associated referenced documents represent nationally recognised minimum standards for health and safety for new building works.
- The NCC's treatment of safety precautions during construction is very limited. Additional precautions are required to address WHS requirements during construction.
- Detailed design of features to optimise reliability and facilitate safe installation, maintenance and inspection where practicable.
- Document procedures and allocate responsibilities for determining evidence of suitability for all health and safety measures.

- Document procedures and allocate responsibilities for the verification and commissioning of all health and safety measures.
- Provide details of health and safety measures within the building, evidence of suitability, commissioning results and requirements for maintenance and inspection to the owner as part of the building manual. (Note: Some State and Territory legislation contains minimum requirements for inspection of fire safety measures)
- The building manual should also provide information on how to avoid compromising fire safety through the life of a building (e.g. preventing disconnection of smoke detectors or damage to fire resistant construction).

Some health and safety measures will be impacted by other legislation that may be synergistic with the NCC requirements or potentially in conflict particularly in relation to natural hazards include:

- planning / development
- conservation
- state emergency risk management policies.

Appendix D Resources

D.1 Manual wheelchair use and selection

Canale I, Felici F, Marchetti M, and Ricci B, (1991), Ramp length/grade prescriptions for wheelchair dependent individuals, Spinal Cord, Vol. 29, pp. 479-485.

Cappozzo A, Felici F, Figura F, Marchetti M & Ricci B (1991). Prediction of Ramp Traversability for Wheelchair Dependent Individuals. Paraplegia, 29, 470-478.

DiGiovine MM, Cooper RA, Boninger ML, Lawrence BM, VanSickle DP and Rentschler AJ, (2000) User Assessment of Manual Wheelchair Ride Comfort and Ergonomics, Arch Phys Med Rehabil Vol. 81, pp. 490-494.

Hollingsworth, L. (2010). Understanding and Modelling Manual Wheelchair Propulsion and Strength Characteristics in People with C5-C7 Tetraplegia. (PhD Thesis), University of Canterbury, Canterbury, New Zealand.

Holloway C and Tyler N, (2013), A micro-level approach to measuring the accessibility of footways for wheelchair users using the capability model, Transportation Planning and Technology, Vol. 36, No. 7, pp. 636-649.

Karmarkar AM, Dicianno BE, Cooper R, Collins DM, Matthews JT, Koontz A, Teodorski EF, and Cooper RA, (2011) Demographic Profile of Older Adults Using Wheeled Mobility Devices, J of Aging Research, Article ID560358.

Kim CS, Lee D, Kwo, S, & Chung, MK (2014). Effects of ramp slope, ramp height and users' pushing force on performance, muscular activity and subjective ratings during wheelchair driving on a ramp. International Journal of Industrial Ergonomics, 44, 636-646.

May L, Butt C, Minor L, Kolbinson K & Tulloch K. (2003). Measurement Reliability of Functional Tasks for Persons Who Self-Propel a Manual Wheelchair. Archives of Physical Medicine and Rehabilitation, 84, 578-583.

Medola FO, Elui VMC, Santana C d-S and Fortulan CA (2014) Aspects of Manual Wheelchair Configuration Affecting Mobility: A Review, J. Phys. Ther. Sc., Vol. 26 pp. 313-318.

Paquet V, and Feathers D, (2004), An anthropometric study of manual and powered wheelchair users, Industrial Ergonomics, Vol. 33, pp 191-204.

Rankin JW, Kwarciak AM, Richter WM, and Neptune RR, (2012) The Influence of Wheelchair Propulsion Technique on Upper Extremity Muscle Demand: A Simulation Study, J. Clin. Biomech. (Bristol, Avon), Vol. 27, No. 9, pp. 879-886.

Sabick M, Kotajarvi B, & An K (2004). A New Method to Quantify Demand on the Upper Extremity During Wheelchair Propulsion. Archives of Physical Medicine and Rehabilitation, 85, 1151-1159.

Samuelsson K, Tropp H, & Gerdle B (2004). Shoulder pain and its consequences in paraplegic spinal cord-injured, wheelchair users. Spinal Cord, 42, 41-46.

Stefanov D, Avtanski A, Shapcott N, Dryer P, Fielden S, Heelis M, Moody L (2014, June 11-12). A novel system for wheelchair stability assessment design and initial results. Paper presented at the 2014 IEEE International Symposium on Medical Measurements and Applications (MeMeA).

Steinfeld E, Paquet V, D'Souza C, Joseph C, and Maisel J, (2010) Anthropometry of Wheeled Mobility Project, US Access Board, University at Buffalo, The State University of New York.

