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Developing better design standards for the construction industry

Mariapia Angelino

A dissertation submitted to the University of Bristol in accordance with the requirements for award of the degree of Engineering Doctorate (EngD) in the Faculty of Engineering.

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Abstract

Design standards are fundamental documents for civil and structural engineers, in particular as a key means by which the acceptability of designs can be verified. The scale of construction projects means that there are few opportunities to prototype, thus design verification is fundamentally standard-driven. Despite their importance, very limited attention has been paid by the research community to explore what "good" design standards are and how they can be improved.

The aim of this thesis is to explore this unaddressed yet important topic by bringing together a critical cross-disciplinary review of academic and industrial research and real experiences in the development and application of design standards. Brainstorming sessions with practitioners, interviews of standards writers and five live projects have been employed to develop a detailed contextual understanding of real challenges and practical solutions in the development of good design standards with a specific focus on their usability.

To set the basis for this research, the role of design standards is explored. Core roles are established and new roles relevant to a future and 'smarter' construction industry are suggested. Armed with this initial understanding, the challenges in development and use of design standards are investigated. This exploration reveals a complex socio-technical context, in which the strategies for enhancing technical provisions are typically interwoven with often competing stakeholders' needs, varying designers' skills, inherent tensions, and a multitude of technical, procedural, political, social and economic factors.

Findings of this research reveal that, to develop better design standards, two elements have to be improved: (i) their content and (ii) the standardisation system. These are used as a basis to develop a practical framework to support decision-making of standards' writers. Individual properties and processes within the framework are augmented by relevant strategies for their management. Solutions are recommended for potential issues associated with the identified strategies.

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I would like to thank those who participated in the interviews, the clients (Highways England, HS2, BSI, Temporary Works Forum) and the CEN/TC 250 members. I finally would like to thank my fellow doctoral students, particularly Alison Turner, for their support, feedback, and friendship, and those doctoral students who have moved on for sharing a glimmer of hope for post-dissertation normalcy.

Dedication

To Alessio, my half and my joy
To Anna and Pietro, my parents and my foundation
To Antonio, my big brother and my dreamer
Words cannot express how much I love you all.

Author’s Declaration

I declare that the work in this dissertation was carried out in accordance with the requirements of the University's Regulations and Code of Practice for Research Degree Programmes and that it has not been submitted for any other academic award. Except where indicated by specific reference in the text, the work is the candidate's own work. Work done in collaboration with, or with the assistance of, others, is indicated as such. Any views expressed in the dissertation are those of the author.

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List of abbreviations

ACR	Action Case Research
BSI	British Standards Institution
CAP	Chairman's Advisory Panel on the Ease of Use of the Eurocodes
CEN	*Comité Européen de Normalisation* (European Committee for Standardisation)
CEN/TC 250	CEN Technical Committee 250 responsible for the Structural Eurocodes
CIHT	Chartered Institution of Highways and Transportation
DBFO	Design Build Finance Operate
DfT	Department for Transport
DMRB	Design Manual of Roads and Bridges
EC	European Commission
EC-EID	European Commission Enterprise and Industry Directorate
ISO	International Organization for Standardization
MBR	Method-Based Requirements
MDD	Manual for Development of Documents
MPD	'Major Projects' Directorate of Highways England
OD	'Operations' Directorate of Highways England
NDP	National Determined Parameter
PBC	Performance-Based Contract
PBMC	Performance-Based Maintenance Contracts
PBR	Performance-Based Requirement
SC	Sub-committee
SES	'Safety, Engineering and Standards' Directorate of Highways England
RoWSaF	Road Worker Safety Forum
TAGG	Technical Assurance and Governance Group (Highways England)
WG	Working Group
WSP	Author's host organisation

Publications, Presentations and Awards

Journal papers

[1] Harris A, & **Angelino** M (2017) Temporary Works Toolkit. Part 15: Designing temporary works to European Standards: an introduction to PAS 8812, *The Structural Engineer*, 95(9).

Conference papers

[2] **Angelino M**, Agarwal J, Shave J, & Denton S (2014a) The development of successful design standards: understanding the challenges, *37th IABSE Symposium*, Madrid [published and accepted for presentation].

[3] **Angelino M**, & Agarwal J (2014b) Exploring Quality of Design Standards in the Construction Sector: Lessons from Past and Future Needs, *19th European Academy for Standardisation (EURAS) Annual Conference*, Belgrade [published and accepted for presentation].

[4] **Angelino M**, Taylor C, & Denton S. (2016) What should future design standards in the construction industry look like? The need for new value propositions. In R. J. Mair, K. Soga, Y. Jin, A. K. Parlikad, & J. M. Schooling (Eds.), Transforming the Future of Infrastructure through Smarter Information: Proceedings of the International Conference on Smart Infrastructure and Construction, 27–29 June 2016. (pp. 651-656). DOI: 10.1680/tfitsi.61279.651 [published and accepted for presentation].

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[7] CEN/TC 250 (2013a) *CEN/TC 250 Response to Mandate M/515 Towards a second generation of EN Eurocodes*, Denton S, & **Angelino M** with contributions from CEN/TC250 Subcommittees, Working Groups and Horizontal Groups. CEN/TC 250 N 993 (access from http://psc.ro/wp-content/uploads/2013/07/M515_TC-250-answer+Annexes.pdf).

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Industry standards

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Presentations

Angelino M *Developing successful design standards: Understanding the value of Systems Thinking* (March 2014). Systems Research Showcase, INCOSE's Bristol local group, University of Bristol.

[Guest speaker] *Developments in the Eurocodes for Bridge Design* (June 2014). ICE Bridges conference, London.

Angelino M *Enhancing quality and usability of design standards in the construction sector: A learning journey* (March 2015). Systems Research Showcase, INCOSE's Bristol local group, University of Bristol.

[Guest speaker] *Exploring the latest developments in Standards and Guidance for Basement Temporary Works* (October 2015). Basements and Underground Structures Conference.

Angelino M *Developing better design standards for the construction industry* (November 2016) fib UK Developments in Structural Concrete: Smarter Use of Concrete.

[Guest speaker] *Paving the way for enhanced road design and construction - Challenging technical standards* (November 2018) Traffex Road Expo - Bridges Scotland.

Awards

[Best conference presentation] IDC in Systems Mid-point Conference 2014, University of Bristol. Presentation title: *Enhancing quality and usability of design standards in the construction sector: A learning journey.*

[Best poster] IDC in Systems Annual Conference 2015, University of Bristol. Poster title: *Enhancing quality of design standards in the construction sector: A learning journey.*

[Best conference presentation] IDC in Systems Annual Conference 2016, University of Bristol. Presentation title: *Developing better design standards for the construction industry.*

Regional finalist 2016 in the WSP People awards in the 'Innovative' category for the work done on standards.

Regional finalist 2017 in the WSP People awards in the 'Passionate' category for the work done on standards.

Regional winner 2017 in the WSP Project awards in the 'Innovative' category for the work done on the Design Manual for Roads and Bridges (DMRB).

Finalist 2018 at the European Women in Engineering Awards (WICE) in the category Best Consultant for the work done on standards.

Finalist at the 2018 TechFest in the category "Research Development: Creating the Future" for the work done with WSP colleagues and Highways England on the Technical Standards Enterprise System developed for the Future DMRB project.

Other relevant activities

Member of the Chairman's Advisory Panel (CAP) on Ease of Use of the Eurocodes, from November 2013 to November 2014.

Chair of the technical session "Standards and Innovation" at the 19th European Academy for Standardisation (EURAS) Annual Conference, September 2014.

Trainer of over 300 Highways England and Devolved Administrations staff and supply chain consultants on the drafting rules of the future Design Manual for Roads and Bridges (DMRB), from March to June 2018.

Technical Reviewer of the second generation of Structural Eurocodes for Phases 1 to 4 of Mandate M/515 Work Programme, since June 2017.

Developing better design standards for the construction industry

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Preamble

In the 2012 Autumn statement, the UK Chancellor of the Exchequer acknowledged the importance of standards in the construction sector and the possibility for them to be improved. As a result, he established an industry group to develop recommendations. This high-profile initiative reflected a general concern about the complexity of the current approach to standardisation.

At that time the UK construction industry was undergoing a transition with many national standards replaced by European standards, the Structural Eurocodes *in primis*. A complex system of standards and specification emerged, which operated at many levels ranging from client and industry specifications to international standards. From the perspective of designers and construction clients, the situation was thus becoming increasingly challenging.

WSP (the author's host organisation) has been actively involved in the development of standards and specifications for over 20 years in the UK infrastructure sector. The desire to investigate the complexity of the current generation of design standards and develop rigorous methods to assess their usability, efficiency and effectiveness, led WSP to sponsor this research. This study takes advantage of the opportunities provided by WSP to engage in live projects related to development and application of standards and to be exposed to the operation of national and international standards bodies and committees.

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Chapter 1

Introduction

1.1 Problem definition

Design standards are essential documents for the professional activity of civil and structural engineers. They are a key means to verify the adequacy of designs to meet the fundamental requirements for safety, serviceability, durability and robustness. The scale of construction projects means that there are few opportunities to build full-scale prototypes, thus design is fundamentally code-driven. Design standards also serve as a vital conduit for research outcomes to achieve widespread adoption within the sector, hence providing a key mechanism for the research community to achieve impact from their work. Furthermore, design standards play an important role in enabling or hindering the efficient delivery of construction projects as shown in recent studies carried out in the UK construction sector (Industry Standards Group 2012; Wilson et al. 2015).

Design standards are central to the working practices of many hundreds of thousands of structural engineers across Europe alone (Commission of the European Communities 2008), researchers and the industry as a whole. Nevertheless, research into design standards themselves and how they can be improved has been very limited. Literature shows a paucity of conceptual frameworks to understand what 'good' design standards are and how they can be developed, particularly to meet users' needs. Practicing structural engineers commonly express concerns about design standards and their increasing complexity, citing the ambiguity of clauses, the increasing number of documents and technical provisions, and the limited focus on users as some of the key issues. Interestingly, similar comments can be found in publications from forty years ago as documented by the Institution of Structural Engineers (2000) meaning that these issues are not just a recent phenomenon and that specific research is needed to address them.

Developing better design standards is a complex task. Design standards are not just 'documents'. A holistic view is necessary to appreciate the existence of a broad range of technical, technological, human, environmental, political and economic factors affecting their development and use. Standards' writers are expected to strike the balance among a variety of aspects as noted by Nethercot (2012). These include: prescriptions and performance; simplified design approaches and economy; flexibility and stability; freedom of design and aid for common design situations; conciseness and comprehensiveness of provisions.

Additionally, the construction industry is increasingly recognising the potential of digital and smart technologies (such as building information modelling, computer-aided and machine-based design, new sensor technologies and off-site manufacturing) to positively impact how structures will be designed, built, managed, operated and dismantled. Yet, there does not seem to be an appreciation of the role of design standards in supporting these changes and meeting the emerging vision for the future of the construction sector (Cooperative Research Centre 2004; European Construction Technology Platform 2005; American Society of Civil Engineers 2006; HM Government 2013). Clarity of expectations on what future design standards should look like is necessary in order to realise the opportunities that advances in technologies can offer. It is also vital to avoid design standards becoming blockers rather than enablers of this future.

Filling these theoretical and practical gaps is far from straightforward. A systematic examination of the philosophy behind the development and use of design standards in the construction industry is needed to understand how better design standards can be developed.

1.2 Purpose of the thesis

This thesis delves deeply into the issues presented in the previous section and explores the challenges and potential solutions to develop better design standards in the construction industry from users' perspectives. It brings together a critical cross-disciplinary review of academic and industrial research and real experiences in the development and application of design standards.

1.3 Research questions

This thesis is framed around one main research question:

RQ: How can better design standards for the construction industry be developed?

The term 'better' in the research question indicates something that is more desirable, satisfactory or effective than what exists now. Hence, the first step is to identify the metrics for a good design standard, which in turn requires an understanding of their current and future roles, particularly to meet needs, interests and capabilities of users of these documents. The second step is to understand the issues connected with their development and use. Armed with theoretical and practical learning and evidence, metrics for a good design standard can be derived, as well as a practical framework to guide standards' writers in developing better design standards.

These activities are framed in the following research sub-questions and are explored in this thesis:

RSQ1: Which role do design standards currently fulfil in the construction industry and are expected to fulfil in the future?

RSQ2: What are the issues that affect design standards at different life-cycle stages?

RSQ3: What are good design standards, particularly from a user-perspective?

RSQ4: What practical steps can standards' writers take to develop better design standards?

1.4 Scope of the work

In this thesis, the term "design standard" refers to both design and assessment (load rating) standards for common civil and structural engineering works. Design standards for special cases (e.g. nuclear structures, off-shore structures, etc.) have not been considered unless explicitly mentioned. The emphasis is primarily on European and UK practice.

The focus of this research is not on specific technical requirements contained in design standards, but rather on the key factors affecting their quality.

It is important to recognise that a design standard by itself is often not sufficient to design any structure and it must be used in conjunction with other standards such as those giving provisions for material and products used in the construction industry (i.e. product standards) and those giving provisions on the execution of different types of structures (i.e. execution standards). In this thesis only design standards have been explored; yet, consideration has also been given to their key interactions with other types of standards where needed.

In this thesis the term "users" refers to those who apply design standards such as designers and clients. Users of the constructed facilities are not considered under the term "users". Actors who do not use design standards, but are affected or may influence the standardisation process, are identified as general "stakeholders".

The thesis includes some explanatory background text to aid the understanding of 'systems thinking' principles and standardisation processes by a wide range of audience.

1.5 Structure of the thesis

This thesis guides the reader through the process of inquiry taken by the author to explore the quality of design standards in the construction industry. The thesis is divided into three parts as represented in Figure 1.1 and outlined below.

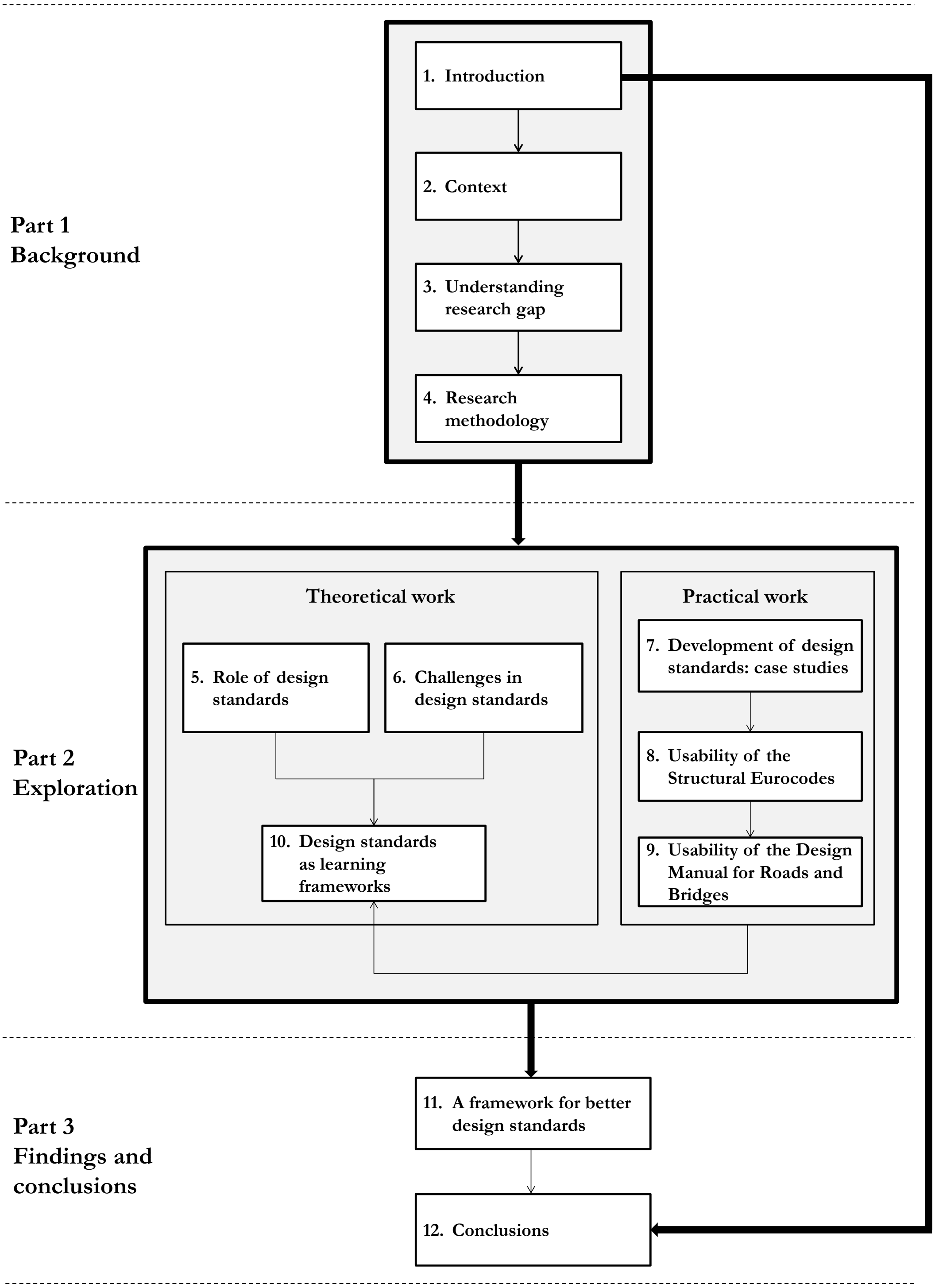

Figure 1.1: Structure of the thesis

Part 1 provides relevant background information.

Chapter 1: Introduction. This chapter provides an overview of the problem this thesis endeavors to address and the purpose of this study. Research questions are introduced, the scope of the work is defined and the structure of the thesis is presented.

Chapter 2: Context. This chapter presents the context of this research and clarifies the key terms used in this thesis. Areas of ambiguity identified and clarified include the term standardisation, the distinction between formal and *de facto* standards, the difference between standards and regulations, the definition of design standards, the hierarchy of regulations, standards and guidance material needed for the design of civil and structural engineering works.

Chapter 3: Research gaps in design standards' quality. This chapter provides a critical review of the literature on the concept of quality in general as well as the quality of design standards in the construction sector. Insights gained from debates by professional associations in the last 40 years are presented. Gaps in literature are identified and discussed, and research directions are presented to define the boundaries of this thesis.

Chapter 4: Research methodology. This chapter presents the research methodology adopted to address the research questions. The research philosophy taken by the author is illustrated. The research design and approach taken, the ethics implications, the role of the author as researcher and the assessment of the quality of this research are discussed.

Part 2 presents the theoretical and practical work (i.e. case studies) carried out by the author.

Chapter 5: Role of design standards. This chapter explores the current and future roles of design standards in the construction industry. It draws together: (i) literature review on the evolution of design standards in the construction industry to identify their historical purposes; (ii) a comparison between constructed facilities and artefacts produced in the aerospace and automotive industry to show the unique role of design standards in the construction industry; (iii) a review of the evolution of the construction industry to understand the impact that its changes may have on future design standards; (iv) a qualitative study.

Chapter 6: Challenges in design standards. This chapter draws together literature review and a qualitative study to investigate the challenges affecting different stages of the life-cycle of design standards in the construction industry. The impact of the identified challenges is illustrated. A list of preliminary features of better design standards is also derived, which is tested in Chapters 7, 8 and 9.

Chapter 7: Development of design standards: cases studies. This chapter reports on three projects related to standards development and implementation. They represent initial practical explorations of the features of better design standards.

Chapter 8: Usability of the Structural Eurocodes. This chapter reports on the project carried out to enhance the usability of the Structural Eurocodes, the main suite of design standards for structures used across all EU and European Free Trade Association (EFTA) Member States and adopted in other countries outside Europe such as Singapore, Ethiopia and South Africa amongst many others. The chapter guides the reader in both the personal learning journey taken by the author and the collaborative process followed within the European panel that was created to develop the recommendations for a more user-orientated second generation of Eurocodes.

Chapter 9: Usability of the UK Design Manual for Roads and Bridges. This chapter reports on the project carried out working alongside Highways England to develop the recommendations to enhance usability, structure and content of the Design Manual of Road and Bridges (DMRB), which is the main suite of standards used in the UK to design and manage the motorway and all-purpose trunk roads.

Chapter 10: Design standards as learning frameworks. The development process of design standards does not seem to explicitly recognise the diverse learning capabilities of different categories of designers. This chapter explores the value in considering a 'learning' component in the development of design standards. Relevant research areas in both learning analytics and engineering design literature are examined and are consolidated with the results of a pilot experiment carried out by the author with practitioners.

For each case study a discussion on the emerging themes is made. It reflects the view of the author only and do not necessarily represent the perspective of WSP and the client organisations. Where the content refers to reflections or activities emerged from discussion with the above stakeholders, those are acknowledged and indicated as such.

Part 3 consolidate the findings from the theoretical and practical work.

> **Chapter 11: A framework for better design standards.** This chapter draws together the evidence collected in this thesis to provide a definition of good design standards and to devise a practical framework, which can support standards' writers in drafting better design standards.
>
> **Chapter 12: Conclusions.** This chapter summarises key conclusions and the contribution to knowledge of the thesis. Directions for further work are also presented.

Part 1 Background

Chapter 2
Context

2.1 Introduction

The context of this thesis is standardisation applied to design standards in the construction industry and the purpose of this chapter is to provide a state-of-the-art review of the standardisation system with a focus on construction industry.

The term “standardisation” can be applied to describe both a process and a product (i.e. a standardised product). In this thesis the term standardisation is used to indicate the process of making standards, i.e. formulating, issuing and implementing them. ISO/IEC GUIDE 2:2004, 1.1 defines standardisation as follows:

> “Activity of establishing, with regard to actual or potential problems, provisions for common and repeated use, aimed at the achievement of the optimum degree of order in a given context.”

The extent of the research field and the existence of ambiguity on specific terms and definitions suggest the importance of clarifying some core concepts to which reference will be made in the following chapters of this thesis.

2.2 Aims of standardisation

The aims of standardisation are wide ranging. A list of key aims, which have been summarise from the seminal booklet on standards issued by ISO (1972) and from BS 0:2016, is provided in Table 2.1.

Table 2.1 is strongly product-orientated as also noted by Nethercot (2012), meaning that some degree of interpretation is needed to apply the aims of standardisation to design standards (see Section 2.9). Nethercot (2012) also noted that there are some potential conflicts among some of these aims, for example between simplifying the growing variety of products and procedures and promoting overall economy.

Table 2.1 Aims of standardisation adapted from ISO (1972) and BSI (2016)

Specific aim	Description
Economy	Standardisation is key to support competitiveness and growth. Economy can be seen in a variety of aspects including: a larger number of standardised products resulting in lower cost goods, and re-distribution of development and implementation costs among different cooperating standardisation bodies. Some conflicting effects can also arise when economy is the only driver for standardisation, such as the issues related to health and safety, or the potential negative impact on small enterprises. [ISO] Standardisation provides a "framework for achieving economies, efficiencies and interoperability". [BSI]
Simplification	Standardisation enables "the ever-increasing complexity of human life" to be reduced by limiting variety of products and procedures and fixing the selected ones for a defined period. [ISO] The degree to which product, process or service are fixed for a specific period of time largely depends on the type of product, process or service considered.
Safety	Protection of human life is guaranteed by manufacturing products that have a high degree of reliability and by specialising or reducing the variety in equipment. [ISO]
Interchange-ability	Important particularly to products, which must be identical in size, shape and performance to enable their easy replacement whilst giving the same performance. [ISO]
Communication	Important for customers and manufacturers insofar as approved standards show available products and provide confidence that goods which are compliant with a standard are reliable and of quality, whilst ensuring that manufacturing interests are not too much strong. Effective communication also requires some harmonisation effort, particularly when dealing with international standards. [ISO]
Protection	Protection of consumer and community interest is required. This can be achieved by introducing standards that guarantee the quality of products ("conformity" of a product to a relevant standard) and by involving relevant stakeholders in the consensus process. [ISO] Enhancing consumer protection and confidence [BSI]
Elimination of trade barrier	This can be achieved in different ways. For example: by reaching agreement among different countries on the technical content of the standard; by applying the principle of "reference to standards" in drafting regulations and laws, which in turn leaves enough freedom to each country to frame their own rules; by introducing standards where necessary, as the mere absence of an approved standard can be a barrier to trade. [ISO] "Facilitating trade, particularly in reducing technical barriers and artificial obstacles to international trade". [BSI]
Support	"Supporting public policy objectives and, where appropriate, offering effective alternatives to regulation". [BSI]

2.3 Formal standards

2.3.1 Definition

The term "standard" derives from the Latin word *extendere*, i.e. to stretch out. The Oxford dictionary provides different definitions of the term standard including "a required or agreed level of quality or attainment" or "something used as a measure, norm, or model in comparative evaluations". Allen and Sriram (2000) argue that standards are "documented agreements containing technical guidelines to ensure that materials, products, processes, representations, and services are fit for their purpose". In other words, a standard is "an agreed way of doing something" (Spivak and Brenner 2001). Standards serve to align practice among different categories of users to ensure the achievement of specific requirements such as quality, safety, compatibility, interoperability, and economy.