Vignier N, Ravaud J-F, Winance M, Lepoutre F-X, and Ville I, (2008) Demographics of wheelchair users in France: Results of national community-based handicaps-incapacities-dependence surveys, J Rehabil Med Vol. 40 pp. 231-239.

Yao F, (2007) Measurement and Modeling of Wheelchair Propulsion ability for people with Spinal Cord Injury, Master of Mechanical Engineering Thesis, U of Canterbury.

D.2 DV3 and manoeuvring analysis

Ackermann, M., Leonardi, F., Costa, H., & Fleury, A. (2014). Modeling and Optimal Control Formulation for Manual Wheelchair Locomotion: the Influence of Mass and Slope on Performance. Paper presented at the 2014 5th IEEE RAS & EMBS International Conference on Biomedical Robotics and Biomechatronics (BioRob), Sao Paolo, Brazil.

Bascou, J., Sauret, C., Pillet, H., Vaslin, P., Thoreux, P., & Lavaste, F. (2012). A Method for the Field Assessment of Rolling Resistance Properties of Manual Wheelchairs. Computer Methods in Biomechanics and Biomedical Engineering, 16(4), 381-391.

Chen, M.J., Fan, X., and Moe, S.T., (2002) Criterion-related validity of the Borg ratings of perceived exertion scale in healthy individuals: a meta-analysis. Journal of Sports Sciences, 20(11), 873-899, DOI: 10.1080/026404102320761787.

Chesney, D., & Axelson, P. (1996). Preliminary Test Method for the Determination of Surface Firmness. IEEE Transactions on Rehabilitation Engineering, 4(3), 182-187.

Choi, Y., Lee, H., Myoung, H., & Kwon, O. (2015). Effects of ramp slope on physiological characteristic and performance time of healthy adults propelling and pushing wheelchairs. Journal of Physical Therapy Science, 27, 3.

Corfman, T., Cooper, R., Fitzgerald, S., & Cooper, R. (2003). Tips and Falls During Electric-Powered Wheelchair Driving: Effects of Seatbelt Use, Leg rests and Driving Speed. Archives of Physical Medicine and Rehabilitation, 84, 1797-1802.

Das, B., and Forde, M., (1999), Isometric Push-up and Pull-down Strengths of Paraplegics in the Workspace: 1. Strength Measurement Profiles Journal of Occupational Rehabilitation, 9(4), 277-289, doi:10.1023/A:1021383702684.

Gavin-Dreschnack, D., Nelson, A., Fitzgerald, S., Harrow, J., Sanchez-Anguiano, A., Ahmed, S., & Powell-Cope, G. (2005). Wheelchair-related Falls: Current Evidence and Directions for Improved Quality Care. Journal of Nursing Care Quality, 20(2), 119-127.

Hollingsworth, L. (2010). Understanding and Modelling Manual Wheelchair Propulsion and Strength Characteristics in People with C5-C7 Tetraplegia. (PhD Thesis), University of Canterbury, Canterbury, New Zealand.

Hurd, W., Morrow, M., Kaufman, K., & An, K.-N. (2009). Wheelchair propulsion demands during outdoor community ambulation. Electromyography and Kinesology, 19, 942-947.

Kauzlarich, J., & Thacker, J. (1985). Wheelchair tire rolling resistance and fatigue. Archives of Physical Medicine and Rehabilitation, 22, 25-41.

Koontz, A., Cooper, R., Boninger, M., Yang, Y., Impink, B., & vander Woude, L. (2005). A kinetic analysis of manual wheelchair propulsion during start-up on select indoor and outdoor surfaces. Journal of Rehabilitation Research and Development, 42(4), 447-458.

Kotajarvi, B., Subick, M., An, K., Zhao, KD, Kaufman, K., & Basford, J. (2004). The effect of seat position on wheelchair propulsion biomechanics. Journal of Rehabilitation Research and Development, 41(3B), 403-414.

Kulig, K., Newsam, C., Mulroy, S., Rao, S., Gromley, J., Bontrager, E., & Perry, J. (2001). The effect of level of spinal cord injury on shoulder joint kinetics during manual wheelchair propulsion. Clinical Biomechanics, 16, 744-751.

Lin, C.-J., Lim, P.-C., Guo, L.-Y., & Su, F.-C. (2011). Prediction of applied forces in handrim wheelchair propulsion. Journal of Biomechanics, 44, 455-460.

Minns, J., & Tracey, S. (2011). Wheelchair pushing forces over a vinyl and a new shock absorbing flooring. British Journal of Occupational Therapy, 74(1), 41-43.