The International Organization for Standardization (ISO/IEC Guide 2:2004, 3.2) provides the following definition of formal (or *de jure*) standard:

> "Document, established by consensus and approved by a recognised body that provides for common and repeated use, rules, guidelines or characteristics for activities or their results, aimed at the achievement of the optimum degree of order in a given context".

The three key aspects of this definition are:

(i) the organisation responsible for its development, i.e. a "recognised body" (see Sections 2.3.3);

(ii) the concept of "consensus" (see Sections 2.3.4), which has stringent implications on how the standard is developed (see Sections 2.3.5 for the governance process and Section 2.3.6 for the stages of standardisation);

(iii) the type of technical content, i.e. rules, guidelines etc. (see Section 2.3.2 for different types of formal standards).

2.3.2 Types of formal standards

A variety of formal standards exist, which are often confused with one other. These include technical specifications, codes of practice and guides. A distinction among them is made in this section.

2.3.2.1 Technical specifications

The International Organization for Standardization (ISO/IEC Guide 2:2004, 3.4) provides the following definition of technical specification:

> "Document that prescribes technical requirements to be fulfilled by a product, process or service".

A technical specification may be a standard, a part of a standard or independent of a standard. The British Standard Institution (BS 0:2016) clarifies that a specification gives "absolute" and "non-negotiable" requirements to be satisfied, each objectively verifiable. Due to its nature, BS 0:2016 clarifies that a specification is particularly suitable for products or for service or management systems. The scope of a technical specification is typically presented using the following expression: "*This document specifies requirements for…*".

2.3.2.2 Codes of practice

The International Organization for Standardization (ISO/IEC Guide 2:2004, 3.5) provides the following definition of code of practice:

> "Document that recommends practices or procedures for the design, manufacture, installation, maintenance or utilization of equipment, structures or products".

As for technical specifications, a code of practice may be a standard, a part of a standard or independent of a standard. The British Standard Institution (BS 0:2016) clarifies that "a code of practice contains recommendations and supporting guidance, where the recommendations relevant to a given user have to be met in order to support a claim of compliance". It also clarifies that a code of practice usually reflects current good practice as employed by competent and conscientious practitioners. The scope of a code of practice is typically presented using the following expression: "*This document gives recommendations and guidance for…*".

2.3.2.3 Guide

The term "guide" is introduced by the British Standard Institution (BS 0:2016) to indicate another example of formal standard containing primarily broad and general information and guidance. A guide can also provide recommendations, but "these are generally of a nature that would not support reliable claims of compliance" (BS 0:2016). The scope of a guide is typically presented using the following expression: "*This document gives guidance on…*".

2.3.3 Recognised bodies at international, regional and national level

Formal standards are developed by "recognised bodies", which can be any organisation, authority, company or foundation developing a standard at any level (ISO/IEC Guide 2:2004, 4.1). Recognised bodies act at three levels primarily:

- **International level**. Such standards are developed by international organisations, the most prominent being the International Organization for Standardization (ISO). ISO is an independent, non-governmental organisation with a membership of over 160 countries (one member per country). Standards are published as "ISO".

- **Regional level.** Such standards tend to serve a number of countries linked through a geo-political or geo-economic arrangement, typically at continent level. In Europe, for example relevant bodies are the European Committee for Standardization (CEN), the European Committee for Electrotechnical Standardization (CENELEC), and the European Telecommunications Standards Institute (ETSI). Of these three organisations, design standards for the construction industry fall within CEN remit. CEN comprises member bodies of the 28 European Union countries, the Former Yugoslav Republic of Macedonia, Serbia and Turkey plus three countries of the European Free Trade Association (Iceland, Norway and Switzerland). CEN standards are published as "EN".

- **National level**. Such standards are recognized by governments as serving a national purpose. The management of a national standards catalogue is commonly delegated by government to the relevant nationally-based standards organisation also called National Standard Body (NSB), for example the British Standard Institution (BSI) in the UK, the Deutsches Institut für Bautechnik (DIN) in Germany, the Ente Nazionale Italiano di Unificazione (UNI) in Italy. These bodies form the national member of the international and regional standards organisations. For the purpose of this thesis, the relevant NSB is BSI. National standards in the UK on all subjects are published by BSI and designated by the code "BS". Over 84% of BS standards published by BSI are international (ISO, IEC) or European (EN). .

While it is useful to make a distinction between standards developed at international, regional and national level, it is important to point out that CEN members are obliged to adopt ENs as identical national standards and withdraw conflicting national standards (CEN/CENELEC 2017a). In other words, European standards are effectively national standards. These are published in the UK as "BS EN", e.g. BS EN 1990 covering basis of structural design. Over 50% of BS standards are derived from the EN process. It is worth noting that, although EN standards are adopted identically as national standards in the UK and other countries, they may contain deviations for specific national requirements.

CEN members are also obliged not to take any action, either during the preparation of an EN or after its approval, which could prejudice the harmonization process, and not to publish a new or revised national standard which is not completely in line with an existing European standard. This policy is called "standstill" (CEN/CENELEC 2017a).

There is no obligation to implement ISO standards at national level. However, BSI's policy is to adopt ISO standards that are not adopted as European standards as British Standards unless "(i) there is an existing BS EN or BS EN ISO on the same subject, (ii) the national committee have indicated that there is a more suitable existing national standard on the same subject, and (iii) the national committee have provided a justification for non-implementation" (BS 0:2016). The policy towards national standards in the UK may be described as international first, regional second and national third. An important consequence of this approach is that it avoids conflicting standards in the national standards collection.

2.3.4 Consensus

The development of a formal standard within a technical committee is a social process (Vries 2001). There is a general agreement in literature on considering standardisation as a consensus-driven process (Yates and Aniftos 1998; Bredillet 2003; Sherif et al. 2005). Consensus is defined (ISO/IEC Guide 2:2004, 1.7) as:

> "General agreement, characterized by the absence of sustained opposition to substantial issues by any important part of the concerned interests and by a process that involves seeking to take into account the views of all parties concerned and to reconcile any conflicting arguments.

Key aspects of this definition are:

- "sustained oppositions", which refer to views expressed at minuted meetings and sustained by an important part of the concerned interests, and which are incompatible with the committee consensus (ISO/IEC Directives 2018);

- "concerned interests", which are determined by the committee leadership on a case by case basis (ISO/IEC Directives 2018).

BS 0:2016 states that achieving consensus aims to ensure that "the interests of all those likely to be affected by it are taken into account, and that individual concerns are carefully and fairly balanced against the wider public interest". This concept is not new. The seminal booklet on standards issued by ISO (1972) introduced the principle of consensus in the seven principles of standardisation asking for mutual collaboration of all people concerned and the "sacrifice" of a few for the benefits of many. These aspects have been re-affirmed in the ISO publication "Engaging stakeholders and building consensus" (ISO 2010), which acknowledges that the "achievement of consensus entails recognizing the wider interest and sometimes making certain compromises" (Guidance 3.2G5).

2.3.5 Governance process

Formal standards are developed through independent and neutral governance processes, which provide the framework within which a recognised body conducts the standardisation work. ISO, CEN and BSI have slightly different governance processes (ISO/IEC Directives 2018; CEN/CENELEC 2017a; BS 0:2016). However, broadly speaking, three levels of governance can be identified at committee level, management of technical work level, and governing level as shown in Figure 2.1. The bodies working at each level and their activities are illustrated in the following paragraphs. A clarification of how different standards organisations cooperate is also made.

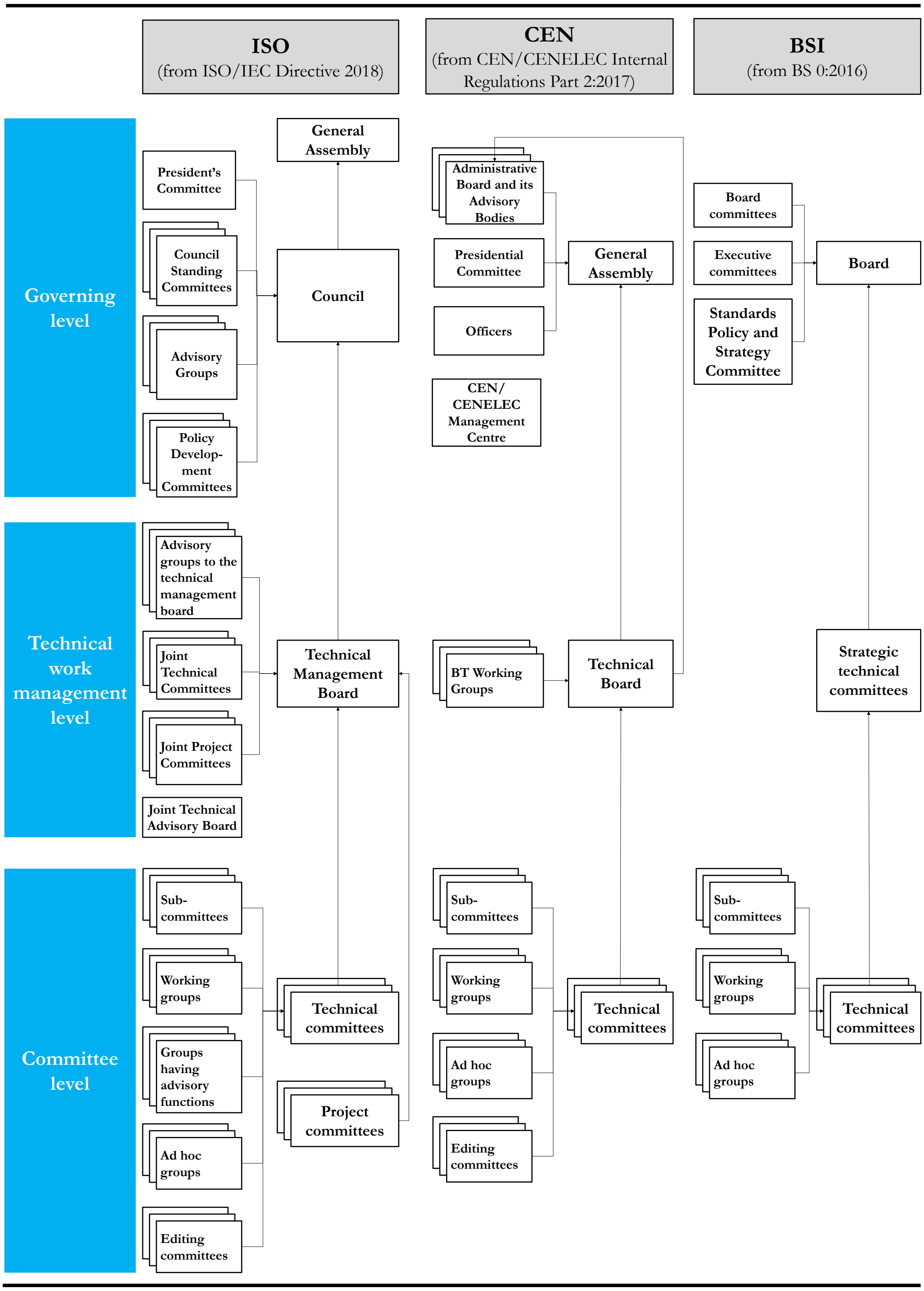

Figure 2.1 ISO, CEN and BSI governance structure to manage standardisation work

2.3.5.1 Activities undertaken by technical committees

The development of formal standards is a collective endeavour, with experts organised in "balanced and broadly representative committees" (BS 0:2016). A technical committee must represent the markets or interests affected by a particular standard. Subcommittees and working groups are generally established for large work programmes. Groups having advisory functions within a committee and *ad hoc* groups may also be established as needed (ISO/IEC Directives 2018).

ISO and CEN committees comprise national delegations appointed by member bodies. BSI participates actively in most of these committees through national mirror committees, which are responsible for the formulation of coherent national positions (BS 0:2016). BSI also has its own technical committees responsible for the development of British Standards, which represent a small proportion of standardization documents that are developed within the UK. Committee members have to demonstrate an expertise in areas relevant to the task of the technical committee. Typically, they represent collective interests.

In addition, ISO, CEN and BSI have in place processes to establish and maintain liaison between technical committees. At ISO for example, liaison representatives may be designated to follow the work of other ISO technical committees. Similarly, at BSI inter-committee liaison may be established if a committee identifies a need to liaise with or be represented on another technical committee.

2.3.5.2 Activities undertaken by managing bodies

Technical committees report to the managing bodies of their respective organisations, which are: the ISO Technical Management Board, the CEN Technical Board, and the BSI Strategic Technical Committees. The overall aim of these boards is to control the standards programme and oversee all work undertaken in technical committees, while advising on matters of standardisation policy and strategy. Additional boards and committees may also be established in ISO (see Figure 2.1) to support a joint approach between committees. Similarly, additional working groups may be established in CEN whenever a technical need for information, advice, a study or rules is identified (see Figure 2.1).

2.3.5.3 Activities undertaken by governing bodies

The bodies managing the technical work report to the governing bodies of their respective organisations, which are: the ISO Council, which in turn reports to the ISO General Assembly; the CEN General Assembly or Administrative Board as appropriate; and the BSI Group Board. Additional advisory bodies, boards and committees are also in place to provide advice on specific areas and discuss policy issues (see Figure 2.1).

2.3.5.4 Cooperation between standards organisations

ISO, CEN and BSI work in close collaboration to ensure the creation of a coherent and consistent system of standards. CEN and ISO work closely together according to the Vienna Agreement, with CEN supporting the promotion of European participation in the work of ISO, as well as the adoption of European Standards at national level. Equally, national standard bodies participate in ISO and CEN committees (see Section 2.3.3 for national implementation of ENs and the standstill policy).

2.3.6 Stages of standardisation

At committee level, different standards bodies follow similar standardisation processes. Figure 2.2 shows the typical stages involved in the development, publication and maintenance of formal standards developed by ISO, CEN and BSI. Despite the slightly different terminology, at any stage the activities of ISO, CEN and BSI are similar and characterised by openness and transparency.

Stage 1: This stage is typically characterised by five activities:

- Initial exploration of the need for standardisation work. While at national level there is no obligation to adopt ISO standards, there is instead an obligation to adopt relevant ENs without any changes (see Section 2.3.3). The UK for example is required to adopt ENs as a condition of membership of CEN.
    - Development of a proposal of the new standard or modification of an existing one.
    - Identification of relevant stakeholders.
    - Preliminary exploration of stakeholders' needs.
    - Identification of the scope of the standard.

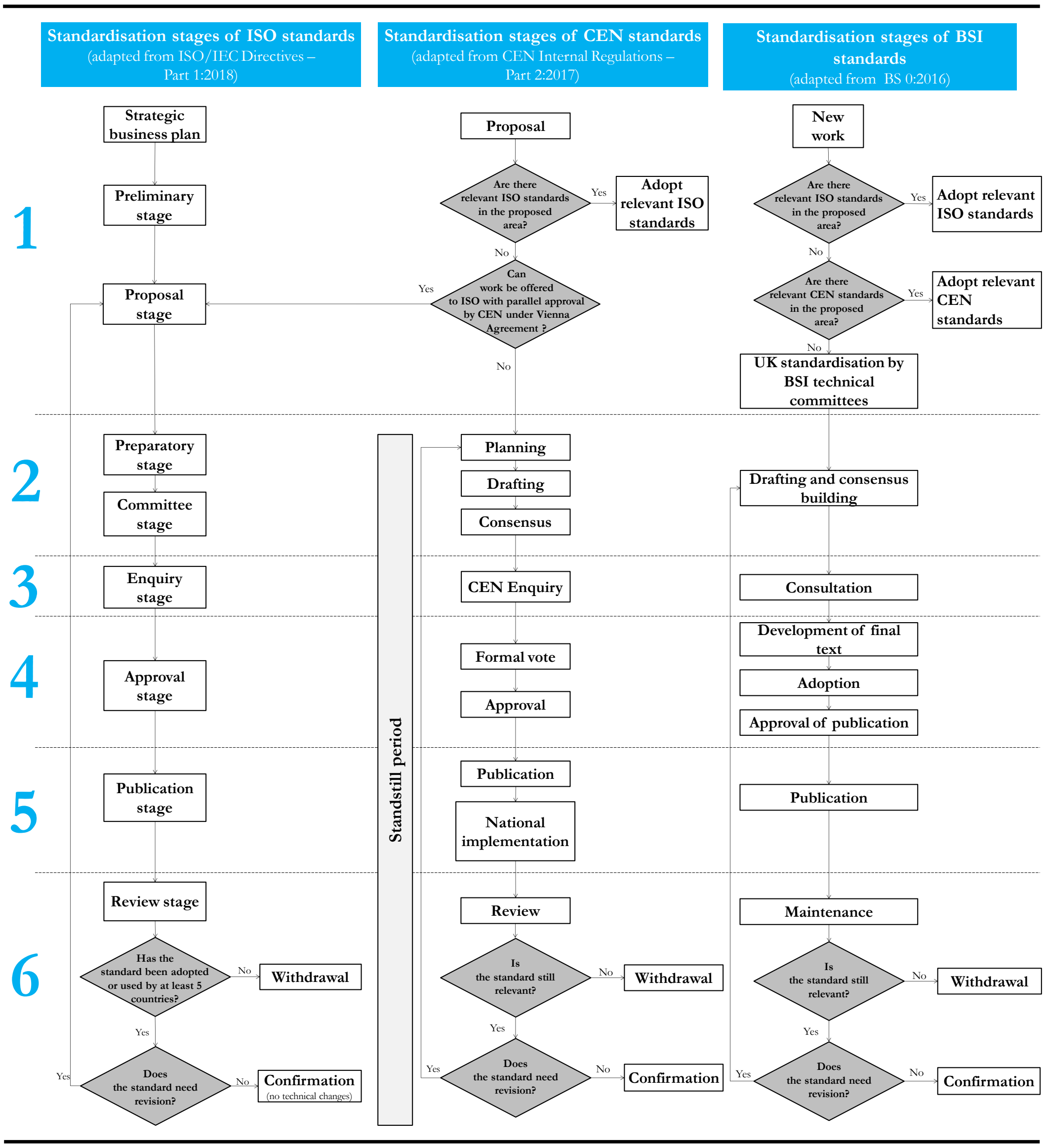

Figure 2.2 Stages of standardisation in ISO, CEN and BSI

Stage 2: This stage is typically characterised by three activities:

- Formation of a technical committee responsible for the standardisation work (for a new standard or to update an existing one).
- Production of working drafts by the technical committee.
- Review of working drafts, which typically entails several iterations until consensus is achieved.

Stage 3: This stage is characterised by the external consultation or enquiry, which is undertaken when consensus has been reached in a committee and the draft is distributed either to the national members (for ISO and ENs) or to the public (for British Standards) for comments.

Stage 4: This stage is typically characterised by three activities:

- Production of a final agreed document taking account of the findings from the enquiry.
- Formal vote.
- Approval for publication.

Stage 5: This stage is characterised by the publication of the standard. In case of ENs, this stage requires national implementation, i.e. the document is given the status of national standard with publication of an identical text and endorsement, and any conflicting national standards are withdrawn.

Stage 6: This stage is characterised by the periodic systematic review of the standard (typically every five years), which is essential to ensure validity of the document and keep it up-to-date. The standard can be confirmed without technical changes, withdrawn as no longer needed or obsolete, or it may require revision. In this case, the development process re-starts from stage 1.

Looking at how these stages are presented in relevant publications, three aspects emerge.

1. Inputs and feedback are expected to be collected and analysed at different stages of the standard's life-cycle, for example during the development of the business plan, the enquiry and the systematic review. Key external inputs are new regulations, new policies and plans, new best practice and, in case of civil and structural engineering works, learning from the built environment (for example due to structural collapses).

2. There does not seem to be any emphasis on education to use, which arguably enables standards to be used efficiently and effectively.

3. The application of the standard by users and the resulting feedback received are not explicitly included as a separate stage.

A comprehensive standardisation model for formal standards is represented in Figure 2.3.

This draws together stages from both the ISO, CEN and BSI standardisation processes undertaken at committee level and presented above, and it introduces additional stages (*education* and *use*) and key external inputs as relevant.

A distinction is made in Figure 2.3 between the "standardisation process" and the "standardisation system". The latter has been introduced to include the *education* and *use* stages which, strictly speaking, do not belong to the standardisation process. The model for formal standards in Figure 2.3 is used as a reference in the following chapters.

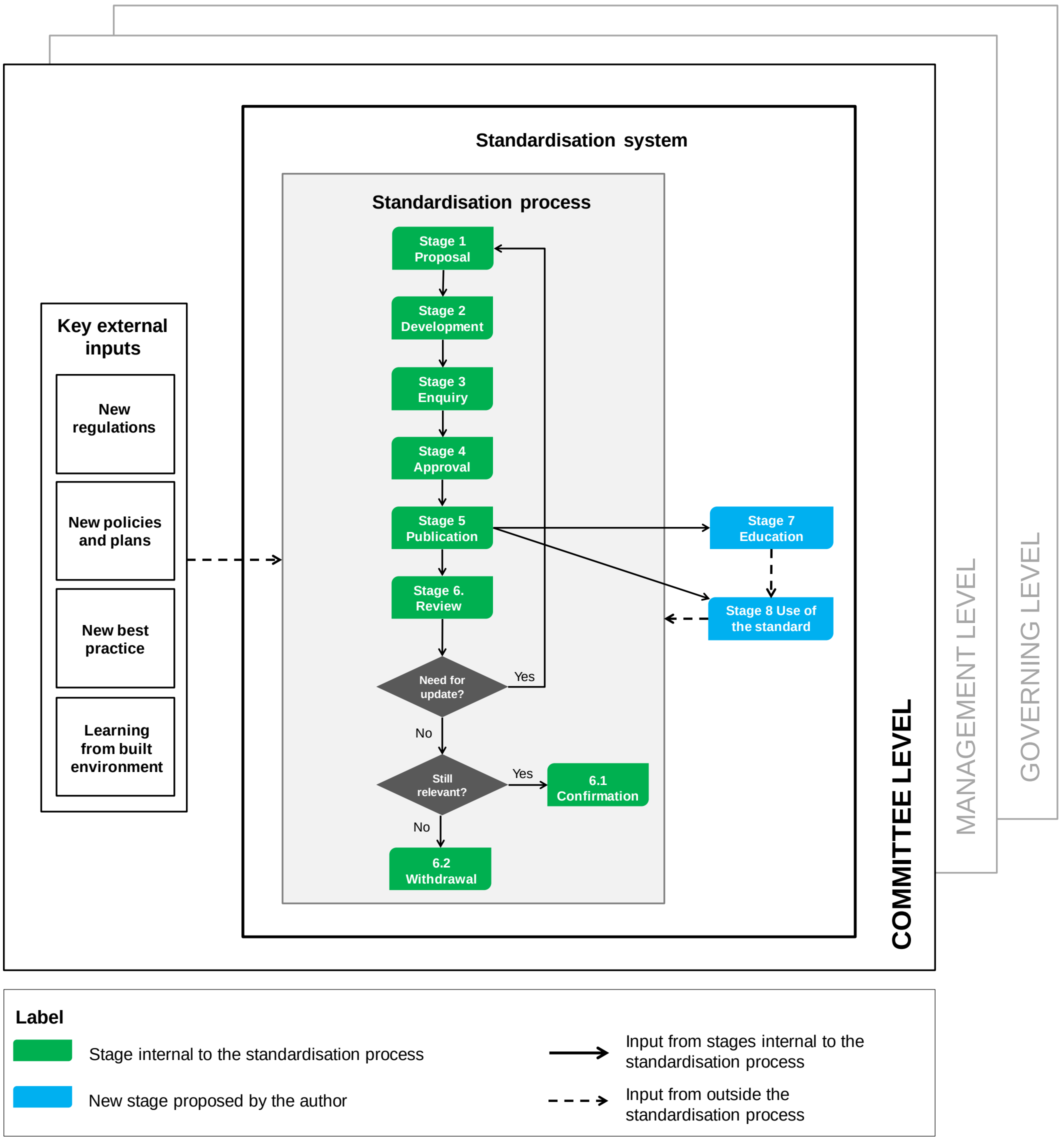

Figure 2.3 Reference standardisation model for formal standards

2.4 Other types of standardisation documents

2.4.1 Technical Specifications and Technical Reports

Formal standards are only one of the types of standardisation documents which are developed by ISO and CEN. Other publications include Technical Specifications and Technical Reports (ISO/IEC 2018; CEN/CENELEC 2017a).

A Technical Specification (TS) is a document that addresses work still under technical development, or where it is believed that there will be a future possibility of agreement on an ISO or CEN formal standard, but for which at present there are specific reasons precluding immediate publication as a formal standard. It is worth noting that the Technical Specifications presented in this section are not the technical specifications discussed in Section 2.3.2.1, which are an example of a formal standard. A Technical Report (TR) is a document containing informative material not suitable to be published as an ISO or CEN formal standard or a Technical Specification.

Technical Specifications and Technical Reports have the following features in common with formal standards: initiation by a technical committee; participation through national delegations; wide interests represented; approval by national members. In contrast, there are some key differences which are summarised in Table 2.2.