Mortensen, W., Miller, W., Boily, J., Steele, B., Crawford, E., & Desharnais, G. (2005). Perceptions of Power Mobility Use and safety within Residential Facilities. Canadian Journal of Occupational Therapy, 72(3), 142-152.

Mulroy, S., Farrokhi, S., Newsam, C., & Perry, J. (2004). Effect of Spinal Cord Injury Level on the Activity of Shoulder Muscles During Wheelchair Propulsion; An

Electromyographic Study. Archives of Physical Medicine and Rehabilitation, 85, 925-934.

Otami, R., Moussaoui, A., & Priski, A. (2009). A new approach to indoor accessibility. International Journal of Smart Home, 3(4), 1-14.

Pan, X., Han, C., & Law, K. (2010). Using Motion-Planning to Determine the Existence of an Accessible Route in a CAD Environment. Assistive Technology, 22(1), 32-45. doi:10.1080/10400430903520249

Qi, L., Ferguson-Pel, M., Salimi, Z., Haennel, R., & Ramadi, A. (2015). Wheelchair users' perceived exertion during typical mobility activities. Spinal Cord, 53, 687–691.

Sauret, C., Bascou, J., Remy, N., Pillet, H., Vaslin, P., & Lavaste, F. (2012). Assessment of field rolling resistance of manual wheelchairs. Journal of Rehabilitation Research and Development, 49(1), 63-74.

Steinfeld, E., Maisel, J., Feathers, D., & D'Souza, C. (2010). Anthropometry and Standards for Wheeled Mobility: An International Comparison. Assistive technology: the official journal of RESNA, March. doi:10.1080/10400430903520280

Tolerico, M., Ding, D., Cooper, R., Spaeth, D., Fitzgerald, S., Cooper, R., . . . Bodinger, M. (2007). Assessing mobility characteristics and activity levels of manual wheelchair users. Journal of Rehabilitation Research and Development, 44(4), 561-572.

Tomlinson, D.J., Erskine, R.M., Morse, C.I., Winwood, K., and Onambele-Pearson, G., (2016) The impact of obesity on skeletal muscle strength and structure through adolescence to old age. Biogerontology. 17, 467-483.

Vander Wiel, J., Harris, B., Jackson, C., & Reese, N. (2016, July 10-14). Exploring the Relationship of Rolling Resistance and Misalignment Angle in Wheelchair Rear Wheels. Paper presented at the RESNA/NCART Conference 2016, Arlington, USA.

Vanderthommen, M., Francaux, M., Colinet, C., Lehance, C., Lhermerout, C., Crielaard, J., & Theisen, D. (2002). A multistage field test of wheelchair users for evaluation of fitness and prediction of peak oxygen consumption. Journal of Rehabilitation Research and Development, 39(6), 685-692.

Vredenburgh, A. G., Hedge, A., Zackowitz, I. B., & Welner, J. M. (2009). Evaluation of Wheelchair Users' Perceived Sidewalk and Ramp Slope: Effort and Accessibility. Journal of Architectural and Planning Research, 26(2), 145-158.

Xiang, H., Chany, A., & Smith, G. (2006). Wheelchair related injuries treated in US emergency departments. Injury Prevention, 12, 8-11. doi:10.1136/ip.2005.010033

Zamuner, A.R., Moreno, M.A., Camargo, T.M., Graetz, J.P., Rebelo A.C.S., Tamburus, N.Y., and DaSilva, E., (2011) Assessment of subjective perceived exertion at the anaerobic threshold with the Borg CR-10 scale. Journal of Sports Science and Medicine, 10, 130-136.

D.3 Tactical ground surface indicators and luminance contrast

D.3.1 Safety

Bowman R, (2010) Slip Resistance Testing – Zones of Uncertainty, Qualicer’10, Castellon, Spain.

Brown SJ, Handsaker JC, Bowling FL, Boulton AJM, and Reeves ND (2015) Diabetic Peripheral Neuropathy Compromises Balance During Daily Activities, Diabetes Care, Vol. 38, pp. 1116-1122, DOI:10.2337/dc14-1982.

Brown SJ, Handsaker JC, Maganaris CN, Bowling FL, Boulton AJM, and Reeves ND (2016) Altered joint moment strategy during stair walking in diabetes patients with and without peripheral neuropathy, Gait and Posture, Vol.46, pp. 188-193.

Harley, C., Wilkie, R.M. and Wann, J.P. (2009) Stepping over obstacles: Attention demands and aging. Gait & Posture, Vol. 29 No.3, pp. 428-432.