Table 2.2 Comparison among formal standards, technical specifications and technical reports

	ISO standard	ISO/TS	ISO/TR	EN	CEN/TS	CEN/TR
Standstill	Not relevant	Not relevant	Not relevant	Yes	No	No
Public enquiry	Yes			Yes	No	No
Voting policy	Two-thirds majority vote of the P-members voting is in favour, and not more than one-quarter of the total number of votes cast are negative.	Two-thirds majority vote of the P-members voting.	Simple majority vote of P-members voting.	Weighted vote: 55% or more of the votes cast are in favour and the population of the countries of the Members having voted positively reaches 65% or more of the population of the countries of all Members having voted.	Weighted vote (same as EN)	Simple majority
Publication and implementation	International standard that can be made national at discretion of the NSB.	Not relevant	Not relevant	EN becomes National Standard.	Optional	Optional
Withdrawal of national conflicting standards	Not relevant	Not relevant	Not relevant	Yes	No	No
Competing documents	Competing formal standards are not permitted.	Competing technical specifications offering different technical solutions are possible, provided that they do not conflict with existing International Standards	Not clarified in ISO/IEC Directives Part 1, 2018	Competing formal standards are not permitted.	Competing technical specifications may be developed.	Not clarified in CEN/CENELEC Internal Regulations Part 2, 2017
Review	At least every 5 years	At least every 3 years	Not specified, but should be reviewed regularly. Not subject to systematic revision.	At least every 5 years	At least every 3 years	Not specified, but should be reviewed regularly

2.4.2 PAS

Another type of standard publication developed by ISO and BSI is the PAS[1], which is a document published to respond to an urgent market need. A BSI PAS has the following features, which distinguish it from formal standards (from PAS 0:2012):

- Financial sponsorship by one or more parties which are indicated as the "sponsor" and have a particular interest in that standardisation area.
- Client-driven development process.
- Dedicated BSI project manager.
- Rarely a collective effort, often the result of the work of a single technical author.
- Steering group of experts, which is created to resolve conflicting views, both amongst its own members and in the case of any that arise from public consultation.
- Review panel made up of interested parties drawn from those stakeholders identified by the steering group as having expertise and a close interest in the subject matter.
- Sponsor invited to endorse the final draft.
- Short initial lifespan (usually two years) followed by a formal review, which can result in minor amendments, major revisions, or the PAS to be converted into a formal standard.

A PAS has the following features in common with formal standards:

- A PAS can be a specification, a code of practice or a guide (see Section 2.3.2).
- Public consultation is undertaken, usually of shorter duration than for a formal standard, and targeted at a selected review panel and those who expressed interest in the PAS.
- The principle of consensus applies. The steering group resolves comments arising from public consultation in order to achieve the consensual basis on which the final document is published.

Figure 2.4 compares the stages of standardisation of a BSI formal standard with a PAS.

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[1] Initially called "Publicly Available Specification", today the acronym PAS is preferred as not all PAS documents are structured as specifications (PAS 0:2012).

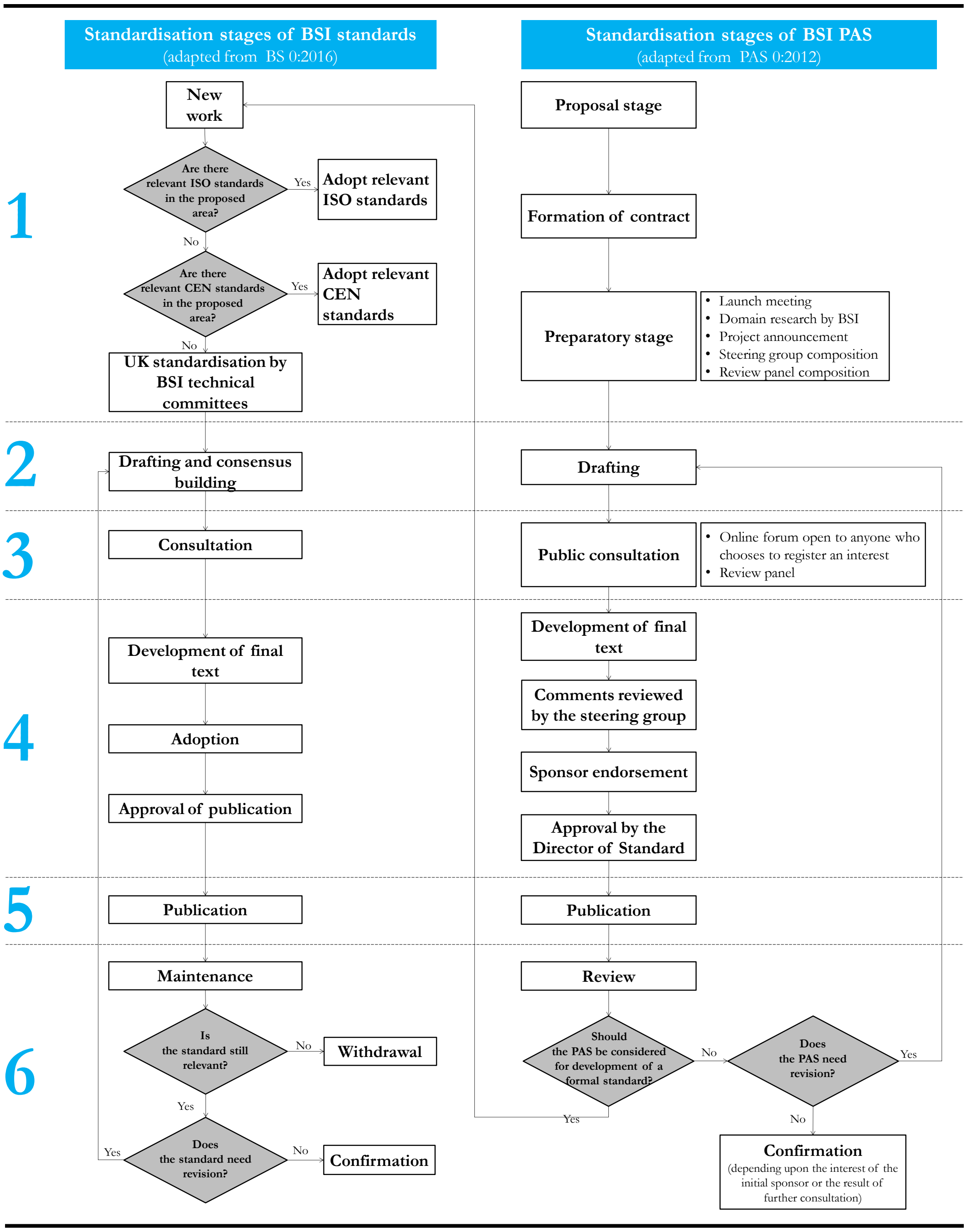

Figure 2.4 Stages of standardisation for a BSI formal standard and a PAS

2.5 *De facto* standards

Standards can also be developed unilaterally by non-recognised bodies[2] such as companies, client organisations or industry bodies. Such proprietary documents, when widely accepted and used in the marketplace, constitute *de facto* standards. Examples of UK *de facto* standards are the Design Manual for Roads and Bridges developed by Highways England (http://www.standardsforhighways.co.uk/ha/standards/dmrb/index.htm) and the technical standards developed by Network Rail.

De facto standards differ from formal standards in the following ways.

1. They are not developed by a recognised body (see Section 2.3.3). They are meant to be aligned with the business objectives of the organisation, and represent specific organisations' interests and needs.

2. The development of *de facto* standards is not bound by the principle of consensus (see Section 2.3.4). *De facto* standards are not required to meet the principles of full stakeholder engagement and open public consultation that characterise formal standards.

3. The governance process of *de facto* standards generally differs from that of recognised bodies (see Section 2.3.5) and depends on the specific organisation.

4. In principle, the six stages of standardisation (see Section 2.3.6) are also relevant to *de facto* standards. However: authorship is generally individual rather than collective through committee work (stage 2); consultation is not as public and extensive as for formal standards (stage 3); formal vote is not undertaken (stage 4); review process after publication may not be as systematic as for formal standards (stage 6). A reference standardisation model for *de facto* standards is represented in Figure 2.5.

5. *De facto* standards are typically implemented as a contractual condition imposed by a client on a supplier and are therefore effectively mandatory in their application. Formal standards may be used in the same way by the supply chain, but as they are openly available (rather than proprietary) publications, organisations may choose to implement them for their own business purposes voluntarily.

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[2] See Section 2.3.3 for a definition of recognised bodies.

6. *De facto* standards are generally characterised by an additional stage called derogation process (also known as deviation, departure or concession), which allows users to derogate from specific requirements contained in the document provided that a justification is given (see Figure 2.5). The submission of a departure from a *de facto* standard is made by users, evaluated by the client organisation, and approved or rejected as relevant. It is worth noting that, as formal standards are not regulatory requirements in the UK, a derogation may be negotiated in a contract between a client and a supplier in the same way. This however is not as common as with *de facto* standards.

7. Organisations often commission external technical authors to develop *de facto* standards.

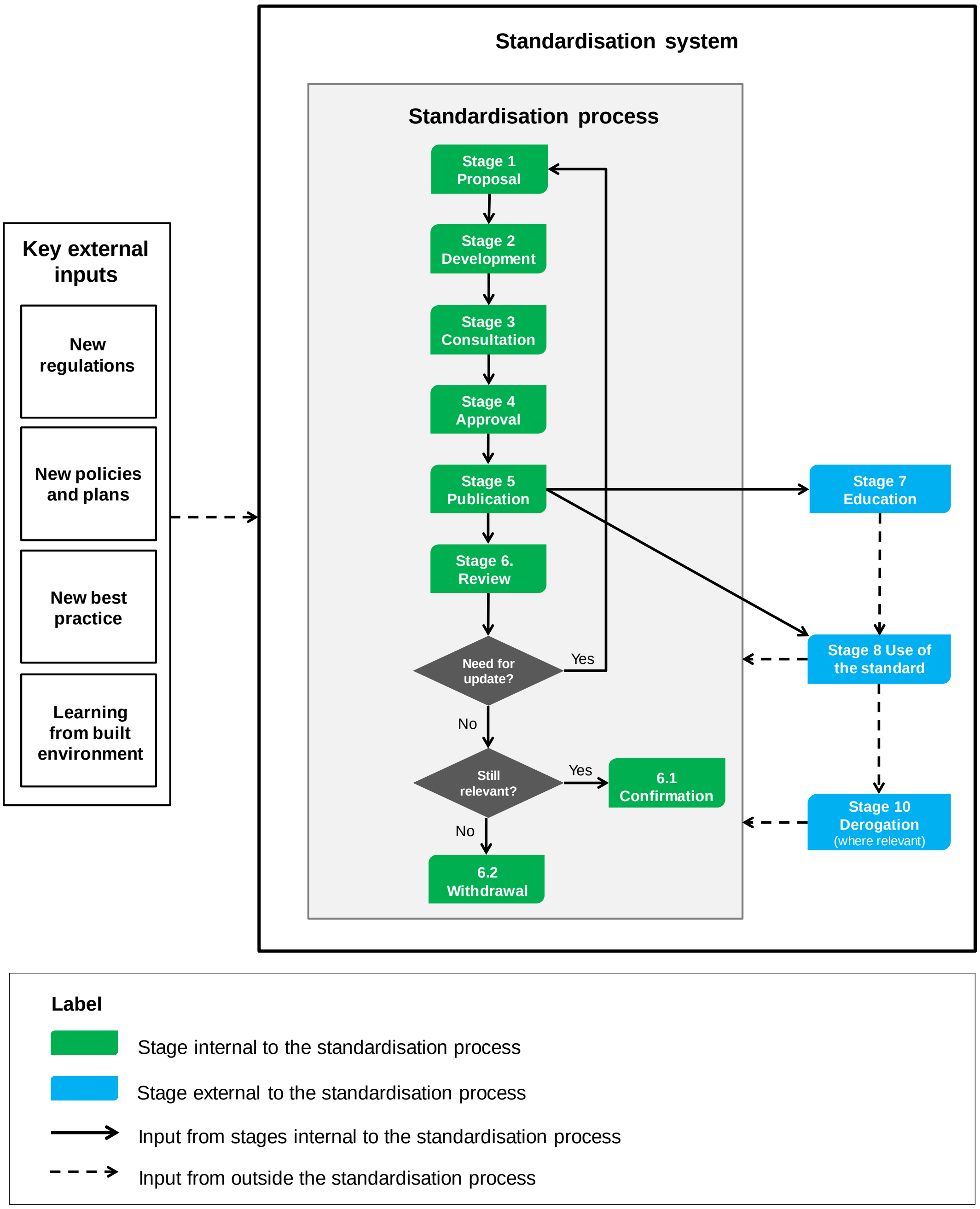

Figure 2.5 Reference standardisation model for *de facto* standards

2.6 Digital transformation

Most standards bodies and their committees use Microsoft Word as their authoring platform. For decades the workflow used for publication has simply converted Word files into PDFs. Over the last few years an increased interest has been demonstrated by standards organisations to improve their own publication processes and try to have multiple output formats, not just PDF, but also extensible mark-up languages such as HTML, XML and EPUB (this is used for eBook readers).

In 2010, ISO started a project together with Mulberry Technologies, Inc., to develop a derivative of the Journal Article Tag Suite[3] (JATS) to be used for ISO standards. This was called the ISO STS, which is the Standard Tag Set (see https://www.iso.org/schema/isosts). ISO STS was issued in 2011 and started to be used by organisations to develop their own XML models. To harmonise approaches and improve interoperability, ISO STS was "standardised" and an official relationship with JATS was created. The result of this project was ANSI/NISO Z39.102-2017, a standard for XML mark-up of standards that can be used to publish and exchange full-text content and metadata of standards.

Compared to PDF formats, XML supports rich metadata structures, Digital Object Identifiers (DOIs) to link standards, and features for adoption of content by different standards organisations. It provides the platform for a more dynamic user's experience from the information provided in the standard, and better accessibility of the content through online browsing. Examples of standards products that are based on XML and have added functionality to support users are the BSI's Eurocodes PLUS and Compliance Navigator products.

Eurocodes PLUS has been developed to make it easier and quicker to navigate the Eurocodes, associated National Annexes, relevant Test and Execution Standards, and British Standards, by means of hyperlinks and facilitated move from PDFs to HTML files documents, while giving simultaneous user access to share information among team members. The BSI's Compliance Navigator is used to manage UK and EU regulatory information for Medical Device and In Vitro Diagnostic products. It contains over 3,000 standards, easy to search and with multi-user access, and provides notifications of upcoming changes and expert commentary to give context and guidance.

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[3] JATS is an internationally-recognised standard for full text tagging of journal articles. It is characterised by a robust model for bibliographies and reference lists.

CEN/CENELEC (2017b) has recently adopted a "Strategic Plan for Digital Transformation" to reinforce standardisation as a catalyst in the digital economy. The Plan is being implemented through four key pilot projects (CEN/CENELEC 2017c) covering: (1) online standards development to facilitate collaboration among all relevant parties and be adaptable to new digital practices; (2) characterisation and implementation of 'standards of the future' including to deliver XML-format and machine-readable standards; (3) establishment of strategic alliances through a formal engagement strategy; (4) identification of opportunities to support the uptake of open source innovations.

2.7 Standards and regulations

The distinction between standards and regulations is often overlooked as noted by Foliente (2000). Nethercot (2012) recognised that "the perception of their legal standing [the legal status of codes] is even more wide-ranging (and often misunderstood), with structural engineers often believing codes to be more influential than is actually the case". It is therefore important to make a clear distinction between standards and regulations because of their different connotation from a legal point of view.

Regulations are purely legal documents and provide binding legislative rules (ISO/IEC GUIDE 2:2004, 3.6). Coeckelbergh (2006) argues that regulation is "a conduit to inject wider societal expectations into the practice of the profession" as it provides "a floor to performance". He also notes that regulations reduce uncertainty for engineers, who are not expected to think about risks and how society perceives them. Regulations can be issued at European, national or local level. In contrast, standards are by definition voluntary documents and "there is no obligation to apply them or comply with them" (BS 0:2016). Standards are always subordinate to the law and should not provide requirements imposed by legislation (BS 0:2016).

However, standards can be cited or referencedby regulatory instruments as technical means by which public policy goals and objectives (either at European, national or local level) can be reached. In doing so, their status can change. Specifically:

- where a regulation states that "the only way" to meet its requirements is to comply with a specific standard, the standard becomes mandatory and its application compulsory to meet the regulatory requirements. In such a case the standard is an "exclusive" reference document (ISO/IEC GUIDE 2:2004);

- where, instead, a regulation states that "one way" to meet its requirements is to comply with a specific standard, such a standard assumes the form of "deemed-to-satisfy" document providing a means of compliance with the regulatory requirements. In such a case the standard is an 'indicative' reference document (ISO/IEC GUIDE 2:2004).

Legal boundaries are a significant aspect for the implementation of a standard. Standards' writers must be conscious of the legal regulatory system existing in the country where the standard is expected to be enforced to ensure that standards achieve their full practicality.

2.8 Standards in the European construction industry

The construction industry is a wide sector, which comprises "all those organisations and persons concerned with the process by which building and civil engineering works are procured, produced, altered, repaired, maintained and demolished. This includes companies, firms and individuals working as consultants, main and sub-contractors, material producers, equipment suppliers and builders' merchants. The industry has a close relationship with clients and financiers" (Definition agreed at the First Conference of CIB TG 29 (1999) on Construction in Developing Countries, reproduced from Hillebrandt 2000).

Due to its size, it is thus not surprising that this industry relies upon a large number of standards, which cover three areas (Centre for Economics and Business Research 2015): (1) construction contracting; (2) construction products; (3) construction services. Typical standards used in the construction industry for each area are summarised in Table 2.3. The focus of this thesis is on standards for construction services and specifically design standards, which are presented in the next section.

Table 2.3 Typical standards used in the construction industry

Area	Typical standards covered
Construction contracting	Standards in this category provide requirements and advice on the construction of buildings and infrastructure. These include: - Health and safety standards such as ISO 45001 on "Occupational health and safety management systems - Requirements". - Execution standards, i.e. standards giving technical provisions for the execution of construction works such as EN 13670 "Execution of concrete structures" and EN 1090 "Execution of steel structures". - Quality management standards (e.g. ISO 9001), which are increasingly being adopted by companies to demonstrate their commitment to quality management (Centre for Economics and Business Research 2015). - Environmental standards (e.g. ISO 14001). - BIM standards such as PAS 1192-2 "Specification for information management for the capital/delivery phase of construction projects using building information modelling".
Construction products	Standards in this category provide requirements and advice on the manufacturing of products relevant to civil and structural engineering works. These include: - Material and product standards, i.e. those specifying requirements to be fulfilled by a product such as concrete, steel, timber or a group of products, to establish its fitness for purpose (ISO/IEC Guide 2:2004, 5.4) - Test standards, i.e. "those concerned with test methods, sometimes supplemented with other provisions related to testing, such as sampling, use of statistical methods, sequence of tests" (ISO/IEC Guide 2:2004, 5.3) - Environmental standards (e.g. ISO 14001)
Construction services	- Standards in this category provide requirements and advice on services typically provided by engineers and architects. These include design standards (see next section).

2.9 Design standards

Design standards are a specific group of documents in a vast realm of publications relevant to the design, execution and management of civil and structural engineering works.

2.9.1 Definition, subject and content

For the purpose of this thesis the following definition of design standard is used:

> Document, approved by a recognised body, that represents the highest expression of professional consensus on technical requirements for the design and assessment of civil and structural engineering works so that they exceed a minimum threshold for safety, serviceability, economy and durability.

This definition combines the ISO definition of standards given in Section 2.3.1 with the definition of design standards provided by Galambos (1992). It is worth pointing out that this definition refers to both design and assessment (load rating) requirements.

The subject of design standards is design and assessment of common civil and structural engineering works, i.e. assets or constructed facilities. These include buildings, bridges, geotechnical structures. Special engineering works such as nuclear plants are not considered in this thesis as they require a specific treatment. For example, following rules and guidelines for the structural design of nuclear plants is generally necessary but not sufficient to meet the ALARP (As Low As Reasonably practicable) principle, which requires to demonstrate the tolerability of risk from nuclear power stations, specifically that cost of risk reduction and further safety improvements are disproportionate to the benefits that may be achieved.

Design standards are generally made up of core content (technical provisions, equations, figures, diagrams, tables, etc.) organised into the main text (summary, introduction, scope, definition of terms, sections) and annexes.

2.9.2 Requirements and advice

Technical provisions are generally differentiated into *requirements* and *advice* according to whether they are exclusive (i.e. mandatory) or indicative (i.e. optional) respectively. Requirements convey criteria to be fulfilled when adopting that specific standard, whereas advice gives optional provisions, which can be expressed as background information, commentary to specific requirements, or best practice (ISO/IEC GUIDE 2:2004, 7.5).

There are two main ways in which requirements can be specified: (i) in terms of specific materials, procedures, methods or activities; (ii) in terms of general principles, desired quality levels or performance objectives of the finished work. Following this distinction, requirements can be classified into “method-based requirements” (also called “prescriptive requirements”) and “performance-based requirements”.

2.9.3 Structure and presentation

The structure of a design standard typically follows either a structure-type (e.g. design standard for bridges and buildings) or a material-type (e.g. design standard for concrete and structures). For example, the Structural Eurocodes give specific technical provisions according to structural materials (see EN 1992 for concrete, EN 1993 for steel, EN 1994 for composite concrete and steel structures, etc.), whereas the American AASHTO standards are organised according to the structure-type (see AASHTO HB 17-1-4 Design of Foundations, AASHTO HB 17-1-6 Design of Culvert, etc.).

Presentation follows the editorial style chosen for that specific standard according to the internal rules of the organisation responsible for its development. For example, the Eurocodes use a single column format, which contains both requirements and advice, whereas AASHTO standards use a double column format with main text on the left column and related commentary on the right column.

2.9.4 Stakeholders and specific users of design standards

Standardisation aims at defining agreed outcomes among all those likely to be influenced by them, i.e. the stakeholders. Engaging stakeholders is a fundamental aspect of standardisation. A BSI report (2013) emphasises the importance of the collaborative effort among experts and stakeholders on the knowledge-creation process in standards. Wider consultations generally provide a mechanism to involve as many stakeholders as possible (see Stage 3 in Section 2.3.6).

Key stakeholders in the standardisation process of design standards include: designers, standards' writers, clients, contractors, industry bodies, professional institutions, research organisations, universities, learned societies, educators, software producers, regulators, certification bodies, and lawyers. They may have different interests in design standards. For example: designers use them for structural analysis and verification; clients to stipulate their requirements; researchers to disseminate research outcomes; educators to extract key notions to present to students. Designers and clients are key users of design standards and represent the focus of this thesis. For clarity, users of the constructed facilities are not considered under the term "users".

2.10 Hierarchy of design documentation in the UK construction industry

Technical requirements and supporting advice for the design of common civil and structural engineering work can be set out in different documents and at different levels (see Figure 2.6).

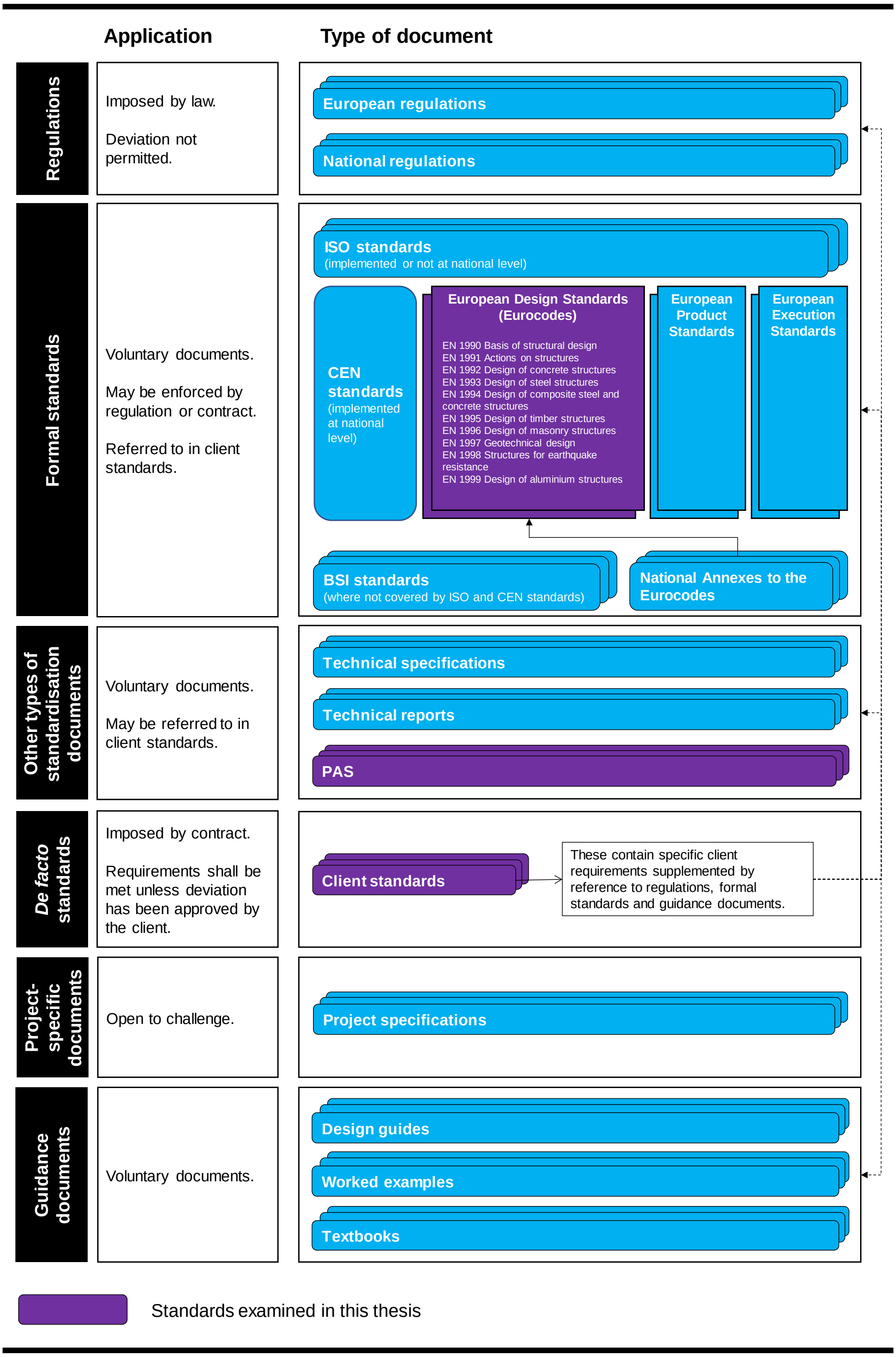

Figure 2.6 **Documentation for design and assessment of civil and structural engineering works in the UK**

Regulations provide a minimum fixed level of mandatory requirements, which are not subject to derogations. Requirements and advice contained in International, European and national formal standards (see Section 2.3 for the link between BSI standards and ISO and CEN standards) may be required by regulatory instruments (see Section 2.7), prescribed by contracts or referred to by *de facto* standards.