Loo-Morrey M and Jeffries S (2006) Trip Feasibility Study, Report No. HSL/2006/77.

Ormerod M, Newton R, MacLennan HA, Faruk M, Thies SB, Kenney L, Howard D and Nester C, (2014) Older people's experience of using tactile paving , Municipal Engineer, http://dx.doi.org/10.1680/muen.14.00016 .

Pedestrian Projects (2014) Testing Different Materials for Tactile Walking Surface Indicators, Pilot Project Evaluation Report, City of Toronto.

Siu K-C, Lugade V, Chou L-S, Van Donkelaar P, and Woollacott MH, (2008) Dual-task interference during obstacle clearance in healthy and balance-impaired older adults, Aging Clin Exp, Vol. 20, No.4, pp. 349-354.

D.3.2 Validity of contrast

Dain S, (2018) Issues in specifying contrast in building elements for people with a visual disability, Article for Review, Submitted to Ergonomics in Design, Refer to Emeritus Professor Stephen Dain in Vision Science at the University of New South Wales, Sydney.

Lukman A, Bridge C and Barlow G (2017) How to define suitable colours for the homes of people with ageing eyes or vision impairment, HMInfo Industry Fact Sheet, ISBN: 978-0-7334-3712-0 Industry Factsheet Series ISBN: 978-0-7334-3466-5, visit www.homemods.info

Lukman A, Dain S, Bridge C and Boom M Y (2014) Developing perception-based criteria of inclusive (architectural) design, Assistive Technology Research Series, Vol. 35, pp. 109-118.

D.3.3 Illumination

ANSI/IES RP-28-16, Lighting and the Visual Environment for Seniors and the Low Vision Population, 2016.

Hegde, A. L. (2017) Environmental lighting in nursing homes: A comparison of agency standards that regulate nursing homes with industry ANSI/IES RP-28 Lighting Standards. The International Journal of Design in Society, 12(1), 1-16.

Huszarik N, Hodgson P and Watson L, (2018) Lighting in around the home: A guide to better lighting for people with sight loss, Thomas Pocklington Trust,

Jeon G-Y, and Hong W-H, (2009) An experimental study on how phosphorescent guidance equipment influences evacuation in impaired visibility, Journal of Loss Prevention in the Process Industries, Vol. 22, pp. 934-942.

National Institute of Building Sciences, (2013) Design Guidelines for the Visual Environment, Low Vision Design Program.

Ousley C, McGuinn G, Scilley K and Kallies K, (2006) Development of a Questionnaire to Assess Vision Problems under Low Luminance in Age-Related Maculopathy, Investigative Ophthalmology & Visual Science, Vol. 47, No. 2, pp. 528-535.

Pitch M, and Bridge C, (2015) Summarised in IDeA, where the Research Question was; “This research investigates the range of illumination values needed for safe mobility of a visually impaired person in residential hallways/ corridors/ accessways and the relevant effectiveness of task vs. ambient lighting”, Center for Inclusive Design and Environmental Access, State Uni. of NY, Buffalo.

Schambureck, E M, & Parkinson, S F (2018) Design for Sight: A Typology System for Low-Vision Design Factors. Journal of Interior Design, 43(2), 33-54.

Wright DB (2012) Low location lighting and the IMO requirements, Trans ImarE, Vol. 108, Part 1, pp. 37-46, retrieved from http://ekosasmito.blog.undip.ac.id/files/2012/10/Low-location-lighting-and.pdf

D.4 Health

Butler, M. (2017). The effect of light on the health of older adults with low vision: A narrative review. Contemporary Research Topics, 45.

Owsley, C. (2016). Vision and aging. Annual review of vision science, 2, 255–71

van Bommel, W. (2005). Visual, biological and emotional aspects of lighting: Recent new findings and their meaning for lighting practice. Leukos, 2(1), 7-11.

D.5 Mobility

Brunnström, G., Sörensen, S., Alsterstad, K., & Sjöstrand, J. (2004). Quality of light and quality of life–the effect of lighting adaptation among people with low vision. Ophthalmic and Physiological Optics, 24(4), 274-280.

Chou, C., & Chen, L. C. (2013). Effects on different age levels of distinct lighting environment design. Journal of Industrial and Production Engineering, 30(8), 488-494.

Cornelissen, F. W., Bootsma, A., & Kooijman, A. C. (1995). Object perception by visually impaired people at different light levels. Vision research, 35(1), 161-168.

Evans, B. J. W., Sawyerr, H., Jessa, Z., Brodrick, S., & Slater, A. I. (2010). A pilot study of lighting and low vision in older people. Lighting Research & Technology, 42(1), 103-119.

Figueiro, M. G., Gras, L. Z., Rea, M. S., Plitnick, B., & Rea, M. S. (2012). Lighting for improving balance in older adults with and without risk for falls. Age and ageing, 41(3), 392.

Haymes, S., Guest, D., Heyes, A., & Johnston, A. (1994). Comparison of functional mobility performance with clinical vision measures in simulated retinitis pigmentosa. Optometry and vision science: official publication of the American Academy of Optometry, 71(7), 442-453.

Lovie-Kitchin, J., Woods, R., & Black, A. L. E. X. (1996). Effect of illuminance on the mobility performance of adults with retinitis pigmentosa. Optom Vis Sci, 73, 203.

Mital, A., Ayer, L., & Gorman, J. (1991). A lighting evaluation of a facility for the elderly. Journal of human ergology, 20(2), 171-180.

Popescu, M. L., Boisjoly, H., Schmaltz, H., Kergoat, M. J., Rousseau, J., Moghadaszadeh, S., Djafari, F. & Freeman, E. E. (2011). Age-related eye disease and mobility limitations in older adults. Investigative ophthalmology & visual science, 52(10), 7168-7174.

Sinoo, M. M., van Hoof, J., & Kort, H. S. (2011). Light conditions for older adults in the nursing home: Assessment of environmental illuminances and colour temperature. Building and Environment, 46(10), 1917-1927.

Turano, K. A., Broman, A. T., Bandeen-Roche, K. A. R. E. N., Munoz, B., Rubin, G. S., West, S. K., & SEE Project Team. (2004). Association of visual field loss and mobility performance in older adults: Salisbury Eye Evaluation Study. Optometry and vision science, 81(5), 298-307.

D.6 Wayfinding

Cook, G. K., Wfiot, M. S., Webber, G. M. B., & Bright, K. T. (1999). Emergency lighting and wayfinding provision systems for visually impaired people: Phase II of a study. International Journal of Lighting Research and Technology, 31(2), 43-48.

Wrigbt, M. S., Cook, G. K., & Webber, G. M. B. (1999). Emergency lighting and wayfinding provision systems for visually impaired people: Phase of a study. International Journal of Lighting Research and Technology, 31(2), 35-42.

D.7 Colour temperature

Figueiro, M. G., Bierman, A., Plitnick, B., & Rea, M. S. (2009). Preliminary evidence that both blue and red light can induce alertness at night. BMC neuroscience, 10(1), 105.

Figueiro, M. G., Hunter, C. M., Higgins, P. A., Hornick, T. R., Jones, G. E., Plitnick, B., Brons, J. & Rea, M. S. (2015). Tailored lighting intervention for persons with dementia and caregivers living at home. Sleep health, 1(4), 322-330.

O'Connor, D. A., & Davis, R. G. (2005). Lighting for the elderly: The effects of light source spectrum and illuminance on color discrimination and preference. Leukos, 2(2), 123-132.

D.8 Stairs

Alderson, A. (2010). Stairs, ramps and escalators: Inclusive design guidance. London, UK: Centre for Accessible Environments, RIBA Publishing.

Bakken, G. M., Cohen, H. H., Abele, J. R., Hyde, A. S., & LaRue, C. A. (2006). Chapter 19: Stairways and handrails Slips, trips, missteps and their consequences (2 ed.). Tucson, AZ: Lawyers and Judges Publishing Company.

Bergland, A., Sylliaas, H., Jarnio, G. B., & Wyller, T. B. (2008). Health, balance, and walking as correlates of climbing steps. Journal of Aging and Physical Activity, 16(1), 42-52. doi:10.1123/japa.16.1.42

Bosse, I., Oberländer K.D, Savelberg, H. H., Meijer, K., Brüggemann, G. P., & Karamanidis, K. (2012). Dynamic stability control in younger and older adults during stair descent. Human Movement Science, 31(6), 1560-1570. doi:10.1016/j.humov.2012.05.003

British Standards Institution (BSI). (2010). BS 5395-1:2010 Stairs, Part 1: Code of practice for the design of stairs with straight flights and winders London, UK: BSI.