In the European construction industry, the Structural Eurocodes represent the main suite of standards for civil, structural and geotechnical design. They are made up of 10 Standards (EN 1990 to EN 1999), which together comprise 58 parts. The Eurocodes can be adapted by each Member State through National Annexes (NAs), which are developed by the National Standards Bodies. The NAs can only contain parameters related to matters that are left open to national choice and vary from State to State. These parameters are called Nationally Determined Parameters or NDPs. In the majority of cases, the Eurocodes give recommended values to assist standards writers of NAs and promote consistency across different Member States.

The Eurocodes also serve as reference documents for the following purposes:

- as a means to prove compliance of building and civil engineering works with the basic requirements of the EU Construction Products Regulation (CPR) No 305/2011;
- as a basis for specifying contracts for construction works and related engineering services in accordance with Directive 2014/24/EU (Public Procurement Directive) and Directive 2014/25/EU (Directive on services in the internal market);
- as a framework for drawing up harmonised technical specifications[4] for construction products.

Under the Public Procurement Directive, it is mandatory that all public works are designed to the EN Eurocodes, unless an alternative design approach is demonstrated to be technically equivalent to an EN Eurocode solution. In practice, this means that there is little option but to use the EN Eurocodes in the European construction market.

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[4] Harmonised European Standards provide a common language to express technical requirements and declare product performance. For construction products that are not covered or not fully covered by a harmonised standard, a European Technical Assessment is issued on the basis of a European Assessment Document.

For the design and construction of buildings and other civil engineering works, the Eurocodes are intended to be used in combination with execution, material, product and test standards (see Table 2.3 for a definition).

Client (*de facto*) standards contain client requirements (see Section 2.5), which in turn can make reference to national or international regulations, and/or to international, European and national formal standards, and/or other types of standardisation documents such as PAS (see Section 2.4). They are enforced by contract and can be subject to deviation where approved by the client (see "departure from standards" process introduced in Section 2.5).

Project specifications are contract documents between the designer and client setting out client requirements relating to a project. As such, they are generally open to variation subject to the necessary agreements. Finally, guidance documents provide supporting information contained in designers' guide, worked examples, and textbook material. They are developed by trade associations, professional institutions or the academia to help achieve an agreed level of good practice or quality. Guidance documents are voluntary documents unless explicitly required in client standards or in the contract.

Figure 2.6 also shows the design standards examined in this thesis within this vast realm of design publications.

2.11 Conclusions

Standardisation aims at promoting efficiency, consistency and value for money. It puts a strong focus on stakeholders and on building consensus among them. Formal standards are developed by recognised bodies such as ISO, CEN and BSI, which work in close cooperation to enable a coherent and consistent set of consensus-driven standards to be created. They are managed in an independent and neutral way through governance processes, which are typically structured around technical committees, managing bodies and governing bodies. Over the last decade significant effort has been put to digitalise standards developing XML, machine-readable standards. XML enable multiple output formats to be extracted, richer metadata structures to be supported, and enhanced users' experience through the provision of additional online functionalities.

Codes of practice, specifications and guides are all formal standards. The difference between them resides in the focus of the document, be it a set of recommendations reflecting good practice, detailed technical requirements, or general guidance on a specific subject. Other types of standardisation documents exist alongside formal standards, such as technical specifications, technical reports and PAS. A distinction needs to be made between formal standards and *de facto* standards. The latter are not developed by a recognised body, but rather by companies, client organisations or industry bodies, and generally are not consensus-driven documents. Importantly, derogation from requirements contained in *de facto* standards is allowed through a specific process called deviation, departure or concession, provided that the client organisation approves it.

Another important distinction needs to be made between standards and regulations. Standards are not regulations, but rather voluntary documents. However, they can become compulsory where referenced by regulations "exclusively", or can be used as deemed-to-satisfy documents where referenced by regulations "indicatively". Moreover, standards can become mandatory where required by contract or referred to in client standards.

Design standards are part of a wider family of publications relevant to the design, execution and management of common civil and structural engineering works, specifically those related to "construction services". They represent the highest expression of professional consensus on technical requirements for the design and assessment of civil and structural engineering works so that they exceed a minimum threshold for safety, serviceability, economy and durability. In the European construction market, the Structural Eurocodes represent the main suite of standards for civil, structural and geotechnical design.

The design of civil and structural engineering works requires designers to apply a variety of documents, which have different legal force ranging from documents imposed by law (such as regulations) to documents imposed by contract, which could include formal or *de facto* standards, and include project specifications and guidance documents. Design standards are applied by a variety of different users. Designers and clients are key users of design standards and represent the focus of this thesis.

Chapter 3

Research gaps in design standards' quality

3.1 Introduction

> "To design for better quality, it is necessary first to understand what quality means and then how it is measured". (Wand and Wang 1996)

Design standards play a fundamental role in the construction industry and it is reasonable to ask whether enough attention is paid to their quality. This issue is examined in this chapter, which presents a critical review of the state-of-the-art of academic and industrial research on the concept of quality applied to design standards in the construction industry.

The state-of-the-art of the concept of quality is examined in Section 3.2. The concept of quality applied to standards in general is presented in Section 3.3. The concept of quality applied to design standards in the construction industry is explored in Section 3.4. Debates held in professional organisations in the last forty years have been reviewed to find out specific concerns and expectations of practitioners, clients and industry bodies on what good standards should provide. Contributions from experienced designers generally involved in standardisation committees have also been presented. Conclusions are drawn in Section 3.5.

It is worth highlighting that the literature presented in this chapter focuses on the concept of quality. Yet, other research areas have also been examined and are discussed in the following chapters as relevant.

3.2 The concept of quality

Quality is an essential property of all systems and is the most studied “ility” (i.e. desired property of a system) in engineering (De Weck et al. 2011). Over the centuries the concept of quality has acquired multiple definitions as illustrated in Table 3.1. Some of the definitions focus on the quality of manufactured products (e.g. “quality as conformance to specifications”); some others focus on the quality of services and have customers or users as a focal point (e.g. “quality as meeting and/or exceeding customers’ expectations and needs”).

None of these definitions is perfect as acknowledged by Reeves and Bednar (1994). However, two clear conclusions to be drawn from the review of literature on quality are that (i) quality depends on the specific purpose that the artefact is expected to fulfil and (ii) it is generally evaluated against customers’ needs. Clarity of purpose and understanding of the users’ perspective are thus crucial.

Table 3.1 Definitions of quality

Definition	**Context**	**Source**
Quality as excellence	Quality in an absolute sense.	Greek philosophers
Quality as value	“Quality does not have the popular meaning of best in any absolute sense”. It depends on the actual use and on the product cost, which are both important in customers’ decisions.	Feigenbaum (1951); Abbott (1955)
Quality as conformance to specifications (or specific requirements)	This derived from the manufacturing industry. “If parts did not conform to specifications, they would not be interchangeable”, meaning the failure of the production system.	Levitt (1972); Crosby (1979)
Quality as freedom from deficiencies	This derived from the manufacturing industry.	Juran and Godfrey (1999)
Quality as meeting and/or exceeding customers’ expectations and needs, and providing customers’ satisfaction	This derived from the service marketing literature. Quality is evaluated from customers’ perspectives. Externally focused definition of quality.	Parasuraman et al. (1985); Juran and Godfrey (1999)
	Quality as “the totality of features and characteristics of a product or service that bear on its ability to satisfy stated or implied needs”.	ISO 8402:1994
The artefact or system is well made to achieve its function	Quality is evaluated from a functional perspective.	De Weck et al. (2011)
Quality as fitness for use/purpose	“The extent to which a product successfully serves the purposes of the user”.	Juran and Godfrey (1999)
	Quality is evaluated by looking at the purpose that specific product or service is expected to fulfil.	Blockley and Godfrey (2000)

3.3 Quality of standards

Although standards and standardisation processes are widely studied, what makes a standard 'good' or 'bad' is a problem that has been rarely investigated. In the last 30 years the research in the standardisation sector has primarily focused on specific research topics (Swann 2010). These include: the relation between standardisation and regulation, benefits and impact of standards and standardisation, barriers to standardisation, link between standardisation and innovation, stakeholders' engagement, standards and interoperability. Recent trends in standardisation research include: standardisation in developing countries (Zoo and de Vries 2014); standards and intellectual property rights (IPRs) (Torti 2016); multi-mode standardisation (Wiegmann et al. 2017), which combines committee-based, marked-based and government-based standardisation.

Most of the guidance on how to develop standards produced by standards organisations acting at international or national levels (ISO/IEC Directive 2016a, 2016b; BS 0:2016) seems to focus more on the quality of the standardisation process in terms of defining administrative aspects related to layouts and formats, establishing responsibilities for the technical work, having in place effective governance policies, clarifying the stages needed for the development of the standard, and ensuring that consensus among stakeholders is achieved (see Chapter 2). These are necessary aspects to ensure a good standardisation process. Yet, concerns expressed in meetings, workshops and discussions by designers and clients on the current generation of standards show that these aspects may not be sufficient for the development of good design standards and some extra factors should be brought in to develop better design standards.

Furthermore, academic research on standardisation seems to focus mainly on some specific sectors, such as information and communication technology (ICT). Indeed, the only journal existing on standardisation, *The International Journal of IT Standards and Standardization Research*, was historically targeted to ICT. Only in 2015 the journal broadened its coverage to include standardisation in all fields.

Not surprisingly the first attempt to define the quality of a technical standard was in the ICT sector by Sherif et al. (2005). They argued that providing a definition of quality relevant for standards is a complex task due to the involvement of many stakeholders, who state different requirements or have different objectives. They also noted that "business considerations, social interactions, ideological principles" exert a strong influence on the development of standards, thus making this a complex process.

3.4 Quality of design standards

If the concept of quality applied to standards is poorly defined as noted above, what characterises a good design standard in the construction industry is even less clear. Indeed, the focus of standardisation research in the construction industry seems to be on health and safety procedures and quality management, particularly for construction products and materials, and for the reduction of waste (Centre for Economics and Business Research 2015).

A few publications exist on the technical basis for new standards as part of the support for their introduction, for example the designers' guide series related to the introduction of the Structural Eurocodes (Gulvanessian et al. 2002, for EN 1990; Hendy and Smith 2007, for EN 1992-2; etc.). Nethercot (2012) noted that effort has also been put on suggesting improved formats and different approaches. However, very limited literature is available on the characteristics of good design standards. The existing contributions were typically stimulated by professional associations and were produced by experienced designers generally involved in standardisation committees.

In 1981 an open debate was held at the Institution of Civil Engineers (Moffatt and Dowling 1981). It stemmed from the question "*How should rules of structural design be codified?*" formulated by Moffatt and Dowling (1980). One year later, an open discussion (Sunley and Taylor 1982) was held at the Institution of Structural Engineers. This stemmed from the statement "*Simple codes can stifle structural technology*" proposed by Sunley and Taylor (1981). Contributions to these two debates were received from universities, standards organisations, consulting firms, national departments, research organisations and practitioners.

From the analysis of these publications four key aspects affecting the quality of design standards emerged.

- First, clarity of purpose / role emerged as a crucial step to develop good design standards. There did not appear to be an agreement among participants on their roles, which in turn affected their expectations on what a design standard should provide.

- Second, the importance of considering users' expectations and skills more explicitly was acknowledged. A variety of different users exists and writing a perfect code addressing all their needs, although highly desirable, was considered unachievable. Developing user-orientated standards seems to be a subject area almost totally unexplored in literature. Only one guideline (International Federation of Standards Users 2008) is available to assist standards' writers in preparing user-orientated standards. Whilst this provides a useful list of general principles, there is very little guidance on how the principles proposed should be converted into specific actions for standard makers to ensure that the application of these principles can lead to user-orientated standards, and how to assess the usability of the standard produced.
- Third, participants to the debates (Moffatt and Dowling 1981; Sunley and Taylor 1982) listed a number of aspects having a negative impact on design standards. These include: (i) the development of more comprehensive and precise codes which contain "too much peripheral, non-structural information" (Sunley and Taylor 1982); (ii) the intrinsic complexity of engineering products including the multiplicity of types of loading and structural systems; (iii) the conflict between economy and simplicity; (iv) the tension between current good practice and technological developments; (v) an uneven representation of experts and designers in the team of standards developers.
- Fourth, it was suggested that all standards should have an appropriate balance between "generalities of practice" and "specific design rules" (Moffatt and Dowling 1981) and it was suggested to differentiate clearly between "mandatory" and "desirable" provisions.

In 1990, Dibley[1] (1990) presented his reflections on what an "ideal code" should contain. He argued that good codes should be "easy to understand and use", "unambiguous and obvious in meaning", "clearly written and presented", "sectioned into a logical sequence" with careful consideration to "the best form of presentation and procedure", and "as short as possible". Dibley (1990) also argued that good codes should provide "only essential and very beneficial knowledge", as well as "comprehensive coverage of all structural member and loading forms". Interestingly, in his final remarks Dibley noted that code writers should give considerably more attention to the needs of the users of these documents.

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[1] Dibley has been member of some BSI (British Standards Institute) and ECCS (European Convention for Constructional Steelwork) code drafting committees for many years.

In 2012, a special issue "*Codes of Practice in Structural Engineering*" was published in Structural Engineering International (SEI). In this special issue Leivestad and Mehus (2012) expressed the need for simplification in design standards, particularly for the benefit of users. In the editorial to the special issue the vice-president of IABSE Ulrike Kuhlmann (2012) also raised the issue of simplification in modern codes of practice. While she claimed that "there is a general request for simplification of codes", she also noted that the interpretation of what is meant by simplification is very diverse according to the party involved (from "a reduction of the too-detailed application rules" to the "addition of more detailed rules for the common cases of so-called simple structures").

In his contribution to the special issue of SEI, Nethercot[2] (2012) emphasised the tension between concise and comprehensive codes, and the need to strike a balance between these aspects. Nethercot also highlighted the tension existing between simplified design approaches and more sophisticated approaches, which have a direct impact not just on design cost, but more importantly on the cost of the solution developed. Similarly, he acknowledged the tension existing between performance-based and method-based standards, and the need to understand clearly the impact these may have on design.

Nethercot also noted the lack of a holistic view in the development of codes of practice, and the need to consider their development as a generic "engineering project", which is characterised by effective stages of planning, designing, implementing and monitoring. Indeed, he argued that infrequently in the past "those responsible for a new code spent significant time and thought upfront carefully defining the precise brief and then working in a way that imposes some discipline in adhering to it".

In the UK clients and industry bodies have expressed their concerns on the current generation of design standards in the construction industry, particularly on the impact that their inconsistent use may have on the effective delivery of infrastructure projects (Industry Standards Group 2012; Wilson et al. 2015).

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[2] Nethercot has been a member of many standardisation committees at the UK and European level. His paper drew on more than 40 years' experience in structural code preparation and use.

3.5 Conclusions

While quality is a widely studied topic, what makes standards and – in particular – design standards good documents is weakly covered in literature. Despite their fundamental role, the study of design standards in the construction industry has received very limited attention by the research community and an overall re-examination of the philosophy behind their development and use is needed to understand what good design standards are and how better design standards might be realised.

As a general principle, quality should be evaluated against the specific purposes and roles of the element under consideration. However, the issue of clarity about the role of design standards appears to be a long-standing one and requires a specific study. There is not a great deal of relevant previous work to draw upon to define what a good design standard is. Understanding how better design standards can be developed is even less clear.

Assessing the quality of standards emerged as a challenging task in the ICT sector due to the multiplicity of stakeholders involved in the standardisation process and a variety of external inputs, such as business considerations and ideological principles. These issues are confirmed in the publications covering design codes and standards for the construction industry.

Developing a good design standard appears to be a complex problem affected by a variety of intertwined factors, including not just technical issues but also some significant human aspects involving users, their needs, expectations and skills. In addition, economic, social and technological aspects also exist, which affect the way standards are developed. However, a systematic review of these aspects and how they could be managed does not seem to be carried out in literature.

Research gaps have been grouped into four areas, which are explored in this thesis:

Role: A specific investigation into current and future roles of design standards is undertaken in Chapter 5.

Challenges: Challenges in development and use of design standards, their interdependences and impact, and relevant management strategies are investigated in Chapters 6 and 10 from a theoretical perspective and in Chapters 7, 8 and 9 from a practical point of view by working on real projects.

Definition: Throughout the thesis, theoretical and practical work is used to develop a definition of good design standard, particularly from a user-perspective. The findings are presented in Chapter 11.

Framework: A proposed framework that helps integrate various factors governing the quality of design standards and guide standards' writers in developing better design standards for the construction industry is presented in Chapter 11.

Chapter 4
Research methodology

4.1 Introduction

The research methodology adopted in this study emerged from the specific gaps that the research endeavors to fill (see Section 3.5). This chapter is structured as follows. Section 4.2 establishes the philosophical position of the author and the research assumptions. Section 4.3 justifies the research design applied in this thesis and discusses the research approach taken. Section 4.4 presents the role of the author as researcher. Section 4.5 establishes the criteria to assess the quality of the research and related findings. Section 4.6 discusses the ethical implications of this research.

4.2 Research philosophy and assumptions

4.2.1 A wicked problem

Literature review presented in Chapter 3 shows a variety of intertwined factors affecting the quality of a design standard, including not just technical issues but also some significant human aspects related to stakeholders and their needs. Standardisation is a social process involving a variety of stakeholders (see Section 2.6.5), who may have different interests and may judge solutions differently according to their specific needs and personal values.

As a result, the exploration of the quality of design standards should not be undertaken as a classical scientific or engineering problem such as solving equations, understanding structural behaviour, or improving the efficiency of an aircraft's engine, which typically require structural simulation models. Instead, it should be interpreted as an inquiry or "learning cycle" (Checkland 1999) to explore a complex problem.

For such complex situations Checkland (1999) argued that it is necessary to move from the "idea of an obvious problem that requires solution" to "the idea of a situation which some people, for various reasons, may regard as problematic". As discussed in the previous chapters it is difficult to define what better design standards are, thus the formulation of the problem is in itself the problem. This is a typical feature of "wicked" or "ill-defined" problems as defined by Rittel and Webber (1973).

Wicked problems are different from relatively "tame" problems. The former are characterised by a much more complex context, many interdependences and different stakeholders perspectives, which make them difficult to define and solve. Importantly, in ill-defined problems "one cannot first understand, then solve". Instead, there should be an "argumentative process" that involves participants and evolves during the research activity.

The need for a continuous feedback loop between formulating the problem and conceiving solutions has thus driven the choice of the research philosophy and the approach taken in this research as explained below.

4.2.2 Pragmatism and research assumptions

Due to the co-existence of a variety of factors affecting development and use of design standards, it was unhelpful to take one specific philosophical position such as positivism[1] or interpretivism[2] and the associated research methods. In such a wicked context, a pragmatic position has been taken. Pragmatism emphasises the importance of focusing on the research

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[1] *Positivism* or empirical science represents the worldview typical of natural scientists. The positivistic researcher is concerned with collecting data, reducing phenomena to simple elements, studying their causal relations, making reliable predictions and explanations and achieving results which are as more generalizable as possible (Gill and Johnson 2010). In other words, positivism is about factual knowledge that considers the world to be external and objective. Such knowledge is gained through observation and possible experiments, which in turn enable to develop, test, confute or confirm relevant hypotheses. Undoubtedly, taking a positivistic view enables exploration of the 'hard' (technical) aspects of the problem. Yet, it does not enable appreciation of the 'soft' (human) aspects.

[2] The term *interpretivism* comprises diverse approaches such as social constructionism and phenomenology, which "reject the objectivist view that meaning resides within the world independently of consciousness" (Collins 2010). Interpretivism assumes that reality is socially constructed and depends on social actors (Saunders et al. 2012) and the meaning that individuals give to situations. Following the interpretivist approach, the world cannot be understood by trying to identify objective causal relations since individuals act following a variety of intentions and beliefs. Undoubtedly, taking an interpretivist view would enable better exploration of this wicked situation, which is characterised by a high degree of subjectivity in both our understanding of the problem and related solutions.

problem and the research questions rather than on specific methods. Pragmatists recognise that “no single point of view can give the entire picture” (Saunders et al. 2012), therefore multiple methods may be needed and used to develop a better understanding of the problem (Creswell 2014).

A simplified research philosophy spectrum is shown in Figure 4.1. This figure assumes the research philosophy as a “multidimensional set of continua” (Niglas 2010) with positivism and interpretivism at the extremes and pragmatism in the middle. Taking a pragmatic perspective enabled both objective and subjective points of view to be adopted according to the specific aspect that the research aims to explore or address. In this study a particular emphasis has been on ‘soft’ (human) aspects, which are indicated on the right-hand side of the spectrum (see Figure 4.1). To explain and reinforce the pragmatic position taken, the four philosophical assumptions adopted in this research are presented in Table 4.1.

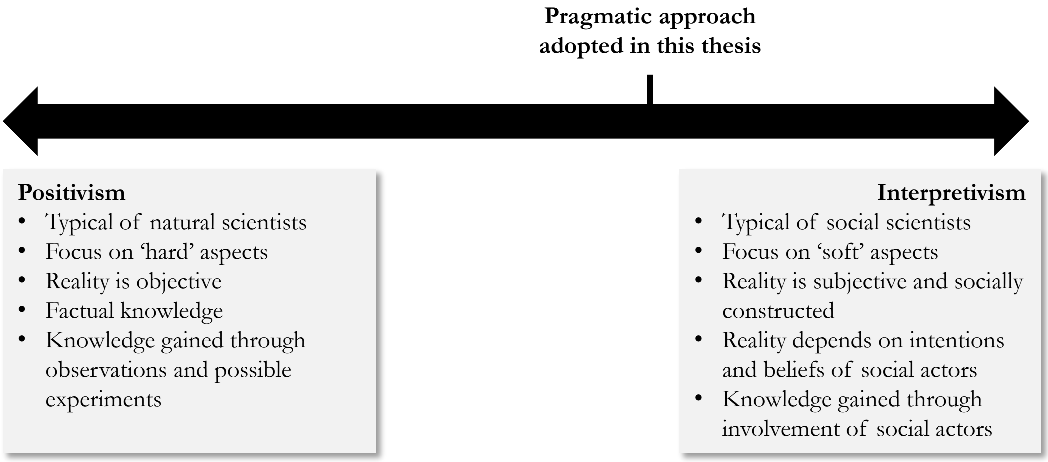

Figure 4.1 Research philosophy spectrum

Table 4.1 Research assumptions

Research assumption	Application in this research
Ontological assumption (nature of reality)	It can be argued that design standards are purely documents. They are objective entities which can be studied by looking at the correctness and completeness of information provided and, more in general, by exploring what design standards 'have'. On the other hand, design standards are the result of the socially-constructed process involving stakeholders. Individual meanings, personal views and social interpretations may influence significantly the development of the design standard itself, thus its usage. As a result, design standards can be potentially studied by taking a more subjective view and looking at what they 'are' or are meant to be to different users. In this thesis both the objective and subjective components have been considered important to answer the research questions.
Epistemological assumption (nature of knowledge)	From a pragmatic perspective, observable phenomena and subjective meanings can both provide acceptable knowledge (Saunders et al. 2012). In this research the approach taken recognises the importance of both of them, but with an emphasis on personal views and social interpretations.
Axiological assumption (what is valued or considered right)	Taking a pragmatic perspective, both objective and subjective views have been adopted. Gaining an understanding of what better design standards are requires on one hand, some intrinsic value judgments and a personal involvement of the researcher in the systems being researched (in this thesis the author as researcher actively participates with others in the exploration of the problem). On the other hand, it requires objectivity in data analysis and reporting.
Rhetorical assumption (appropriate language of research)	In this thesis the researcher's values will not be included and the content will be presented from the perspective of an observer using a formal style (passive voice, past tense).