Buckley, J. G., Heasley, K., Twigg, P., & Elliott, D. B. (2005). The effects of blurred vision on the mechanics of landing during stepping down by the elderly. Gait and Posture, Vol. 21, 65-71. doi:10.1016/j.gaitpost.2003.12.001

Canada Housing and Mortgage Corporation (CMHC). (2016). Preventing Falls on Stairs (63637). Retrieved from CMHC website: https://www03.cmhc-schl.gc.ca/catalog/productDetail.cfm?cat=17&itm=87&lang=en&sid=hTmEzB0aQaIFBAUIyB41vCQk5RyNtOm0ETfkZEISsp35wBFJwD7k5gMHYP9nO9BG&fr=1499403886265

Cesari, P., Formenti, F., & Olivato, P. (2003). A common perceptual parameter for stair climbing for children, young and old adults. Human Movement Science, 22(1), 111-124. doi:10.1016/S0167-9457(03)00003-4

Dusenberry, D., Simpson, H., & DelloRusso, S. (2009). Effect of handrail shape on graspability. Applied Ergonomics, 40(4), 657-669. doi:10.1016/j.apergo.2008.05.006

Elliott, D. B., Foster, R. J., Whitaker, D., Scally, A. J., & Buckley, J. G. (2015). Analysis of lower limb movement to determine the effect of manipulating the appearance of stairs to improve safety: a linked series of laboratory-based, repeated measures studies. Public Health Research, 3(8). doi:10.3310/phr03080

Foster, R. J., Hotchkiss, J., Buckley, J. G., & Elliott, D. B. (2014). Safety on stairs: Influence of a tread edge highlighter and its position. Experimental Gerontology, 55, 152-158. doi:10.1016/j.exger.2014.04.009

Fujiyama, T., & Tyler, N. (2009). Bidirectional collision-avoidance behaviour of pedestrians on stairs. Environment and Planning B: Planning and Design, 36(1), 128-148. doi:10.1068/b33123

Fujiyama, T., & Tyler, N. (2010). Predicting the walking speed of pedestrians on stairs. Transportation Planning and Technology, 33(2), 177-202. doi:10.1080/03081061003643770

Hamel, K., Okita, N., Higginson, J., & Cavanagh, P. (2005). Foot clearance during stair descent: effects of age and illumination Gait & Posture, 21(2), 135-140. doi:10.1016/j.gaitpost.2004.01.006

Hamel, K. A., Okita, N., Bus, S. A., & Cavanagh, P. R. (2005). A comparison of foot/ground interaction during stair negotiation and level walking in young and older women. Ergonomics, 48(8), 1047-1056. doi:10.1080/00140130500193665

Irvine, C., Snook, S., & Sparshatt, J. (1990). Stairway risers and treads: acceptable and preferred dimensions. Applied Ergonomics, 21(3), 215-225. doi:10.1016/0003-6870(90)90005-I

Kendrick, D., Zou, K., Ablewhite, J., Watson, M., Coupland, C., Kay, B., . . . Reading, R. (2015). Risk and protective factors for falls on stairs in young children: multicentre case–control study. Archives of Disease in Childhood, 101(10), 909-916. doi:10.1136/archdischild-2015-308486

Kim, H. (2009). A comparison of the center of pressure during stair descent in young and healthy elderly adults. Journal of Physical Therapy Science, 21, 129-134. doi:10.1589/jpts.21.129

Kim, K., & Steinfeld, E. (2016). An evaluation of stairway designs featured in architectural record between 2000 and 2012 International Journal of Architectural Research, 10(1), 96-112.

Komisara, V., Novak, A. C., Kinga, E. C., Makie, B. E., Zabjek, K. F., & Fernie, G. R. (2015). Effect of handrail height on the speed and accuracy of reach-to-grasp balance recovery reactions during ramp descent: A pilot study. In G. Lindgaard & D. Moore (Eds.) Proceedings 19th Triennial Congress of the IEA, Melbourne 9-14 August 2015. Melbourne, Australia: International Ergonomics Association. http://www.iea.cc/congress/2015/451.pdf

Law, N.-H., Li, J., & Law, N.-Y. (2011). The moment of the hip and knee in obese and non-obese individuals during stair ascent and descent. Portuguese Journal of Sports Sciences, 11(Suppl 2), 523-526.

Lee, H.-J., & Chou, L.-S. (2007). Balance control during stair negotiation in older adults. Journal of Biomechanics, 40(11), 2530–2536. doi:10.1016/j.jbiomech.2006.11.001

MacLennan, H. A., Ormerod, M., Newton, R., & Faruk, M. (2011). Are older people confident climbing steps in outdoor public places? Paper presented at the International Conference on Best Practices in Universal Design: Festival of International Conferences on Caregiving, Disability, Aging and Technology (FICCDAT), June 5-8 2011, Toronto, Canada.