4.3 Interpretative research design

4.3.1 Definition

The lack of plausible existing theories on what good design standards are suggests that specific effort has to be paid to define the nature of the problem itself first and then explore the strategies to develop better design standards. This theory-building exercise can be described as "interpretative research" in Braa and Vidgen's (1999) terms (see Figure 4.2).

Interpretative research generally tackles "new problems on which little or no previous research has been done" (Brown 2006). It provides the necessary flexibility and freedom to the researcher to change or adjust the direction of the research as a result of the themes emerging from the exploration (Saunders et al. 2012).

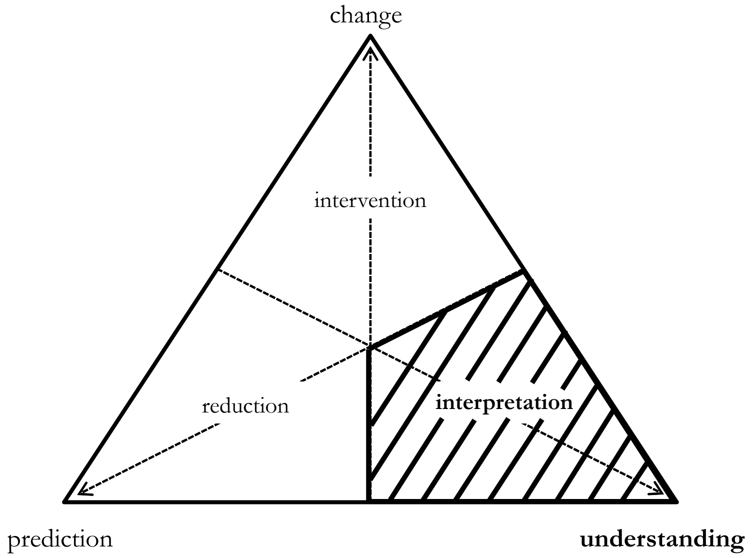

Figure 4.2 Research framework from Braa and Vidgen (1999)

In this study, both qualitative and quantitative methods (i.e. mixed methods) have been applied as required by the research stage:

(i) to investigate diverse aspects of the problem;
(ii) to integrate and triangulate results (Greene et al. 1989);
(iii) to maximise researchers' interpretations of data (also called "significance enhancement" in Collins et al.'s (2006) terms); and
(iv) to generate a picture that is as much representative of reality as possible.

A combination of inductive[3] and deductive[4] approaches has been followed to acknowledge on one hand the novelty of the research field, and on the other hand the existence of some limited insights in literature. The interpretative activities carried out in this thesis are summarised in Figure 4.3 against the steps followed and the chapters / sections where they are examined.

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[3] The inductive approach is typically associated to the interpretivist worldview and is relevant when the focus of research is a specific phenomenon, the field of interest is new and there is no theoretical framework to build upon (Saunders et al. 2012). Following an inductive approach the researcher thus will start collecting data, which will then be used to inform theory and build a conceptual or theoretical structure.

[4] The deductive approach is normally associated to the positivistic worldview and "involves the development of a theory that is then subjected to a rigorous test through a series of propositions" (Saunders et al. 2012). Deduction thus moves from theory to data, and is mostly applied when there exists a vast body of knowledge from which a theoretical framework can be inferred.

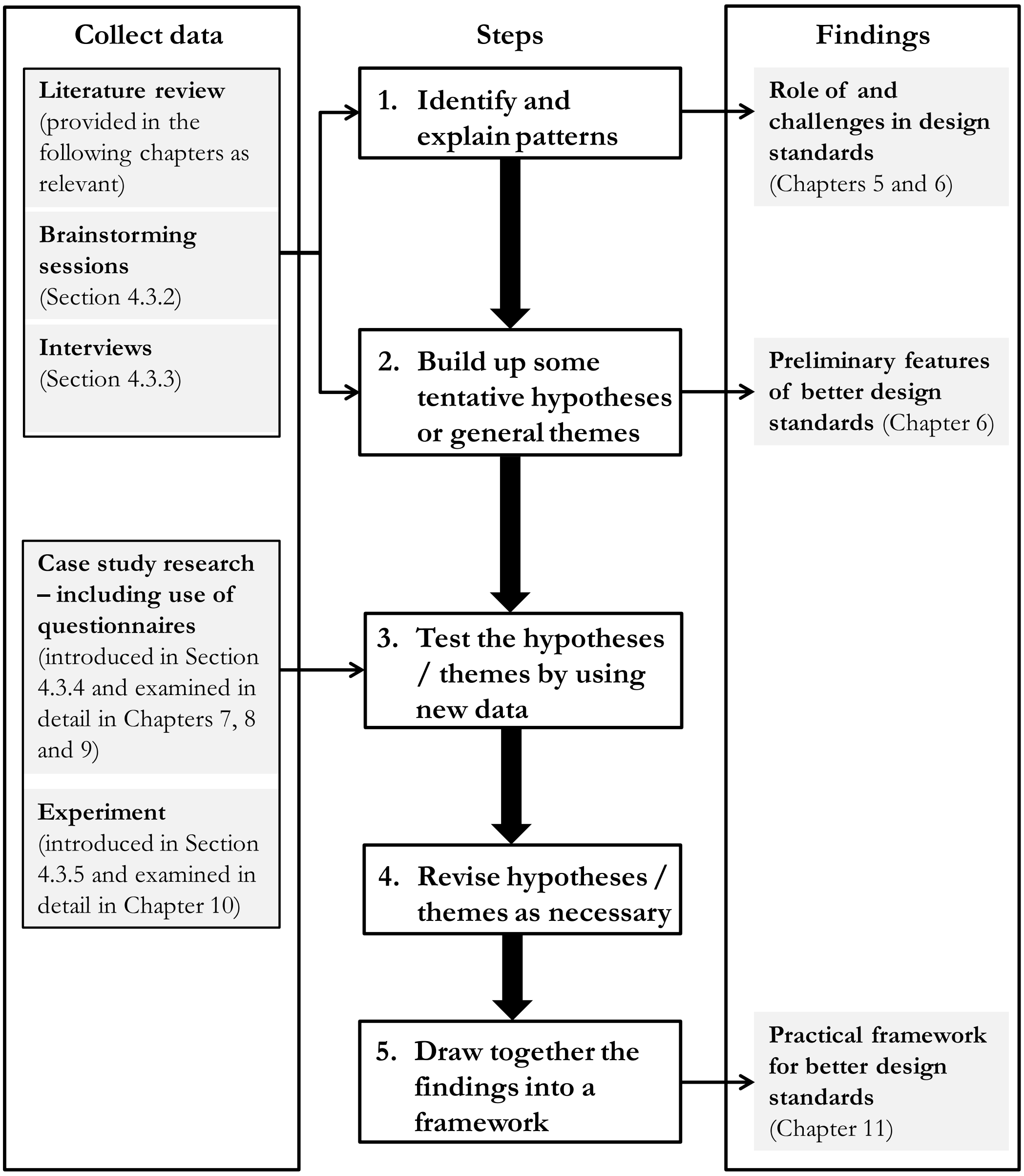

Figure 4.3 Interpretative activities carried out in this thesis

4.3.2 Brainstorming sessions

The author carried out a series of brainstorming sessions with a group of ten practicing engineers of the author's host organisation with different experience and technical expertise, i.e. civil, structural and geotechnical engineers. Specifically: 3 participants with less than 2 years of working experience (graduates), 3 participants with 2 to 4 years of working experience (assistant engineers), 3 participants with around 7 years of working experience (senior engineers) and one participant with more than 15 years of working experience (associate).

They were a selected sample of UK practitioners using design standards in their day-by-day practice. Notably, the participant with more than 15 years of working experience was also involved in standards drafting in several technical committees. While the sample size was small and limited, the aim of the brainstorming sessions was not to derive final conclusions, rather to explore themes with a limited number of subjects first and then to further investigate the results through case studies (see Section 4.3.4).

The brainstorming sessions lasted one hour each. For each session the group of participants were expected to reflect on and discuss the following themes:

1. the role of design standards and the drivers to use them;
2. the complexity of design standards (focus on the Eurocodes);
3. attributes of good design standards;
4. attributes of easy-to-use design standards;
5. attributes of effective design standards.

Participants were informed of the topic ahead of the session to accelerate the discussion due to time constraints. At the beginning of each session a rapid overview of the findings from the previous session was presented to prepare the ground for the new discussion. Brainstorming with Post-it® (Isaksen 1998) was used. It is a variation of classical brainstorming and allows group members to record their own opinions directly on Post-it® notes. The sessions were recorded with the participants' consent. After each session, the author transcribed and analysed the content of post-it notes and audio recordings. The findings of the sessions are presented in Chapters 5 and 6.

4.3.3 Interviews

The author carried out semi-structured interviews with five experts in code development. The aim of the interviews was similar to that of the brainstorming sessions, i.e. to explore themes with a limited number of subjects first and then to further investigate the results through case studies (see Section 4.3.4).

The experts were chosen for their long-standing involvement in standards development (more than 20 years, almost 40 years in one case) either at national or European level. They were internationally recognised experts for their contribution to standardisation in different technical fields (i.e. basis of design, design of concrete structures, design of steel structures, design of bridges, assessment of existing structures). The experts were selected from different European countries: two from UK, one from Italy, one from France and one from Germany. For confidentiality requirements, their names are not indicated.

Semi-structured interviews were preferred to classical structured interviews to allow new ideas to be raised during the discussion. An interview protocol was prepared based on results from brainstorming sessions and literature review. Questions were grouped into seven categories covering:

1. the state-of-the-art of design standards in general and their role;
2. typical problems experienced by users;
3. issues associated with the standardisation process;
4. attributes that make a design standard efficient, good and easy to use and related metrics;
5. the state of the current generation of the Eurocodes;
6. the risk of misinterpretation and misapplication of the Eurocodes;
7. what success and failure mean when trying to develop good design standards.

Knowledge and understanding of the experts was assessed asking general questions on the areas covered in Chapter 2 (for example the distinction between standards and regulations, the differences between different types of standardisation documents, etc.), as well as questioning about examples from their experience and the wider legal context in which they typically work.

The interviews were recorded with the consent of participants. Only one of the interviews was done using a questionnaire and completed by the participant remotely due to location constraint. After each interview, the author transcribed the content of the audio recordings and asked participants to review their responses and confirm their comments. The responses were analysed and emerging themes were identified. The findings of the interviews are presented in Chapters 5 and 6.

4.3.4 Case studies and Action Case Research

Case studies were adopted to develop a detailed contextual understanding of what better design standards are and to investigate real challenges and practical solutions of how they can be developed. The author has been involved in five live projects related to standards' development and implementation. They are summarised in Figure 4.4 along with their purpose and an indicative timeline of the work undertaken.

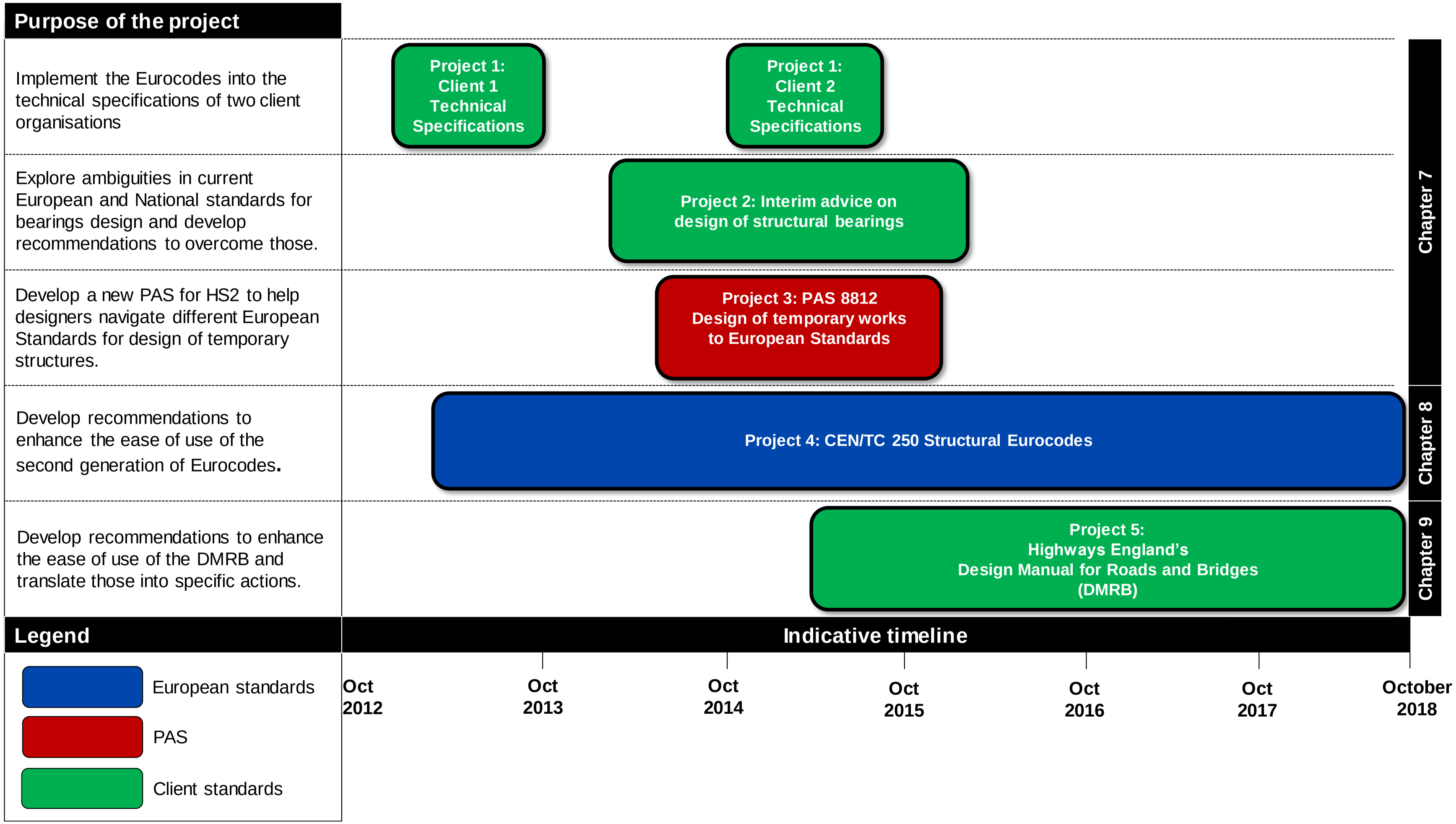

Figure 4.4 Real projects presented in this thesis

Case studies have been structured around Yin's (2009) approach for case study research:

- initial in-depth data have been collected including documents and reports, questionnaires and personal observations in workshops and meetings;
- for each project, a case description (background and methods adopted) and case-based findings or emerged recommendations have been reported in Chapters 7, 8 and 9 ("within-case analysis");
- general themes and lessons emerged from individual projects and those which transcended the cases and occurred in multiple settings ("cross-case analysis") have been extracted, examined and synthesised into the practical framework for better design standards proposed in Chapter 11.

Project 4 on the Eurocodes and Project 5 on the DMRB required repetitive spirals of observing, reflecting, planning and acting, as well as a strong focus on participation by relevant stakeholders. Arguably, this is what characterises the research methodology called Action Research, which encompasses work whereby a method is designed based on previous literature and experience, tried out, reflected upon, redesigned and assessed again (Saunders et al. 2012).

However, 'pure' Action Research could not be adopted in the Eurocodes and the DMRB projects because the projects' timeline would not allow all spirals to be completed. Strictly speaking, the full implementation and monitoring of the recommendations made as well as re-education of users, i.e. change to well-established ways of thinking and acting of individuals in Argyris et al.'s (1985) terms, would require several years.

Nevertheless, the value associated with action research being embedded in live projects adds a critical dimension to this thesis. Therefore, an adaptation of the classical action research has been adopted, that is Action Case Research. It is considered a "hybrid of understanding and change" (Braa and Vidgen 1999) suitable for researchers who work in real settings. It is "a trade-off between being an observer who can make interpretations (understanding) and a researcher involved in creating change in practice".

Action Case Research has been used for two purposes: (i) to develop practical recommendations to enhance the usability of the Structural Eurocodes and the DMRB (see Chapters 8 and 9 respectively) and create the basis for future change; (ii) to engage in the live projects as a researcher, make personal interpretations and generate new insights relevant to the research questions addressed in this thesis.

In all these projects the author has been involved in meetings and workshops with a variety of stakeholders, including designers, standards' writers, clients, researchers. The approach taken by the author has been twofold: (i) she was involved in observing participants as a spectator (i.e. as an "observer-as-participant" in Gill and Johnson's (2010) terms) and interacted with them only where necessary; (ii) she acted as a member of the group (i.e. a "participant-as-observer" in Gill and Johnson's (2010) terms). In both cases, the author clarified her identity as researcher to all participants. The learning and wider knowledge gained from being immersed and working in different standardisation settings for almost six years has been used to support the comments on current practice, which have been made in the following chapters of the thesis.

4.3.5 Experiment

An experiment has been carried out to explore a theme emerged from the case studies and literature review, that is the link between designers' skills and capabilities and how they use design standards. The aim of the experiment was to support, refute, or validate a set of hypotheses formulated from the case studies and review of literature. Ten civil engineers (different from those involved in the brainstorming sessions) with different years of working experience and design practice were selected. Details of the experiment are provided in Chapter 10.

4.4 Role of the author as researcher

In this research a combination of quantitative and qualitative methods has been employed. While quantitative studies aim to be repeatable and the researcher is typically separated from the phenomenon being researched, in qualitative studies (such as those involving interviews, workshops or observations) the researcher is immersed in the situation being studied and data are typically mediated through his or her interpretation of reality. This could potentially lead to some significant issues that need to be avoided or at least minimised. In Table 4.2, the role taken by the author as researcher is illustrated for different activities. Potential issues and actions taken by the author to minimise those are presented.

Table 4.2 Role of the author as researcher and actions taken to minimise issues

Research instruments	Role of the researcher	Potential issues	Actions adopted by the author to minimise potential issues
Brainstorming sessions	Moderator or facilitator	Dominant or monopolising behaviour	- An introduction of all participants was made at the start to acknowledge the specific contribution and experience of members. - When senior members tended to monopolise the conversation, the discussion was diverted to other people asking their opinion and moving on.
		Crowd behaviour or group-thinking	- Controversial issues and alternative scenarios were introduced to stimulate conversation and support independent thinking.
		Over/under confidence	- Over confidence was mitigated taking the same approach used to manage dominant behaviours. - Under confidence was mitigated by actively supporting shy members of the group to participate in conversations and express their views without forcing them.
		Loss of focus	- The group was kept in the boundaries of the topic being discussed.
		Loss of interest	- Discussion was encouraged and momentum was kept by introducing examples or short tests.
		Participation bias – generally due to the nature of the people involved.	- Participants were left to express themselves without influence their responses. - Reasonable time was given to participants to develop their responses. - Participants knew one another, but were selected to cover different civil engineering disciplines.
Semi-structured interviews	Selector of the participants	Lack of calibration of experts	- Experts were selected to have longstanding experience in standards drafting, to cover different technical areas, and to represent design experience in different European countries.
	Interviewer	Interviewer bias – generally	- Questions were posed in a

Research instruments	Role of the researcher	Potential issues	Actions adopted by the author to minimise potential issues
		due to the way questions are posed and answers are interpreted.	neutral way, without attempting to influence the answers. - During the interviews, answers were summarised to test understanding and enable participants to add further points. - Answers were then analysed by following a structured and rigorous process of codification.
		Interviewee bias – generally due to the potential sensitivity of answers and the potential effects those might have on the interviewee's reputation.	- Questions were carefully selected to be as less invasive as possible.
		Participation bias – generally due to the nature of the people interviewed.	- Participants were left to express themselves without influence their responses. - Reasonable time was given to participants to develop their responses.
Observation (primarily in meetings)	Observer-as-participant (Gill and Johnson 2010)	Observer error – generally due to lack of understanding of the setting in which to operate.	- Discussions were held with the supervisors to appreciate key aspects of the setting. - Prolonged time in the research field (almost five years).
	Participant-as-observer (Gill and Johnson 2010)	Observer bias – generally due to the limited time to observe a phenomenon.	- Feedback asked to participants to check the appropriateness of the interpretations and findings ("informant verification", Saunders et al. 2012).
		Observer effect – generally due to the presence of the researcher, which may affect the behaviour of participants.	- Minimal interaction with participants. - Act as a simple moderator or facilitator (Zuber-Skerritt and Perry 2002). - Being familiar with participants ("habituation" in Saunders et al.'s (2012) terms).
Questionnaire	Developer of the questions	Unclear or ambiguous questions	- Questions shared and reviewed by supervisors to assess their clarity. - Pilot tests.
		Inadequacy of the questions to cover the phenomenon being explored	- Questions shared and reviewed by supervisors to assess their completeness.

Research instruments	Role of the researcher	Potential issues	Actions adopted by the author to minimise potential issues
		Inconsistency in answers	- Introduction of "check questions".
	Selector of the participants	Lack of calibration of participants	- Discussion with the client and the other members of the WSP team to identify relevant stakeholders. - Engagement strategy in place to elicit responses. - Recognition of the limited number of responses received from specific categories of stakeholders when analysing and presenting the findings.
	Reviewer of responses	Mistakes in reporting results	- Analyse and report data in an objective way through a rigorous process of codification.
Experiment	Developer of questions	Unclear or ambiguous questions	- Pilot tests.
		Inconsistency in answers	- Introduction of "check questions", i.e. the same question presented in a different way to detect inconsistencies and establish credibility of responses.
	Reviewer of responses	Mistakes in reporting results	- Analyse and report data in an objective way through a rigorous process of codification.

4.5 Research quality

There are numerous ways to describe wicked problems, much more than those used to deal with classical engineering problems. The explanations chosen by the researcher are generally those closer to the researcher's worldview and may affect the solution of the problem itself. To ensure that the results of the research are credible, establishing the right assessment criteria or "canons of enquiry" (Saunders et al., 2012) is crucial. These generally depend on the philosophical position taken by the researcher.

When dealing with mixed methods, the traditional assessment criteria such as *reliability* (i.e. consistency of findings), *internal validity* (i.e. truth value which clearly links cause and effect) and *external validity* (i.e. applicability and generalizability of findings), can be inappropriate and difficult to apply. To overcome this issue, three criteria have been considered in this research as suggested by Lincoln and Guba (1985): *dependability*, *credibility* and *transferability*. These canons of enquiry are examined below.

4.5.1 Dependability

Dependability represents the degree to which the research methods adopted produce consistent results across different projects or different researchers. In line with the recommendations of Yin (2009) for qualitative studies, the procedures followed in this research have been detailed as much as possible in order to demonstrate the dependability of results. Specific details provided in this thesis include: (i) research process and procedures adopted; (ii) time scale for the study; (iii) steps followed and their rationale; (iv) data collection and analysis; (v) people involved; (vi) key challenges faced; (vii) analysis and reflections by participants and by the researcher (viii) limitations; (ix) lessons learned; (x) suggestions for future works.

4.5.2 Credibility

Credibility is concerned with accuracy in the process of generation and presentation of research findings. Following Creswell's (2014) line of thinking eight strategies to check credibility of this research have been followed:

(1) Triangulation, which entails the employment of different data sources to support and justify emerging themes.
(2) Member checking, which requires taking back parts of the emerging themes to participants and ask for feedback.
(3) Rich description, which refers to the provision of detailed descriptions of the setting, including different perspectives about a theme.
(4) Clarity on researcher's bias, which requires self-reflection and critical comments on relevant background information.
(5) Discrepant information, which refers to the provision of contrary information that makes the discussion more realistic and valid.
(6) Prolonged time, which indicates the need to spend a great deal of time in the research field to gain an in-depth understanding of the phenomenon.
(7) Peer debriefing, which is concerned with the identification of a person other than the researcher, who may challenge the qualitative study.
(8) External auditor, which is concerned with the identification of a person not familiar with the research, who can provide objective feedback about the study.

In addition to the eight strategies, the calibration of the participants to the brainstorming sessions and of the pool of experts interviewed was undertaken as discussed in Sections 4.3.2, 4.3.3 and 4.4.

The above strategies are either explicitly mentioned in the following chapters, or are implicit. It is worth noting that strategy (7) was implemented by means of meetings with industrial and academic supervisors, while strategy (8) by presenting the research to national and international audience at conferences and by publishing papers.

4.5.3 Transferability

Transferability is a critical concept in qualitative studies and needs to be tackled carefully. In qualitative research it is generally not appropriate to claim the generalizability of findings as the aim is to understand, describe or provide insights on a specific situation or phenomenon, not to predict. Findings of this thesis have been classified into four categories. Their degree of transferability is indicated in Table 4.3.