Maganaris, C. N., Di Giulio, I., Jones, D. A., Kingdon, E., Reeves, N. D., Spyropoulos, G., . . . Roys, M. (2014). Biomechanical and sensory constraints of step and stair negotiation in old age (NDA Findings 31). Retrieved from NDA Programme, The University of Sheffield website: http://www.newdynamics.group.shef.ac.uk/assets/files/NDA%20Findings_31.pdf

Maki, B. E. (1997). Gait changes in older adults: predictors of falls or indicators of fear? Journal of the American Geriatrics Society, 45, 313-320.

Maki, B. E., Cheng, K. C. C., Mansfield, A., Scovil, C. Y., Perry, S. D., Peters, A. L., . . . McIlroy, W. E. (2008). Preventing falls in older adults: New interventions to promote more effective change-in-support balance reactions. Journal of

Electromyography and Kinesiology, 18(2), 243–254. doi:10.1016/j.jelekin.2007.06.005

Maki, B. E., Perry, S. D., & McIlroy, W. E. (1998). Efficacy of handrails in preventing stairway falls: A new experimental approach. Safety Science, 28(3), 189-206. doi:10.1016/S0925-7535(98)80008-8

Maki, B. E., Perry, S. D., Scovil, C. Y., Peters, A. L., McKay, S. M., Lee, T. A., . . . McIlroy, W. E. (2008). Interventions to promote more effective balance-recovery reactions in industrial settings: New perspectives on footwear and handrails. Industrial Health, 46(1), 40-50. doi:10.2486/indhealth.46.40

Marigold, D. S. (2006). Negotiating varying ground terrain during locomotion: Insights into the role of vision and the effects of aging. (PhD Thesis), University of Waterloo, Ontario, Canada. Retrieved from http://hdl.handle.net/10012/2623

Mayagoitia, R., Harding, J., & Kitchen, S. (2017). Identification of stair climbing ability levels in community-dwelling older adults based on the geometric mean of stair ascent and descent speed: The GeMSS classifier. Applied Ergonomics, 58(81-88). doi:10.1016/j.apergo.2016.05.014

Menant, J. C., Smith, S., & Lord, S. R. (2008). Visual determinants of instability and falls in older people. Aging Health, 4(6), 643-650. doi:10.2217/1745509X.4.6.643

Menegoni, F., Galli, M., Tacchini, E., Vismara, L., Cavigliloni, M., & Capodaglio, P. (2009). Gender-specific effect of obesity on balance. Obesity Research, 17(8), 1951-1956. doi:10.1038/oby.2009.82

Mian, O. S., Narici, M. V., Baltzopoulos, V., & Minetti, A. E. (2007). Centre of mass motion during stair negotiation in young and older men. Gait & Posture, 26(3), 463–469. doi:10.1016/j.gaitpost.2006.11.202

Nagata, H. (2006). Evaluation of safety dimensions of stairways based on human peripheral vision. In E. Koningsveld (Ed.), Proceedings of the 16th World Congress of the International Ergonomics Association (IEA). [CD ROM]. Maastricht, The Netherlands: International Ergonomics Association.

Novak, A., Komisar, V., Maki, B., & Fernie, G. (2014). Age-related differences in dynamic balance control during stair descent and effect of varying step geometry. Paper presented at the Watch Your Step: 2014 National Fall Prevention Conference, Toronto, Canada. Presentation slides retrieved from http://watchyourstepcanada.com/wp-content/uploads/2013/10/Novak-Komisar-Maki-Fernie.pdf

Novak, A., Komisar, V., Maki, B., & Fernie, G. (2016). Age-related differences in dynamic balance control during stair descent and effect of varying step geometry. Applied Ergonomics, 52, 275-284. doi:10.1016/j.apergo.2015.07.027

Ozanne-Smith, J., Guy, J., Kelly, M., & Clapperton, A. (2008). The relationship between slips trips and falls in the design and construction of buildings (Report No. 281). Retrieved from Monash University Accident Research Centre website: http://www.monash.edu/muarc/research/our-publications/muarc281

Pauls, J. L. (2011). Workshop on crowd use of stairs. Paper presented at the International Conference on Stairway Use and Safety (ICSUS), June 9-10, 2011, Toronto, Canada.