Table 4.3 Degree of transferability of the research findings presented in this thesis

Category	Description	Degree of transferability
1	Recommendations to tackle specific problems (see the Eurocodes and DMRB projects examined in Chapters 8 and 9).	Not intended to be transferable as context-specific.
2	Lessons and themes emerged from the theoretical work (see Chapters 5, 6 and 10) and confirmed in the live projects (see Chapters 7, 8 and 9).	Intended to be transferable. Included in the practical framework presented in Chapter 11.
3	Lessons and themes either emerged from the theoretical work (see Chapters 5, 6 and 10), or from individual live projects (see Chapters 7, 8 and 9), thus not confirmed in multiple settings.	Included in the practical framework presented in Chapter 11, but a clear distinction has been made with those belonging to Category 2.
4	The approach/process to explore the problem space.	Intended to be transferable and applied to other projects.

4.6 Research ethics

Ethical concerns in this research mainly arose from the interaction and engagement with people in a variety of situations both formal (such as interviews and brainstorming sessions) and informal (such as meetings and open discussions). Ethical concerns also arose from the recruitment of participants and the analysis and reporting of the findings.

To overcome or at least minimise harm, the fundamental ethical principles outlined by Saunders et al. (2012) have been followed. These have been grouped into four categories:

- integrity and objectivity;
- avoidance of harm;
- rights of participants;
- responsibility in the analysis of data and reporting of findings.

Integrity and objectivity

The researcher acted openly and honestly. In all situations it was made clear to participants her role within the host organisation, therefore potential conflicts of interest were declared.

Avoidance of harm

Harm may take a number of forms including stress, pain, social pressure, violation of confidentiality. Risk of harm was assessed by seeking answer to the questions suggested by Saunders et al. (2012) such as: *How intrusive is the proposed research method? Does the information provided to participants allow them to contact you to discuss potential concerns?*

From this assessment, the potential harms for the interviewees were broadly those related to the category *rights of participants* presented below. The potential harms for the colleagues in the sponsoring company included the following specific situations in addition to those related to the category *rights of participants*: to force them to cooperate and participate to the research; to choose unsuitable time to involve them (such as during the working hours); to give very short notice, thereby stressing them unduly. To minimise those harms, it was clarified that participation was voluntary, they were free to withdraw at any time, and invitations were sent weeks before the scheduled session.

Rights of participants

The conduct of the researcher was respectful of participants in all circumstances. In particular, in the interview protocols, during the brainstorming sessions and in the questionnaires:

- the overall research was presented at the start – participants confirmed that the information provided was sufficient to understand the purpose of the study and the scope of their involvement;
- opportunity to ask questions was given during the session and after it (by email for example);

- the voluntary nature of participation was recognised;
- confidentiality requirements were assured and anonymity was guaranteed when specifically required by the participant.

A consent form covering these aspects was signed by all participants.

Responsibility in the analysis of data and reporting of findings

In this thesis data was anonymised, sources of information were carefully acknowledged, and findings were reported accurately (see Section 4.5.2 on the credibility of the results).

4.7 Conclusions

The research design of this thesis has been orientated towards understanding what better design standards are for the construction industry and exploring the strategies to develop better design standards. The research approach adopted in this thesis does not fall absolutely within one research paradigm, but instead adopts a mixture of tools and approaches to facilitate investigation. A ‘pragmatic’ philosophical position has been taken, which considers both objective and subjective aspects with a specific focus on the latter.

Qualitative and quantitative methods (i.e. mixed methods) have been applied as required by the research stage. These comprise: brainstorming sessions with practicing engineers; semi-structured interviews of standards’ writers; open discussion with clients and researchers; a pilot experiment; five case studies related to standards’ development and implementation. For each method the potential issues have been identified (e.g. observer bias) and mitigation measures have been put in place (e.g. feedback asked from participants to check the appropriateness of the interpretations and findings).

Dependability, credibility and transferability are the three criteria that have been used to assess the quality of the research findings. Detailed descriptions of settings, data collection, lessons learned and limitations will be presented in the next chapters to demonstrate the dependability of results. Triangulation of data, request of feedback from participants, and prolonged time in the field of interest are the main strategies adopted to ensure credibility of this study. The degree of transferability of the research findings to other settings is also clarified.

Part 2 Exploration

This part contains the theoretical work carried out to develop an understanding of this research topic and the practical work undertaken to advance knowledge through real projects.

Chapter 5

Role of design standards

5.1 Introduction

As noted in Chapter 2, design standards represent "the most common document to regulate the design of buildings and other civil engineering works and the highest expression of professional consensus on design of structures which are minimally safe, serviceable and economical" (Galambos 1992). In other words, design standards drive agreed outcomes on what a "well-designed" structure looks like.

Notwithstanding their relevance, a study on the specific role that design standards play and are expected to play in the future of the construction sector seems to be neglected in the research community, particularly to meet needs, interests and capabilities of users of these documents.

The aim of this chapter is to explore the role of design standards in the construction industry. The following subject areas are examined in detail:

(i) the historical evolution of design standards and design practice over the centuries to understand why design standards are where they are, and whether there are any fundamental purposes that need to be retained in the future;
(ii) a cross-sectorial analysis of artefacts (i.e. engineered entities) developed in construction, manufacturing and aerospace industries to gain insights into the reasons for the specific reliance of the construction industry on design standards;
(iii) the emerging vision of the future construction industry and the role that design standards are expected to play to support this future;
(iv) a qualitative study carried out to explore the role of design standards to different categories of users, as well as some specific aspirations and needs of designers.

5.2 Evolution of design standards

5.2.1 A historical perspective

Design standards, as we intend them today, are a relatively recent phenomenon. Before the twentieth century there was rarely a clear distinction between design and construction and between engineering and architecture. For centuries the knowledge of design and construction was passed by builders from generation to generation (Novak and Collin 2010) without written codification. Builders, architects and engineers were guided by rules of thumb or heuristics, and the procedure adopted for design and construction were fundamentally trial and error. Galambos (1992) noted that in the past the components of art and experience were predominant.

An indicative timeline for the evolution of publications related to the design of civil and structural engineering works over the centuries is illustrated in Figure 5.1. Specific details are provided in the following sub-sections on:

- ancient times;
- modern codes of practice;
- the Structural Eurocodes.

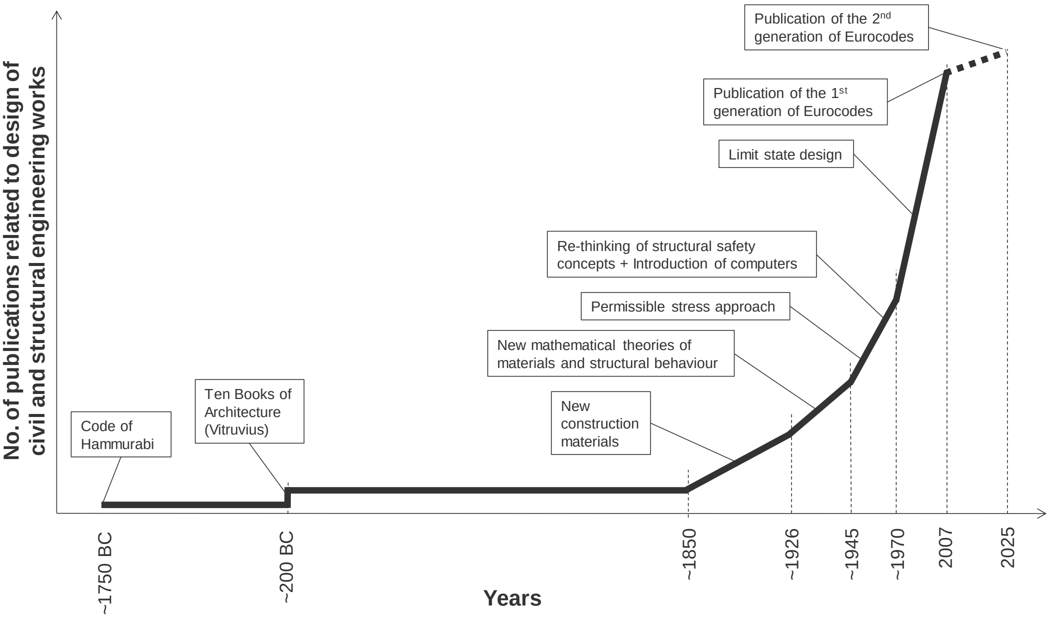

Figure 5.1 Indicative timeline for the evolution of publications related to design of civil and structural engineering works

5.2.1.1 Ancient times

The first known example of a building code was issued by King of Babylonia Hammurabi between 1792 BC and 1750 BC.

> "If a designer-builder has designed-built a home for a man and his work is not good, and if the house he has designed-built falls in and kills the householder, that designer-builder shall be slain". *(Rule 229 Code of Hammurabi)*

The Code of Hammurabi recognised the issues associated with design and construction, and defined responsibilities and specific punishments depending on the consequences of structural failure. This was a purely legal instrument, which did not provide any technical requirements. Interestingly, it contained one of the first performance statements set out on structural safety (see Rule 229 above). As noted by Foliente (2000), Rule 229 does not say anything about materials or construction methods, rather it states a clear outcome for the structure, i.e. that it does not collapse and kill someone.

In the ancient Greek and Roman period (from the 8th century BC to the 5th century DC) the design process depended primarily on architectural rules and proportional canons (involving both plan and elevation) combined with the study of preceding buildings (Jones 2003). Practice typically preceded a theory. Moving to the fourth century BC, Aristotle acknowledged the importance of some rules (*kanon*) in the "art of building" following Plato's considerations on the necessity of learning house-building by "building" (Brochner 2009). The focus was on construction knowledge rather than on design as illustrated by:

> "We learn an art by doing: it is by building houses that people become house builders".
> *Nicomachean Ethics by Aristotle reproduced by Brochner 2009*

A couple of centuries later the Roman architect Marcus Vitruvius Pollio wrote the treatise entitled *De Architectura* ("Ten Books on Architecture"), which is generally considered the oldest existing book on engineering (Petroski 1994) and the most important surviving source of ancient architectural theory (Jones 2003). *De Architectura* reports on the state-of-the-art of building in ancient Greece and Rome and provides rich information on methods for planning, designing and building structures. Perhaps the most notable statement in *De Architectura* is the following:

> "Haec autem ita fieri debent, ut habeatur ratio firmitatis, utilitatis, venustatis". *Vitruvius, I.iii.2*

This declaration expresses the importance of considering stability (*firmitas*), functionality (*utilitas*) and beauty (*venustas*) as prerequisites for good architecture. In the first book of *De Architectura* Vitruvius also identified the six fundamental principles of design called order (*ordinatio*), arrangement (*dispositio*), gracefulness (*eurythmia*), symmetry (*symmetria*), appropriateness (*decor*) and economy (*distributio*). The notion of *symmetria* is perhaps the most important. This is related to the Latin concept of proportion, i.e. "the mathematical harmony that comes of commensurable numbers entering into form via distinct modes, principally ratio, shape, dimension and the repetition of like elements" (Jones 2003).

In the fifteenth century, Leon Battista Alberti wrote his book on the art of building (*De Re Aedificatoria*), which was the first architectural treatise since antiquity as testified by Rykwert et al. (1991). It was mainly inspired by *De Architectura*. The fundamental difference between these two treatises is that Vitruvius explained how the ancient monuments were built, while Alberti discussed how future structures should be built (Rykwert et al. 1991).

For centuries master builders were accountable for both design and execution of the works and there was no systematic codification of knowledge and the best practice in design. It is noted that some early technical requirements were issued for quality control of building products such as brick and mortar in the seventeenth century (Allen 1992).

5.2.1.2 Modern codes of practice

In the UK the Rebuilding of London Act 1666 issued as a result of the Great Fire of London was one of the first example of regulation aimed at intervening on the built environment by minimising the consequences of fire. The first building code for London was published in 1844 (London Building Act) to regulate aspects of fire resistance, for example by setting criteria for wall thickness and construction materials.

The industrial revolution provided a major drive to the construction industry. During the second half of the nineteenth century new construction materials emerged, such as concrete and structural steel. The initial incentive for the introduction and use of these new materials was mainly led by the need to better withstand fire. Later in the nineteenth century reinforced concrete, prefabricated components and precast concrete were also introduced.

These new materials and technologies brought about an increasing interest in the construction community. A number of books and papers started to be published to cover design and construction using these new materials, as well as materials' quality. So far as the

UK is concerned, the main publications related to structural concrete from the end of the nineteenth century to today, are indicated in Table 5.1 as an example. Similar publications were also issued to cover structural steel. Table 5.1 includes textbooks, standards, reports and regulations. The establishment of relevant institutes and commissions is also indicated.

Table 5.1 Evolution of design of concrete structures including publications and relevant institutes

Year	Publication	Category
1877	First book on reinforced concrete published by Hyatt (1877).	Textbook
1904	First British textbook on reinforced concrete design and construction, *Reinforced concrete*, published by Marsh (1904).	Textbook
	The Engineering Standards Committee (which changed the name to British Standards Institution in 1931) published BS 12 covering the quality of Portland cement.	Standard
1906	The *Concrete & Constructional Engineering* journal started to publish record of concrete practice. Last issue in 1966.	Journal
	Establishment of the Special Commission on Concrete Aggregates by the British Fire Prevention Committee.	Commission
1907	First report on the use of structural reinforced concrete issued by the Committee on Reinforced Concrete established by the Royal Institute of British Architects (RIBA) (Joint Committee on Reinforced Concrete 1907).	Report
1908	Formation of the Concrete Institute, which then became the Institution of Structural Engineers (Witten 1996).	Institute
1909	Publication of the *London County Council (General Powers) Act* (London County Council 1909), which covered the design of steel, wrought iron and cast-iron structures in the British building regulations.	Act
1910	Report on concrete specifications issued by the Committee on Reinforced Concrete (established by the Institution of Civil Engineers).	Report
1911	New report on reinforced concrete issued by the RIBA Committee on Reinforced Concrete. Fire considerations were a key issue for durability.	Report
1915	First British regulations codifying design and construction for reinforced concrete was issued by the London County Council (1915). These were based on the report issued by the RIBA Committee on Reinforced Concrete in 1911. The 1915 Reinforced Concrete Regulations enabled practitioners to apply an acceptable method of designing reinforced concrete structures without being specialists as now these could be "approved under regulatory by-law" (Bussell, 1996a). Very little used until the end of the First World War (Bussell 1996b).	Regulation
1931	Establishment of the Reinforced Concrete Structures Committee by the Building Board of the Department of Scientific and Industrial Research.	Committee
1932	First edition of the reinforced concrete designer's handbook published by Reynolds (later editions in 1939, 1946, 1948, 1957,1961,1971,1974, 1981 and 1988).	Textbook
1933	First British code of practice issued by the 1931 Reinforced Concrete Structures Committee (1933). This was based on the 1915 Regulations.	Code of practice

Year	Publication	Category
	The focus was on strength requirements for concrete mixes. Appendices to the code included loadings because a British Standard on loading had not been published (Bussell 1996b).	
1938	Model building by-law promulgated by the Ministry of Health, which scarcely mentioned concrete (Ministry of Health 1938).	Regulation
	Publication of BS 785 "Hot-rolled bars and hard drawn wire".	Standard
1939	Code issued by the Building Industries National Council (1939).	
1943	Publication of BS 1144 for cold worked bars.	Standard
1945	Publication of BS 1221 for steel fabric.	Standard
1948	Publication of CP 114 "Structural use of reinforced concrete in buildings". The 1957 edition introduced the load-factor method for slabs and beam design.	Standard
1959	Publication of CP 115 "The structural use of prestressed concrete in buildings".	Standard
1960	Publication of CP 2007 Part 2, "Design and construction of reinforced and prestressed concrete structures for the storage of water and other aqueous liquids".	Standard
1965	Publication of CP 116 "The structural use of precast concrete".	Standard
1972	Publication of CP 110 "The structural use of concrete", which unified CP 114, CP 115 and CP 116. This adopted the limit state design exclusively.	Standard
1973	Publication of Technical Memorandum (Bridges) BE 1/73 "Reinforced concrete highway structures", BE 2/73 "Pre-stressed concrete highway structures".	Standard
1976	Publication of BS 5337 "Code of practice for the structural use of concrete for retaining aqueous liquids".	Standard
1984	Publication of BS 5400 "Steel, concrete and composite bridges. Part 4 - Code of practice for design of concrete bridges".	Standard
1985	Publication of BS 8110 "Structural use of concrete". This replaced CP 110.	Standard
1987	Publication of BS 8007 "Code of practice for design of concrete structures for retaining aqueous liquids".	Standard
2004	Publication of BS EN 1992 "Design of concrete structures".	Standard

The documents that underpin the current American design standards for civil and structural engineering works started to be published in the first half of the twentieth century. For example: the first report on "Recommended Practice and Standard Specifications for Concrete and Reinforced Concrete" was issued in 1916; the first "Steel Construction Manual" was published in 1927 by the American Institute of Steel Construction (AISC); the first recommendations for earthquake engineering ("Uniform Building Code") were published by the Pacific Coast Building Officials (PCBO) in 1927; the first "Standard Specifications for Highway Bridges" was issued by the American Association of State Highway and Transportation Officials (AASHO) in 1931.

The evolution of codes must be read in conjunction with the development of new mathematical theories of materials and structural behaviour, which became mature enough to be incorporated into the design process (Kulhawy and Phoon 1996). During the post-World War II, boom in re-construction brought about extensive re-examination of structural safety concepts. Early work on risk assessment applied to structural engineering was done by Freudenthal (1947) and Pugsley (1951). Since then, researchers were involved in the development of reliability analysis for more than thirty years to take account of the sources of uncertainty in terms of capacity and demand. Yet, the complexity of the analysis required appropriate machines to carry out computations, which were not available at the time.

The introduction of computers in the second half of the twentieth century was another revolution, which affected design practice significantly (Warszawski 2003) and opened up new possibilities. Reliability methods reached a higher degree of maturity by the 1970s and formed the basis for the development of new design codes, where traditional permissible stress design approaches were gradually substituted by limit state design approaches.

Since the mid-1970s, several new design codes were introduced (Kulhawy and Phoon 1996). As an example, in the UK BSI-CP110 "The structural use of concrete" was issued in 1972, while in Canada CSA-S136 "Specification for the design of cold-formed steel structural members" was published in 1974.

5.2.1.3 The Structural Eurocodes

The development of the first generation of the Structural Eurocodes (see Section 2.10) and their implementation in all European Member States are perhaps the most notable change experienced in Europe in recent decades. Johnson (2009) provides a detailed description of the forty-year work on the Eurocodes' development.

The purposes of the first generation of the Structural Eurocodes include (Roberts 2010):

(i) "to provide a common understanding regarding the design of structures between owners, operators and users, designers, contractors and manufacturers of construction products";
(ii) "to increase the competitiveness of civil engineering firms, contractors, designers and product manufacturers in their transnational activities";
(iii) "to allow the preparation of common design aids and software";
(iv) "to be a common basis for research and development in the construction industry".

Recently, the work on the evolution of the Eurocodes has started and is scheduled to be finished around 2020 with the publication of the second generation of the Eurocodes (CEN/TC250 2013a). A specific discussion on the Eurocodes is presented in Chapter 8.

5.2.2 Historical roles of design standards

From the above review of the evolution of design standards over the centuries the following historical purposes of design standards emerge.

5.2.2.1 Control the built environment

As for standards in general, design standards support public policy goals and objectives, which can be set at European, national or local level. Key objective is to control the built environment. Generally speaking, society requires specific criteria which ensure that the design is satisfactory. For centuries the builders' practical experience provided this assurance. However, with industrialisation this *modus operandi* no longer worked. Technology brought about more specialisation; consequently, responsibility started to be shared across many actors (designers, constructors, product manufacturers, etc.).

The role of design standards has evolved from communication to control (Menzies and Armer in Moffatt and Dowling 1981) with the consequent need to cover as many topics as possible. Menzies (from Sunley and Taylor 1982) testifies that the role of design standards has changed since they have assumed a deemed-to-satisfy function and started to be demanded by regulatory instruments (see also Section 2.6 on the link between standards and regulations).

5.2.2.2 Provide a safe built environment

Galambos (1992) stated that the emergence of design codes around the beginning of the twentieth century derived from the necessity for a more ordered and safe building environment. Structural safety has always been a key driver of design practice in the construction industry due to the high degree of social responsibility that the structures have and the impact that structural failures may have on safety, health and well-being of population.

Interestingly, in the past the concept of 'safety' itself addressed different aspects compared to those considered today. In the past, most of the regulations dealing with construction-related issued were mostly concerned with controlling the spread of fire and dangerous structures and protecting the public health for example by governing window sizes and room heights (Knowles and Pitt 1972 mentioned in Nam and Tatum 1988). Fire resistance was a key driver for the study and application of new materials such as concrete and steel.

The current concept of safety and the notions of risk management are more recent – see work done by Pugsley (1951). Initially, researchers were concentrated on developing models describing the behaviour of physical systems; subsequently, the assessment of safety and acceptable risks gained significant attention (Reid 1992).

5.2.2.3 Develop cost-effective technical solutions

Economy is another underlying theme. Galambos (1992) argued that, while safety and serviceability can be easily achieved without taking any economic considerations (the pyramids are an example), “a well-designed structure should be just safe, just serviceable and be optimal in cost”.

5.2.2.4 Codify knowledge

In the first phase of standardisation the primary focus of national standard bodies was directed towards the development of product specifications (ISO 1972), such as those defining and specifying concrete and steel, see also Table 5.1. The aim of these standards was to provide a common basis for tendering through a process of simplification, which reduced variety in terms of size and shape of products, thereby reducing cost of manufacturing.

The appearance of design rules in journals first and then codes of practice / standards started in the second phase of national standardisation (ISO 1972) and was aided by the evolution of mathematical theories of materials and structural behaviour at the end of the nineteenth century. The purpose was to provide reliable guidance to engineers – not necessarily experts – sufficient to enable them to do a “reasonable job with confidence” (Menzies and Armer in Moffatt and Dowling 1981). Needham (in Moffatt and Dowling 1981) also noted the desire of academics to see their latest research results incorporated into code.

Design standards were also introduced or updated in response to events to take on board lessons learned from structural failures. For example, in the early 1970s there was a period of intense construction activity in the UK that was also characterised by a series of bridges collapsed during construction. In 1975 the Bragg’s (1975) report was published as a result of a major falsework collapse near Reading to provide specific guidance on the design, execution and management of falsework systems. The Bragg report provided the basis for BS 5975, which was first published in 1982. The Merrison report (1973) is another example of document issued in response to a structural failure (specifically the steel box girder bridge called Milford Haven Bridge in Wales), which provided the basis for the Interim Design and Workmanship Rules (IDWR) and a new British Standard BS 5400, Parts 3, 6 and 10 covering box girder bridge design.

5.2.2.5 Ensure consistency of design approaches

One of the roles of standards is to provide "consistency and high levels of predictability of technical decisions and solutions" (Coeckelbergh 2006). The process of codification of knowledge aims to maintain consistency of the approach to the performance for different civil and structural engineering works.

5.2.2.6 Frame common understanding among stakeholders

One of the roles of design standards is to frame common understanding among stakeholders including owners, contractors, manufacturers of construction products and operators as also noted by Roberts (2010) in the context of the Eurocodes. In construction projects many parties are involved as noted in Section 2.8.4. Leivestad and Mehus (2012) argued that standards should be written such that they can support "communication both up and down in the project hierarchy". In addition, design standards serve as a vital means for research outcomes to achieve widespread adoption within the sector and as a key conduit for the research community to achieve impact from their work.

5.2.2.7 Support competitiveness

Melchers (1999) argues that the role of design standards is more complex than simply addressing structural safety and that "their overall role might be better seen in terms of national economic competitiveness". In recent years there has been an increasing interest in the role of standards in enabling or hindering the efficient delivery of construction projects in the UK. The Industry Standards Group (2012) recognised that "inconsistent approaches to the application of technical standards lead to inefficient, bespoke solutions that block innovation, add to whole life costs and fail to deliver the required performance and service improvements". Similarly, Wilson et al. (2015) acknowledge that the effective delivery of infrastructure projects can be hampered by inefficient and inconsistent use of standards. The relevance of design standards to support competitiveness also emerges from Roberts' (2010) publication on the Eurocodes.

5.3 Cross-sectorial review

5.3.1 Context

Large facilities like buildings, bridges, aeroplanes and mechanical systems, have all in common the "identification of specific hazards and the technical means for protection against them" as well as "structural redundancy" (Allen 1992). For these similarities manufacturing[1] and aerospace are often looked at as models the construction industry should aim/strive for (Gann 1996).

Manufacturing has always been perceived as a good example of efficiency. It offers intriguing opportunities in terms of: (i) economies of scale thanks to mass-production lines, standardisation of components, prefabrication under factory conditions and interchangeability of parts; (ii) continuous quality improvement; and (iii) "tighter managerial control" (Gann 1996). On the other hand, what makes the aerospace industry particularly appealing is the strong focus on safety, asset management and health monitoring to reduce aircraft maintenance and operational cost (Patankar and Taylor 2003).

However, before drawing parallels between different sectors and deriving lessons relevant to design standards in the construction industry, it is important to understand the distinguishing properties of the artefacts (i.e. engineered entities) covered in different industries. These affect the manner in which designers go about design and ultimately the role of design standards. This section investigates this aspect by carrying out a cross-sectorial review of artefacts in construction, aerospace and automotive and their design. Civil and structural engineering works are examined in detail.

5.3.2 Civil and structural engineering works

Civil and structural engineering works or constructed facilities are generally one-of-a-kind, locally bound and designed to be unique due to physical, economic, legal or environmental situations (Vrijhoef and Koskela 2005). The typical uniqueness of civil and structural

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[1] Manufacturing is defined as "the system of production involving the concentration of materials, fixed capital and labour in one or more plants" (Gann 1996).

engineering works makes the construction industry focused on a "one-off approach" (Turin 2003).

Civil and structural engineering works are large facilities, which do not allow full-scale prototypes (Slaughter 1998). Ballard and Howell (1998) argue that constructed facilities belong to "fixed position manufacturing", i.e. an assembly system in which the product does not move while being assembled, mostly due to its size. Civil and structural engineering works are thus located on site and are characterised by immobility (Nam and Tatum 1988). This in turn leads to the concept of constructed facilities as "rooted in place" (Ballard and Howell 1998), which brings about uncertainty and differentiation.

Civil and structural engineering works are also complex entities, particularly in terms of the number of systems interacting with one another as well as with the environment (Slaughter 1998). Nam and Tatum (1988) note that complexity of constructed facilities also stems from the number of different materials required, the variety of site conditions and finished structures, the variety of individual preferences by owners and designers, and the combination of materials and equipment. They observe that variety of individual preferences is seen as a barrier to mass production, which by definition requires consistency and conformity. Yet, it is worth noting the increase in prefabrication and standardisation of components due to current improvements in automation and off-site manufacturing (see Section 5.4.2). Nam and Tatum (1988) also claim that complexity in civil and structural engineering works is one of the factors leading to the need for specialised knowledge.

Constructed facilities are also long lasting and operate over decades to centuries (Nam and Tatum 1988; Slaughter 1998; Warszawski 2003). Warszawski (2003) recognises two main implications for the long life-cycle of constructed facilities. The first is in terms of quality. If they do not perform well, they cannot be "discarded" like a common manufacturing product, thus their quality should be ensured by designing and controlling the construction properly. The second implication is the potential need to change the function of a civil and structural engineering work during its service life to fit new needs and requirements. This leads to the importance of considering flexibility and some degree of adaptation (Carassus 1998 as cited in Koskela 2000).

Two other implications for the long life-cycle of constructed facilities can also be identified. The first is the importance of having in place an appropriate asset management system for the entire life-cycle of the structure. The long life of constructed facilities coupled with their one-of-a-kind nature make it more difficult to develop and implement an efficient asset management system from a technical and economic point of view. Specifically, the uniqueness of assets often implies *ad hoc* procedures and interventions, which can be inefficient particularly when managing a high number of assets.

The second implication is in terms of decision making. Designing and constructing a civil and structural engineering work (particularly strategic infrastructure which are expected to last longer than traditional buildings) require an in-depth approach to decision making to both maximise utilities of current and future generations and achieve sustainable interventions. Some studies have been carried to explore this issue from an economic perspective. For example, Lee and Ellingwood (2015) reviewed recent developments in intergenerational discounting practices aimed at sharing risk equitably between generations, and examine how those methods might affect the optimal design solutions and long-term decision-making.

As a result of the combination of their complexity and long life, constructed facilities are generally costly (Nam and Tatum 1988). The impossibility of building full-scale prototypes, which are generally costly and time consuming (Slaughter 1998), coupled with the primary need to guarantee acceptable levels of safety, leads to "less trial and error in construction and more conservative design" (Nam and Tatum 1988) and to "rules and conventions" (Koskela 2000) that minimise the risk of low quality levels of the structure.

Finally, as acknowledged by Nam and Tatum (1988), civil and structural engineering works are characterised by a "high degree of social responsibility to the public, both concerning public safety and health". This aspect has two consequences. The first is "ultra-conservatism" with the resulting "proliferation of government regulations, and the need for checks and balances (or for distribution of responsibility) among various team members". The second is an increase in the levels of specialisation in order to guarantee "the necessary competence of each specialty to provide a safe and healthy environment to the general public".

While the construction industry is evolving with an increased focus on standardisation of components and structural elements and new sensor technologies to better understand structural performance (see Section 5.4.2), civil and structural engineering works continue to have a one-of-a-kind nature primarily due to different site conditions and client's individual preferences. Full-scale prototypes are generally not built, and the performance of civil and structural engineering works is much less understood than other artefacts.

5.3.3 Design of artefacts in construction, aerospace and automotive industries

In his conceptualisation of the construction industry, Fernández-Solís (2008) imagines a world where the aircraft industry operates in the same way as the construction sector:

> "Each artefact (airplane) would be constructed for one client with differing requirements from any other, for one specific use (say one route). Although the plane could be constructed out of an existing catalogue of parts, it would be designed and built by a team that came into being just for this purpose. Furthermore, the airplane would have to be built or assembled on a site open to the elements. The artefact would be a unique but distinct product, meeting governing requirements and obeying the laws of nature".

This example is extreme as, in reality, a degree of customisation is allowed for aircrafts, particularly to differentiate individual brands and satisfy operational requirements (Ackert 2013). Nevertheless, the example clearly shows some key differences between construction and aircraft industries. To explore the differences between construction and other fields, a cross-sectorial review of the design of artefacts in construction, aerospace and automotive industries has been carried out and is presented in Table 5.2.

Table 5.2 Design of artefacts in construction, aerospace and automotive sectors

Theme	Construction	Aerospace	Automotive
Key players	Significant diversity of firms characterised by different specialisation and size.	Limited number of major global players (such as Boeing and Airbus) accompanied by a higher proportion of small ones (Voordijk and Vrijhoef 2003).	Variety of companies, not as high as construction. Manufacturers play a key role to ensure that the products are easy to manufacture ('design for manufacturability').
	Designers are a very broad category due to the high variety of firms and designers with different skills and capabilities (Allen 1992).	Designers are a much narrower category compared to the construction industry as there is a need for a more significant "specialist effort" (Allen 1992).	Designers are a much narrower category compared to the construction industry as there is a need for a more significant "specialist effort" (Allen 1992).
Initial concept	Key aspects to consider: client's needs and requirements; standards and regulations; environmental	Key aspects to consider: customer demand; manufacturer demand; safety protocols; environmental	Key aspects to consider: customer demand; manufacturer demand; performance; safety regulations;

Theme	Construction	Aerospace	Automotive
	constraints.	regulations; physical and economic constraints.	environmental regulations; physical constraints.
	Previous successful examples are particularly important for large assets such as bridges. Small residential buildings instead are typically driven by owners' or users' needs.	Previous successful examples are a useful starting point. Consideration is given to long term needs and expectations of the market (around 35-40 years).	Previous successful examples are a useful starting point.
	The introduction of new solutions requires research and development. R&D in construction appears to be more limited than other industries (Ozorhon et al. 2016).	The introduction of new solutions requires many years of research and development before being adopted (e.g. the "fly-by-wire" technology introduced by Airbus on the single-aisle family in the 1980s or the Boeing 747 introduced in 1970, which are still used). Much effort is put into R&D.	The introduction of new solutions requires significant research and development, but within a timeframe that is much shorter than that required for aircrafts. Much effort is put into R&D.
Facilities or products covered and their features	Buildings, bridges and a variety of civil and structural engineering works.	Aircrafts.	Vehicles.
	A spectrum of different types of constructions: from complex, big, one-of-a-kind bridges to small houses. Complexity is seen in terms of technical, physical, socio-political, economic, legal, environmental situations.	Complex, big and standardised products, which result from a manufacturing process carried out in a highly controlled working environment employing prototypes.	Complex standardised products, which result from a manufacturing process carried out in a highly controlled working environment employing full-scale prototypes.
	Key components: structure, which comprises the load-bearing elements (columns, beams, walls, foundations, etc.); non-structural elements; internal systems.	Key components: structure, which comprises the load-bearing elements; propulsion system; avionics, which comprise control, navigation and communication systems.	Key components: skeleton; engine; transmission system; suspension system; electrical equipment; steering; brakes.
	Typically characterised by low levels of repetitiveness (even in a large stock of housing) and high degree of customisation.	High degree of standardisation of components, in some cases with flexibility in assembly to guarantee a degree of customisation.	High degree of standardisation of components, in some cases with flexibility in assembly to guarantee a degree of customisation.
	Large heterogeneity of	A well-defined demand of	Variable demand of

Theme	Construction	Aerospace	Automotive
	demand, which is also locally bounded.	products within a generally international market.	products within a generally international market.
Service life	Long service life, e.g. the design life of a bridge is 120 years.	Medium service life: an aircraft has typically 20 to 40 years of service life depending on its usage.	Medium to short service life also depending on the life expectancy of the internal electronic equipment.
	Longevity in use implies the potential need to change function of the structure during its service life to accommodate new needs and requirements. This is permitted provided that performance levels are achieved.	Changes on aircrafts are carefully controlled. Configuration management (CM) is a systems engineering process which consists of controlling and tracking all changes to a product in order to maintain consistency of performance and requirements throughout its life (Hitchcock 2002). CM is fundamental for aerospace and it is also a key process for aircrafts maintenance.	Changes to vehicles are made as needed depending on their use (particularly number of miles driven) and the maintenance performed.
Design process	Typically ill-defined in terms of goals.	Well defined.	Typically well defined.
	While each design continues to be based on experience, calculation and materials testing, technological developments have had a significant impact (3D models, computer-integrated design, parametric analysis, etc.).	Design requires consideration of manufacturing engineering and cost implication in early decisions.	Design requires consideration of manufacturing engineering in early decisions.
	Typically no prototype testing.	Design is based on prototype testing.	Design is highly simulation-driven and based on prototype testing.
Time for design	From days to years (Goel and Pirolli 1992)	Many years, including prototyping, testing and refining design.	On average several years depending on the company and the novelty of the model. This cycle includes prototyping, testing and refining design.
Cost for design	Around 6% of the total cost of the construction.	Billions of investments strictly connected to the cost of building and testing full-scale	Strictly connected to the cost of building and testing prototypes (a working production intent

Theme	Construction	Aerospace	Automotive
		prototypes (Hitchcock 2002)	vehicle plus a concept car generally).
Key performance objectives	Dictated by standards and regulations and manufacturers.	Dictated by standards and regulations and manufacturers.	Dictated by standards and regulations and automobile manufacturers.
	Safety, serviceability, durability, robustness, and economy.	Safety, operational reliability, minimum weight, economy (low life-cycle costs), limited noise and engine emission levels, interoperability (of components), interconnectivity (in terms of connectors, wires, power systems), and potential for enhanced aircraft performance (Frangopol and Maute 2003; Staszewski et al).	Safety, reliability, limited exhaust emissions, fuel economy, interoperability (of components), systems interconnectivity, customer-perceived values such as driveability and acceleration capability.
	Multiple, diverse and wide-ranging performance objectives.	Specific performance objectives, which are typically monitored and tested in laboratory. Lower partial factors compared to constructed facilities due to better understanding of performance.	Specific performance objectives, which can be monitored and tested in laboratory.
	Simple loading conditions for common civil engineering works, such as vertical and horizontal actions typically represented by self-weight and additional variable actions such as wind, snow, thermal and seismic actions. Additional conditions must be considered for specific structures such as bridges and tall buildings.	"Coupled multi-physics phenomena such as aeroelasticity [which leads to divergence and flutter] and thermoaeroelasticity" (Frangopol and Maute 2003). Presence of complex loading such as aerodynamic pressure. Strong consideration of degradation models and buckling instabilities. Extensive use of optimisation models to minimise the weight and maximise performance under random load effects.	Structural, vibro-acoustic and kinematic design, coupled with configuration and performance optimisation. Integration of all systems in the complete automobile. Trade-off analysis to deliver all vehicles attributes at acceptable levels (for example, trade-off between engine performance and fuel economy). Some elements requiring trade-off: automobile weight, aerodynamic drag, ride quality, and emission control devices.
Reference documents for design	Design standards in conjunction with product and execution standards: in Europe, the Structural	Local aviation regulations in order to receive a type certificate for the design. In Europe, Certification	Motor vehicle standards cover requirements related to crash avoidance and post-crash behaviour.

Theme	Construction	Aerospace	Automotive
	Eurocodes (EN 199x series). Designers' guidance and textbooks are also used.	Specifications (CS series) for Initial Airworthiness (see https://www.easa.europa.eu/). The type of certification process includes evidence that the design meets all performance criteria (Patankar and Taylor 2003).	These include standards on brake systems, tire selection, accelerator control systems, flammability of interior materials (see https://one.nhtsa.gov/cars/rules/import/fmvss/index.html for US vehicles)
Verification of the adequacy of design	Mostly component based and against design standards. Very limited prototypes.	Prototype testing and modelling.	Prototype testing and modelling. Engineering simulation and test with intelligent reporting and data analytics.

This comparison shows a few similarities between industries. First, similar constraints can be found in the conceptual phase including client or customers' needs, standards, regulations and environmental aspects. Broadly speaking, components of the artefacts covered by these industries are similar, i.e. a structural part combined with non-structural elements and a variety of interacting systems.

Moreover, in all these industries performance objectives are typically dictated by standards and regulations. Artefacts are subjected to a variety of hazards during their life and safety is a common concern due to the fatal consequences of failure. Specific analyses are carried out to minimise the risk of failure to an acceptable level or achieve certain level of reliability (although how this is achieved is different in different sectors). Redundancies are typically introduced.

The cross-sectorial review also shows some key differences between industries, which ultimately affect the role of design standards in the construction sector as presented in the next sub-section.

5.3.4 Special roles of design standards in the construction industry

5.3.4.1 Enable adequacy of design to be verified

Prototype testing and modelling are key tools in aerospace and automotive, with design being highly simulation-driven. In the construction industry instead, full-scale prototypes are generally not used as costly and often impossible to develop. Despite the lack of prototypes, regulatory authorities require "a documented scientific justification" of the adequacy of design (Galambos 1992) and some acceptance criteria so that risks can be reasonably controlled from a societal point of view (Reid 1992).

Equally, designers need a means by which they can verify the adequacy of designs to meet the fundamental requirements of safety, serviceability, durability and robustness. Indeed, the designer of one-off constructed facilities obtains much less feedback about the performance of the construction in the real world outside of the laboratory, than does a designer in a manufacturing process (Blockley 1992). In absence of prototypes, design standards are a key means to verify the adequacy of design[2].

5.3.4.2 Support both common and innovative design solutions

The construction industry is characterised by a multiplicity of design solutions, from common to innovative designs. In contrast, the variety of artefacts covered in aerospace and automotive is much narrower. Design standards in the construction industry endeavour to be flexible documents, which delimit the range of options available to users to fulfil their everyday tasks (thus aiding common design situations) while leaving enough room to innovate and explore new design solutions. In doing so, design standards shape the exercise of practitioner's judgement and contribute to "the delineation of an appropriate discretionary or 'judgement' space for technological practice" (Shapiro 1997). As noted by Shapiro, the importance of design standards in the construction industry derives "not just from the knowledge they embody but from the room for maneuver they leave".

5.3.4.3 Manage risk and uncertainty

Elms (1992) noted that civil and structural engineering community mainly uses risk assessment and reliability methods in the development of standards rather than for structural design. The reason is that common civil and structural engineering projects do not warrant the cost of an individual reliability analysis. This is different from what happens in other fields such as aerospace, where risk assessments are carried out on individual projects. Frangopol and Maute (2003) emphasised the recent development of codes which require reliability analysis in the design process of aerospace systems.

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[2] For special structures, the role of model testing and/or numerical modelling should not be underestimated.

Design standards in the construction industry assess key risks for families of civil and structural engineering works by calibrating partial factors such that the reliability levels are as close as possible to the target reliability index. The calibration of partial factors takes account of their longevity of use and the enormous variety of hazards they can be subjected to during their lives. Design standards can be based on deterministic methods or probabilistic methods (see Figure 5.2 reproduced from EN 1990 Basis of design, Annex C). The Structural Eurocodes for instance are based on deterministic methods (Method a in Figure 5.2).

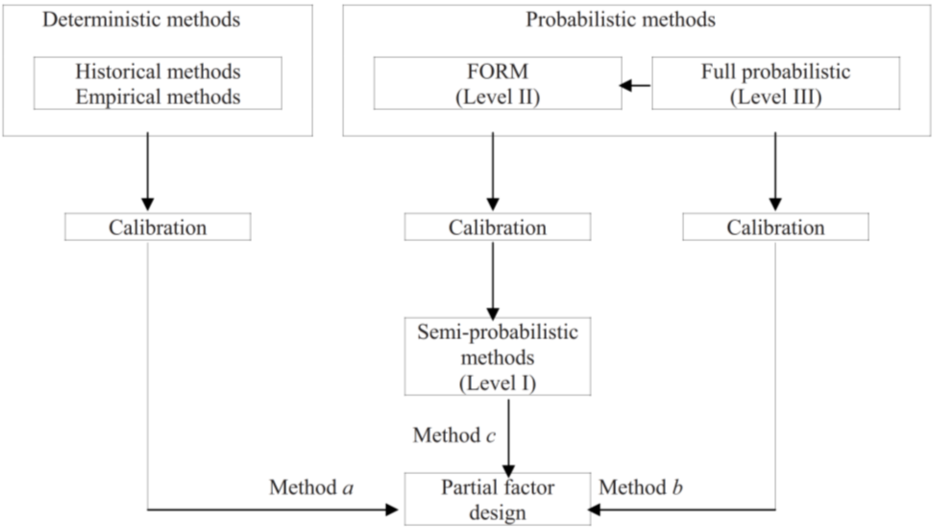

Figure 5.2 Overview of reliability methods, reproduced from EN 1990

5.4 Evolution of the construction industry

Part of the content presented in this section has been published in Angelino et al. (2016) as personal contribution of the author.

5.4.1 Climate change and sustainable development

Climate change is a key driver to change in the construction industry, which is emerged over the last years. Changes to weather characteristics and extreme weather phenomena are becoming increasingly a concern as documented in the five assessment reports published by the Intergovernmental Panel on Climate Change IPCC (1990 and 1992; 1995; 2001; 2007; 2015). Reducing greenhouse gas emissions in the built environment (Ortiz et al 2009) and the whole-life cost of assets while ensuring their full resilience (see HM Government's (2013) report for the UK approach) are key objectives for the construction sector.

Similarly sustainability, with its focus on society, economy and environment, is another key driver to change. Sustainable development is a concept founded on the aspiration of meeting "the needs of the present without compromising the ability of future generations to meet their own needs" formulated by the Brundtland Commission (World Commission on Environment and Development 1987). The sustainability of civil and structural engineering works manifests itself as a combination of: structural durability; use of appropriate materials and resources (ideally renewable, locally sourced, etc.); recycling of building materials; energy saving; reduced waste; reduced pollution of water, air and soil; value for money, also in terms of intergenerational equity (World Commission on Environment and Development 1987); well-being of the communities; protection and enhancement of the environment.

5.4.2 Towards a smarter construction industry

In the last two decades the construction industry has also experienced other significant changes, which include the introduction of BIM[3], computer-aided design (CAD) and computer-aided manufacturing (CAM), automation, new sensor technologies, off-site manufacture, diagnostic tools and new materials. These technologies are changing the way structures are designed, built, managed, operated and dismantled.

Specifically, BIM and CAD enable the interfaces between the artefact and the environment to be managed more effectively, while helping create a valuable digital legacy of assets (Denton and Skinner 2014). Construction projects are becoming more in line with product manufacture thanks to CAM. As a result, the separation of design from construction is likely to become less and less relevant.

At construction level, current improvements in automation, particularly industrialised construction systems, are accelerating construction and reducing labour costs (Bock 2015). Industrialised construction systems are characterised by (Warszawski 2003): (i) modularisation of structural elements which are realised in off-site facilities; (ii) minimum erection, jointing and finishing activities done on site; (iii) design, production and

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[3] BIM is a collaborative way of working for the creation and management of information across the life-cycle of a construction project. One of the key outputs of this process is the Building Information Model, a 3D digital representation of every aspect of physical and functional characteristics of an asset, which is used to support efficient planning, design, construction, and management of infrastructure projects.

construction as part of an integrated process; (iv) large use of automation to improve quality in design, production and construction and reduced need for human involvement.

At project level, advances in technology and a more effective use of digital information enable more collaborative working spaces. They are also promoting new ways of working while improving productivity and enhancing asset management. Cost reduction, quality control, time savings and enhanced communication are the most commonly reported benefit of BIM (Bryde et al. 2013). It is likely that digital models will be closely coupled with machine-based manufacturing and construction, meaning that designers will have the tools to explore wider and more complex and imaginative design spaces in search of good solutions. Digitally-driven design processes are typically mentioned for the architectural opportunities that they offer (Kolarevic 2003). It is also likely that buildability will be embedded more extensively in the design process to avoid redesign– which would add significant cost – and to enable machines to actually build the structure.

The importance of considering these changes has been acknowledged in several publications that attempt to set out the future vision for the construction industry in different countries. In the UK the vision for 2025 (HM Government 2013) recognises the importance of adopting innovative technologies in sensors and data management to fully understand asset performance. It is acknowledged that "this will result in smarter designs, requiring less material, reducing carbon and needing less labour for construction, whilst still ensuring full resilience of the assets."

Similarly, "The vision for civil engineering 2025" published by the American Society of Civil Engineers (2006) envisaged a future where "the civil engineering enterprise is focused on fast-track development and deployment of technologies", which employ results from information technology to enhance how facilities are designed, built and maintained. Likewise, the vision for the Australian construction industry (Cooperative Research Centre for Construction Innovation 2004) identified interrelated items relevant for the future construction industry. These include: virtual prototyping for design, manufacturing and operation; off-site manufacture; improved process of manufacturing.

Recent discussions have been held at the University of Cambridge on how to transform the future of infrastructure through smarter information (Mair and Schooling 2016). Key aspects discussed include new developments in fibre optics sensing and wireless sensor networks, new models and tools for asset management, and new forms of data. Significant efforts thus seem to be paid in making good use of new technologies, particularly to acquire data more representative of the real behaviour of structures. Mair and Schooling (2016) also observed that this will push the boundaries of performance-based approaches while supporting better-informed design as well as maintenance.

5.4.3 Future roles of design standards

The profound changes of the construction industry presented in the previous paragraphs would require design standards to evolve accordingly to support them. As discussed above, climate change is an established theme for future design standards. In contrast, there does not appear to be any study on the role that design standards are expected to play to support sustainable development and meet the expectations for a "smarter" construction industry. These future roles have been outlined in the following paragraphs. The aim is not to provide definitive roles, as these would require a separate exploration outside the scope of this thesis. The goal is instead to show the potential need for bringing in some extra factors to the development of future design standards, which reflect emerging needs in the construction industry.

5.4.3.1 Address climate change adaptation

Climate change adaptation in standards has been examined in CEN/CENELEC (2016) "Guide 32 – Guide for addressing climate change adaptation in standards". It provides valuable recommendations to standards' writers for integrating aspects and impacts of climate change at all stages of the life-cycle of a product, service, testing and infrastructure. In the context of the design standards, a specific focus of the second generation of Eurocodes will be on "analysing and providing guidance for potential amendments for Eurocodes with regard to structural design addressing relevant impacts of future climate change (general and material specific)" (CEN/TC250 2013a).

Themes for consideration to address climate change adaptation in future design standards may include:

- influence of climate change on frequency and intensity of extreme events;
- characteristic values of actions and environmental influences and related partial factors to accommodate the effects of climate change;
- changes of material strength due to climate change;

- more widespread use of data from structural health monitoring system to analyse real mechanical responses of structures to extreme events in particular (see Section 5.4.3.3);
- introduction of risk-based analysis to take extreme events into account (see Section 5.4.3.5).

5.4.3.2 Support design of sustainable civil and structural engineering works

Looking at the factors affecting the sustainability of civil and structural engineering works (Section 5.4.1), the role of design standards can be seen mainly in how they support durability, appropriate selection and use of structural materials for design purposes and a whole-life view. The last aspect is presented in detail in Section 5.4.3.7.

5.4.3.3 Enable informed verification of structural rehabilitation schemes

Data from structural health monitoring could be used to verify structural performance more effectively and efficiently, particularly in the design of structural modifications or rehabilitation schemes. New digital models, for example BIM, can store and process a quantity of information which was inconceivable in the past. This poses questions as to how design standards can enable this change and support more informed verification of structural adequacy for both new and existing structures. Despite its importance, this theme seems to be neglected in the engineering community drafting standards as well as in the academic community.

5.4.3.4 Enable structural verifications to be incorporated into digital models

Allowing the preparation of design aids and software was one of the objectives of the first generation of the Eurocodes (Roberts 2010). Digital models are increasingly used in the construction industry to design civil and structural engineering works. However, the difficulty in automating the application of design standards is often underestimated. This is demonstrated by the limited automation in design. Notwithstanding this, the development of future design standards should be undertaken by recognising the changes that can be anticipated in the construction industry and that can enable this process to happen in the future.