Pauls, J. L., Fruin, J. J., & Zupan, J. M. (2007). Minimum stair width for evacuation, overtaking movement and counterflow - technical bases and suggestions for the past, present and future. In N. Waldau, P. Gatterman, H. Knoflacher, & M. Schrekenberg (Eds.) Pedestrian and Evacuation Dynamics 2005 (pp. 57-69). Berlin Heidelberg: Springer. doi:10.1007/978-3-540-47064-9_5

Proulx, G., Benichou, N., Hum, J. K., & Restivo, K. N. (2007). Evaluation of the effectiveness of different photoluminescent stairwell installations for the evacuation of office building occupants. IRC-RR-232 Research Report (National Research Council Canada. Institute for Research in Construction), doi:10.4224/20377992

Rantanen, T., Guralink, J. M., Foley, D., Masaki, K., Leveille, S., Curb, J., & White, L. (1999). Midlife hand grip strength as a predictor of old age disability. Journal of the American Medical Association, 281(6), 558-560. doi:10.1001/jama.281.6.558

Reed, M. P. (2009). Modeling ascending and descending stairs using the Human Motion Simulation Framework (SAE Technical Paper 2009-01-2282). SAE International doi:10.4271/2009-01-2282

Reeves, N. D., Spanjaard, M., Mohagheghi, A. A., Baltzopoulos, V., & Maganaris, C. N. (2008). The demands of stair descent relative to maximum capacities in elderly and young adults. Journal of Electromyography and Kinesiology, 18(2), 218-227. doi:10.1016/j.jelekin.2007.06.003

Reeves, N. D., Spanjaard, M., Mohagheghi, A. A., Baltzopoulos, V., & Maganaris, C. N. (2008). Influence of light handrail use on the biomechanics of stair negotiation in old age. Gait and Posture, 28(2), 327-336. doi:10.1016/j.gaitpost.2008.01.014

Riener, R., Rabuffetti, M., & Frigo, C. (2002). Stair ascent and descent at different inclinations. Gait and Posture, 15(1), 32-44. doi:10.1016/S0966-6362(01)00162-X

Roys, M. (2001). Serious stair injuries can be prevented by improved stair design. Applied Ergonomics, 32(2), 135-139. doi:10.1016/S0003-6870(00)00049-1

Roys, M. (2008). Slips trips and falls on stairs ramps and escalators Review of Health and Safety Risk Drivers BD2518. London, UK: Communities and Local Government.

Scott, A. (2005). Falls on stairways – Literature review (Report No. HSL/2005/10). Retrieved from Health and Safety Laboratory website: http://www.hse.gov.uk/research/hsl_pdf/2005/hsl0510.pdf

Simoneau, C. G., Cavanagh, P. R., Ulbrecht, J. S., Leibowitz, H. W., & Tyrell, R. A. (1991). The influence of visual factors on fall-related kinematic variables during stair descent by older women. Journal of Gerontology, 46(6), M188-M195. doi:10.1093/geronj/46.6.M188

Sinisammal, J., & Saaranen, P. (2010). Preferred handrail height for spiral stairs—A fitting trial study. International Journal of Occupational Safety and Ergonomics, 16(3), 329-335. doi:10.1080/10803548.2010.11076847

Spearpoint, M., & MacLennan, H. A. (2012). The effect of an ageing and less fit population on the ability of people to egress buildings. Safety Science, 50(8), 1675-1684. doi:10.1016/jssci.2011.12.019

Tiedemann, A., Sherrington, C., & Lord, S. R. (2007). Physical and psychological factors associated with stair negotiation performance in older people. Journals of Gerontology Series A: Biological Sciences and Medical Sciences, 62A(11), 1259-1265. doi:10.1093/gerona/62.11.1259

Verghese, J., Wang, C., Xue, X., & Holtzer, R. (2008). Self-reported difficulty in climbing up or down stairs in nondisabled elderly. Archives Physical Medicine and Rehabilitation, 89(1), 100-104. doi:10.1016/j.apmr.2007.08.129

Yardley, L., Papo, D., Bronstein, A., Gresty, M., Gardner, M., Lavie, N., & Luxon, L. (2002). Attentional demands of continually monitoring orientation using vestibular information. Neuropsychologia, 40(4), 373-383. doi:10.1016/S0028-3932(01)00113-0

Yardley, L., & Redfern, M. S. (2001). Psychological factors influencing the recovery from balance disorders. Anxiety Disorders, 15(1-2), 107-119. doi:10.1016/S0887-6185(00)00045-1

Zielinski, A. E., Rochette, L. M., & Smith, G. A. (2012). Stair-related injuries to young children treated in US emergency departments, 1999–2008. Pediatrics, 129(4), 721-727. doi:10.1542/peds.2011-2314