5.4.3.5 Better enable management of risk and uncertainty

The coverage of probabilistic methods (or risk analysis) in design standards for common civil and structural engineering works is very limited as discussed in Section 5.3.4.3. Probabilistic methods enable all types of uncertainties to be explicitly considered and an optimisation process to be applied (Apostolakis 1990), as well as results and decisions to be more clearly communicated. At European level, semi-probabilistic methods will be introduced more extensively in the second generation of the Eurocodes, such as design assisted by testing (CEN/TC 250 2013a).

On the other hand, probabilistic methods require better clarity on the assumptions used in design, more complex and time-consuming analyses, a mixture of subjective data (i.e. expert judgement) and objective data and observations, and ultimately a more in-depth decision-making process as data has to be collected, processed and analysed (Kirchsteiger 1999). Moreover, specific processes are normally in place in sectors where risk-based standards are used (e.g. nuclear industry) to check results and ensure consistency.

While better coverage of probabilistic methods in future design standards could be beneficial to enable all types of uncertainties to be explicitly considered, where and how these could be meaningfully applied should be examined more extensively and clarified, and the designers' community should be educated to their use.

5.4.3.6 Support modularisation and off-site manufacturing

As mentioned in Section 5.4.2, industrialised construction systems are increasingly used in the construction industry for their strong focus on modularisation and off-site manufacturing. In the UK these aspects gained significant attention in the Transport Infrastructure Efficiency Strategy (2017). While current design standards do not inhibit the adoption of these new systems as technical provisions are generally 'neutral' to the construction system adopted, the role that design standards could have in supporting their adoption more extensively is a topic that would require further investigation. This would probably require a closer interaction with product and execution standards, thus with manufacturing and construction. Key aspects that would need separate exploration are:

- people-related, e.g. in terms of skills and competence in this field, allocation of liabilities, etc.;

- process-related, i.e. how to support design flexibility while giving clear information on assembly of off-site components, interfaces / integration of different elements and materials, tolerances;
- technology-related, i.e. how to make appropriate use of technology including BIM.

5.4.3.7 Support a whole-life view

The disconnected approach to design, construction and maintenance of assets is a major concern to many civil engineering professionals (Aktan et al. 2007). This can be seen in both the technical decisions taken at the early stage of the design process, and the evaluation of costs[4]. Flint (from Sunley and Taylor 1982) for example recognised that "the correct balance between design and construction costs has never been investigated properly". Allen noted (1992) that "codes, written for the design of new facilities, also ignore some important design considerations such as maintenance of the facility (inspection and repair) and future alterations. This is partly because codes emphasize safety, not life-cycle cost." Similarly, the Industry Standards Group (2012) recommended considering whole-life value of assets, not just the design phase.

Major impediments to a more integrated design-construction-maintenance process in the construction industry have been identified in: (i) the fragmentation of responsibilities (Aktan et al. 2007); (ii) specific contract-delivery mechanisms such as those based on least-price (Aktan et al. 2007); (iii) very limited feedback loops through design, construction and maintenance stages, which only emerge once the structure is built and operated, meaning that they cannot have an impact on the project under consideration, but possibly on future projects[5] (Goel and Pirolli 1992); (iv) the difficulty in agreeing what the asset performance is throughout its life-cycle.

The last point is crucial. It can be difficult to define the performance of constructed facilities compared to that of manufactured products. Products are generally small and standardised

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[4] This is different to what happens in other sectors such as aerospace, which is characterised by significant feedback loops between design and production. Aerospace is a typical example of "concurrent engineering" (Kundu 2010), i.e. "a method of designing and developing products, in which the different stages run simultaneously, rather than consecutively". Moreover, aircraft designers must be cost-conscious as the standards chosen during the design phase have significant cost implications that extend throughout the entire lifecycle of the aircraft (Hitchcock 2002).

[5] Arguably, this is true if the designer carrying out the new design is the same and if appropriate procedures are in place to transmit this knowledge to the new project.

artefacts, which result from a manufacturing process carried out in a highly controlled working environment employing full-scale prototypes and that generally fulfil some very specific performance objectives.

In contrast, civil and structural engineering assets are big, one-of-a-kind, long lasting and complex structures, which result from a site-specific project-based activity, meaning that the opportunity to build full-scale prototypes is prevented. Assets are affected by the "inherent randomness in the demands on the facility and its capacity to withstand those demands, imperfect modelling of complex systems, insufficient data and lack of an experience base" (Ellingwood 1992)[6].

Moreover, assets are expected to address multiple, diverse and wide-ranging performance objectives. Their longevity of use suggests that specific consideration should be given to their performance throughout their life-cycle. This becomes even more complicated when dealing with infrastructure systems which are characterised by a strong interaction between engineered, natural and human systems (Aktan et al. 2007).

Digital technologies are radically changing how structures are conceived, designed and constructed. The introduction of BIM, virtual prototyping for design, manufacturing and operation, and improved process of manufacturing is offering significant opportunity to integrate design, construction and maintenance of assets. More integration between the different phases of the life-cycle of a structure is thus emerging, with standards playing an important part in the context of data formats, collaborative production of architectural, engineering and construction information, and specification for information management (see for example BS 1192 and PAS 1192 series). However, it is not clear the role that design standards (in the sense of standards for structural and geotechnical design) should play in this context.

5.5 Qualitative study

Part of the content presented in this section has been published in Angelino et al. (2014a) as personal contribution of the author.

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[6] In aerospace and automotive performance optimization is a key step in design, less relevant to common constructed facilities (special structures such as tall buildings may require specific parametric analysis to optimise the shape).

The role of design standards to different categories of stakeholders have been explored by means of a qualitative study. It involved semi-structured interviews of standards' writers from different European Member States (indicated with 'ISW'), brainstorming sessions with practitioners (indicated with 'BSP'), meetings with clients (indicated with 'MC') and researchers (indicated with 'MR'). Details of the methodology are provided in Section 4.3. Specifically, in one of the brainstorming sessions participants were asked to reflect on the purpose of design standards and the drivers to use them, whereas during the interviews with the experts and meetings with the clients and researchers they were asked to provide their view on the role of design standards.

5.5.1 General findings

The findings from the qualitative study confirm the roles of design standard that emerged from the historical and cross-sectorial reviews. Indeed, it was observed that design standards:

- Codify and share technical knowledge (BSP; ISW; MR).
- Provide an accountability framework (BSP). Participants to the brainstorming sessions recognised that design standards are used primarily because required in contracts and for compliance purposes, with standards providing a key means to fulfil contractual obligations. Participants also noted that a specific design method is not used if it is not explicitly mentioned in a design standard.
- Provide a means for the research community to achieve impact from their work (BSP; ISW; MR).
- Support consistency in design approaches (ISW).
- Handle risk and uncertainty (ISW; MR).
- Assist competent designers in verifying structural adequacy, particularly in checking relevant parameters or finding suitable design methods (BSP; ISW).
- Design safe, serviceable, durable and robust structures (BSP; ISW; MC).
- Enable economical design of structures and promote delivery of cost effective solutions (ISW; BSP; MC).
- Support design of sustainable civil and structural engineering works (BSP; ISW).
- Aid common design situations (BSP; ISW).

Consistent patterns emerged from the brainstorming sessions and the interviews. The only notable aspect was the emphasis on legal issues from experts originating from countries where design standards have a mandatory status (see Section 2.4). It is worth documenting the comment made by one of the interviewed on the concept of whole life-cycle cost, which reinforces the value of taking a whole-life view discussed in Section 5.4.3.7:

> "Talking about efficiency, it is helpful to think about where the costs come from on projects. There is the cost of design, the cost of construction and the cost of maintenance. If you split up the cost of design, you can have the cost of doing the design and the cost of the technical governance around the design, e.g. agreement of design contents. In big project, the latter takes quite a lot of time. When we talk about efficient design standards, at superficial level you might think that the most important thing is just the cost of design, but it is a tiny element of the cost of maintaining it, the technical governance around it. (…) Efficiency needs to be evaluated looking at the entire system".

The qualitative study also provided insights into two specific roles of design standards to designers presented below.

5.5.2 Specific roles of design standards to designers

5.5.2.1 Provide a framework to develop innovative solutions

A general agreement on the importance of standards to provide a framework to develop innovative solutions emerged from the brainstorming sessions and the interviews. An inherent tension also emerged between supporting innovation and aiding common design situations, which also stemmed from the cross-sectorial review (see Section 5.3.4.2).

However, a consensus was not reached on how and to what extent design standards can support innovation. A move towards performance-based (or outcome-based) requirements was advocated as beneficial to develop innovative solutions. However, when asked about performance-based requirements (PBRs) in the context of design, the responses showed limited appreciation of their features, as well as advantages and disadvantages compared to method-based requirements (MBR).

It is worth noting that some practitioners argued that design standards often inhibit freedom to develop innovative solutions, and that more attention should be paid to this issue. While this can be caused by the existence of unduly prescriptive technical provisions in certain standards, this statement can also be explained by the limited understanding of the voluntary status of standards among some participants.

5.5.2.2 Provide easy to use technical provisions

The role of design standards in providing easy to use technical provisions emerged from the brainstorming sessions and was confirmed in the interviews. The attributes of easy to use technical provisions were discussed with the participants and the findings are showed in Table 5.3.

Table 5.3 Attributes of easy to use technical provisions (reproduced from Angelino et al. 2014a)

Category	Attribute	Definition
Intrinsic attributes They represent usability of the content of its own, i.e. independent from the context of the design task in hand	Accuracy	The extent to which technical provisions/clauses are correct and reliable
	Clarity	The extent to which technical provisions are clear in scope, limitations and language with minimised risk of misinterpretation and misapplication
	Coherence	The extent to which technical provisions are presented in a coherent and logical way within the same standard and in cross-referenced standards
	Conciseness	The extent to which technical provisions are succinctly written
	Consistency	The extent to which technical provisions are presented in the same format (language and structure) in different parts of the same document or in other cross-referenced documents
	Credibility	The extent to which design standards are trusted by target users
	Ease of access	The extent to which technical provisions are easily and quickly identified within the same standard or, when cross-referenced, in other documents
	Ease of navigation	The extent to which different technical provisions/clauses/standards are well connected and easy to follow
	Simplified	The extent to which technical provisions are presented in a fashion that can be easily applied by users without requiring an understanding of all the underlying principles
	Speed of application	The extent to which technical provisions can be quickly applied
	Up-to-date	The extent to which technical provisions are not outdated by advances in technology, understanding or practice
	Validity	The extent to which technical provisions are reliable thanks to appropriate research and sufficient practical experience
Contextual attributes They represent aspects that must be evaluated against the context of the design task in hand	Completeness	The extent to which technical provisions are not missing and are sufficient for the design in hand
	Comprehensiveness	The extent to which a specific clause includes all necessary information for the design in hand with no need to make reference to other documents
	Relevance	The extent to which technical provisions are helpful for the design in hand
Representational attributes They focus on understanding by users	Flexibility	The extent to which technical provisions are able to be applied/used easily by users with different expertise for different design applications
	Understandability	The extent to which technical provisions are unambiguous and easily comprehended by all target users with minimised risk of misinterpretation

The definitions of the attributes in Table 5.3 have been developed using those provided in seminal work in data quality research[7] (Wang and Strong 1996; Pipino et al. 2002; Batini et. at 2009), which has been applied in the context of this research on design standards.

In line with Lee et al.'s (2002) assessment of information quality, the attributes of easy to use technical provisions have been classified in 'intrinsic', 'contextual' and 'representational'. The value in adopting this classification resides in the fact that only some attributes such as clarity and consistency are "intrinsic" to technical provisions. The other attributes must be evaluated either against the context of the design task in hand (contextual attributes) or focusing on users and their understanding (representational attributes). These are therefore more complicated to assess than the intrinsic attributes.

Participants were also asked to identify the attributes of good design standards. The emerged attributes cover both the usability attributes indicated in Table 5.3 and three additional attributes, i.e. (1) cost-effectiveness, (2) safety and (3) freedom to develop innovative solutions. These three attributes are not features of the document itself; rather, they refer to asset's design and to the role of design standards in driving outcomes.

Two conclusions have been drawn from this qualitative study. First, the usability of a design standard is largely associated with its technical provisions, whereas its quality requires a broader understanding of other factors. Second, the usability of a design standard is seen as a fundamental component of its quality as demonstrated by the difficulty of participants in providing quality attributes different from the usability attributes. This aligns to Bevan's (1995) claim that usability is "the highest-level quality objective" and to De Weck et al.'s (2011) statement that usability emerges largely from how users perceive quality. Figure 5.3 shows the link between quality and usability attributes of design standards.

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[7] Research into information systems and, specifically, in data quality for communication purposes has a long history and is a mature research field, particularly on techniques to assess and improve the quality of company's data and information (Lee et al. 2002) and on specific data quality dimensions (Batini et al. 2009).

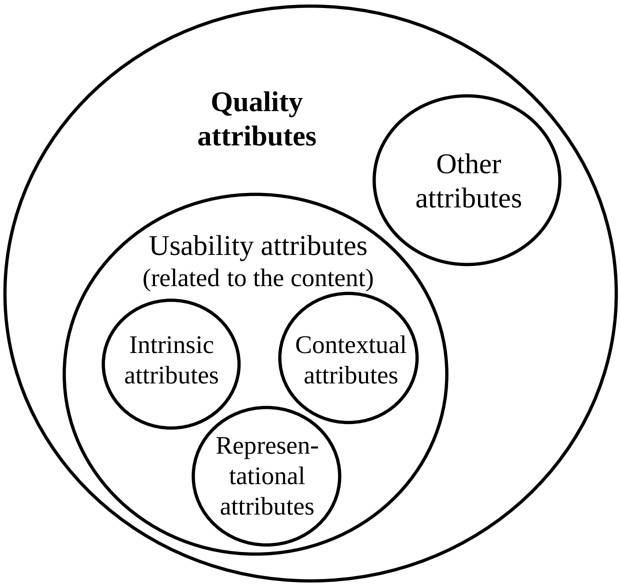

Figure 5.3 Link between quality and usability attributes of design standards

5.5.3 Limitations

One limitation of this qualitative study warrants mention. The sample size used in this study was small, thus it could be argued that the roles and the list of attributes examined above are not exhaustive and further items could be added by other participants. However, the credibility of the research findings (see Section 4.5) resides in their triangulation (different categories of practitioners, clients, researchers, and standards' writers from different countries involved), member checking (feedback asked to participants) and prolonged time of the research (interviews and brainstorming sessions were undertaken from October 2013 to May 2014, meetings with clients were undertaken from 2013 to 2018). The dependability of the findings will be supported and enriched by the themes emerged from the real projects presented in Chapters 7, 8 and 9.

5.6 Discussion

Literature review and the qualitative study reveal that design standards fulfil a variety of roles. Some of them represent core accomplishments and successes of design standards that need to be preserved and reinforced; some others have the potential to support the profound changes in the construction industry. The former mainly reflect historic roles of design standards in the construction industry (see Section 5.2.2) and their special role compared to other industries (see Section 5.3.4). They also aim to address recognised users' needs (see Section 5.5.1).

Drawing together the themes examined in this chapter, the author has identified sixteen distinctive roles of design standards, which are listed in Table 5.4. The table shows:

1. the source of the information, i.e. historic review, cross-sectorial review, evolution of the construction industry, and the qualitative study;
2. key beneficiaries of each role, i.e. designers, clients, constructors, product manufacturers, researchers, software manufacturers, and users of the assets, to show where value from design standards is added;
3. the role category: some roles are about high-level objectives of standardisation for design standards (Category 1), some are strictly connected with the content of the document, i.e. technical provisions (Category 2), and some others refer to the design of civil and structural engineering works and their expected performance (Category 3).

Category 1 embraces the roles that historically have proved to be essential to the process of standardisation of design standards in terms of compliance and control, competitiveness, communication among stakeholders, and means for the research community to achieve impact from their work (roles no. 1 to 4). It also comprises the role of design standards in managing risk and uncertainty and addressing climate change adaptation and extreme events (role No. 5).

Category 2 comprises well-established roles in terms of codification of knowledge, verification of the adequacy of design, consistency in design approaches, framework for innovation, (roles no. 6 to 9) and foreseeable future roles of design standards stemming from current drivers to change in terms of support to the design of structural modifications and digital models (roles no. 7 and 10). It is worth noting the need to move towards more user-orientated design standards (role no. 6), whose attributes are presented in Table 5.3.

Category 3 comprises well-established (roles no. 11, 12, 14) and foreseeable future roles of design standards (roles no. 13, 15, 16) in the context of the design of civil and structural engineering works. They emphasise the role of design standards in supporting the achievement of expected performances of assets (e.g. safety, cost-effectiveness, sustainability) taking a whole-life view, and the potential role in supporting modularisation and off-site manufacturing. Category 3 is linked to Category 2 as the way content is presented may support or inhibit the design of safe, cost-effective and innovative civil and structural engineering works.

Table 5.4 Roles of design standards

Category	Roles of design standards	Source				Key beneficiaries						
		Historic review	**Cross-sectorial review**	**Evolution of the industry**	**Qualitative study**	**Constructors**	**Designers**	**Clients**	**Product manufacturers**	**Researchers**	**Software manufacturers**	**Society / users of the asset**
Cat. 1 Roles related to high-level objectives of standardisation	1. Control built environment.	■						■				■
	2. Support competitiveness.	■				■	■	■	■	■	■	
	3. Frame common understanding among stakeholders.	■				■	■	■	■	■	■	
	4. Provide common basis for research and development	■			■					■		
	5. Manage risk and uncertainty, including climate change and extreme events.		■	■	■		■	■				■
Cat. 2 Roles related to the content of the design standard (technical provisions)	6. Codify technical knowledge in a user-orientated fashion.	■			■	■	■	■	■	■	■	
	7. Enable adequacy of design to be verified, including for the design of structural modifications or rehabilitation schemes.		■	■	■		■	■				■
	8. Ensure consistency in design approaches.	■			■		■	■				
	9. Provide a framework to develop innovative civil and structural engineering works.		■		■	■	■	■	■	■		■
	10. Enable structural verifications to be incorporated into digital models.			■			■				■	
Cat. 3 Roles related to the asset's design	11. Support the design of safe, serviceable and durable civil and structural engineering works.	■			■		■	■				■
	12. Support the design of cost-effective civil and structural engineering works.	■			■		■	■				■

Category	Roles of design standards	Source				Key beneficiaries						
		Historic review	Cross-sectoral review	Evolution of the industry	Qualitative study	Constructors	Designers	Clients	Product manufacturers	Researchers	Software manufacturers	Society / users of the asset
	13. Support the design of sustainable civil and structural engineering works.			■	■		■	■				■
	14. Support the design of common design solutions.		■		■		■	■				
	15. Support modularisation and off-site manufacturing.			■		■	■	■	■	■		
	16. Support a whole-life view.			■			■	■				■

5.7 Conclusions

The construction industry relies heavily on design standards and will continue to do so especially considering the profound changes that it is experiencing. Digital and smart technologies are increasingly transforming the way structures are designed, built, managed, operated and dismantled. Coupled with that, future assets are expected to be more sustainable and able to cope with climate change. However, the one-of-a-kind nature of constructed facilities coupled with their complexity, size and long life, means that civil and structural engineering works are fundamentally different from other types of engineered artefacts such as aircrafts and vehicles, and that design will continue to be primarily standards-driven. This is opposed to manufactured serial products, where prototype testing on full-scale artefacts is the norm to certify that the product meets the requirements contained in relevant standards.

Literature review and a qualitative study carried out with designers, standards' writers, clients and researchers have revealed that design standards fulfil sixteen distinctive roles, which are summarised in Table 5.4. They comprise the roles related to high-level objectives of standardisation for design standards (e.g. control the built environment and enable adequacy of design to be verified), those related to the content of design standards (e.g. codify technical knowledge in a user-orientated fashion and ensure consistency of design approaches), and those related to the design of civil and structural engineering works (e.g. support the design of safe, cost-effective and sustainable civil and structural engineering works). The key beneficiaries of each role have also been identified. As expected, designers, clients and users of the assets are the categories of stakeholders which receive most of the value delivered by design standards.

Although the sample size used in the qualitative study was small (10 practitioners, 5 experts in standards writing, selected UK clients and researchers), the credibility of the research findings resides in the triangulation of the responses with the desk study presented in this chapter, and the prolonged time of the author immersed in the research field.

From the qualitative study some preliminary insights into the attributes of good and easy to use design standards also emerged. They show that the usability of technical provisions is a key component of the quality of a design standard to users. The quality attributes are much broader, meaning that a good design standard is more than a good document and that additional aspects need to be factored in to develop better design standards.

The roles of design standard examined in this chapter represent the starting point for the discussion on the quality of design standards. Assuming that quality means "fitness for purpose", a high-quality design standard should be able to fulfil the identified roles. While this is a useful claim, in reality there are challenges in pursuing this goal and translate it into practical steps for standards' writers. These aspects are explored in the following chapters.

Chapter 6

Challenges in design standards

Part of the work presented in this chapter has been published in Angelino et al. (2014a) as personal contribution of the author.

6.1 Introduction

Over the years design standards in the construction industry have increased in complexity as mentioned in Chapter 3. In 1970, it was observed that "our codes seem to get more and more complicated" (Institution of Structural Engineers 2000). Forty years later, similar comments can still be heard in meetings and workshops with practicing structural engineers, clients and industry bodies. "Too complex", "does not cover what is needed", "too expensive", "difficult to follow", and "poorly organised", are the comments reported by Nethercot (2012) from conversations, correspondence columns of Engineering Journals and Magazines, and discussion sessions at meetings and professional courses.

Design standards deal with complicated technical topics, thus by their very nature some intrinsic complexity in use is to be expected. However, it is worth asking where the high level of perceived complexity of design standards stems from and what can be done to reduce it. The purpose of this chapter is to delve deeply into this topic by looking at the challenges that may emerge at different stages of the life-cycle of a design standard (see Table 2.5 for an overview).

This chapter is structured as follows. Section 6.2 outlines the data used for this study. Section 6.3 examines the challenges in conceptualisation and development of design standards. Section 6.4 illustrates the challenges in their use. Section 6.5 presents the challenges in implementation, maintenance and derogation stages. Section 6.6 reflects on the findings of this study and their relevance to the debate on better design standards.

6.2 Data collection

Existing literature in the UK and the US has been reviewed and a qualitative study has been undertaken.

Key publications for the UK are represented by the reports on two open debates mentioned in Chapter 3. The first debate was proposed by Moffatt and Dowling (1980, 1981) at the Institution of Civil Engineers on how to codify the rules of structural design. The second was proposed by Sunley and Taylor (1981, 1982) at the Institution of Structural Engineers on the role of codes of practice. These documents are presented in the next sections under the general reference "*UK debates*". The participants to the debates are also cited where needed. Although dated, these documents represent a key source of information due to the eminent audience involved and the richness of topics covered. Nethercot's (2012) discussion on modern codes of practice and the Industry Standards Group's (2012) report are also illustrated. Relevant publications for the US reviewed in this chapter are the Poston and Dolan's (2012) discussion on how to enhance codes' user-friendliness in the US, and the Bulleit's (2012) presentation of the process of "encoding" of technical knowledge by standards makers and "decoding" of technical provisions by users. Additional publications are also cited in the following paragraphs as needed.

The qualitative study examined in this chapter has been introduced in Sections 4.3.2 and 4.3.3. For the purpose of this exploration, in one of the brainstorming sessions and during the interviews participants were asked to reflect on the complexity of the current generation of design standards (particularly the Eurocodes), typical problems experienced by users and the issues associated with the standardisation process. The findings are presented in the next sections under the reference "*brainstorming sessions*" and "*interviews*" respectively. The quotes from the five interviews have been left anonymous for confidentiality requirements and indicated with the general abbreviation *P1*, *P2*, *P3*, *P4* and *P5*.

6.3 Challenges in conceptualisation and development

The challenges in conceptualisation and development of design standards emerged from literature review and the qualitative study are summarised in Table 6.1 and examined in detail in the following paragraphs. They have been classified into (i) those related to the content of the document, (ii) those related to human issues, (iii) those related to procedural aspects, and (iv) those linked to external factors.

Table 6.1 Challenges in conceptualisation and development

Content	Human issues	Procedural aspects	External factors
• Balance between advice and requirements • Boundaries between design standards and other documents • Balance between performance-based and method-based requirements • Organisation of content	• Subjectivity in development • Writing skills of standards' writers • Users' engagement • Competing needs of stakeholders • Purpose of design standards	• Time for drafting and review • Resources availability	• Changes towards a smarter construction industry • Political aspects • Legal aspects • Social and cultural aspects • Economic aspects • Sustainability aspects

6.3.1 Content

6.3.1.1 Balance between advice and requirements

As discussed in Chapter 2, design standards are generally made up of some core content and supporting parts. The core provisions are generally differentiated into advice and requirements according to whether technical provisions are indicative (i.e. optional) or exclusive (i.e. mandatory) respectively. In this context, the issue for standards' writers is to balance advice and requirements. However, this is not straightforward.

In the *UK debates*, it was recognised that with increasing technical knowledge codes had become much longer, they have tended to become "anonymous textbooks for design" (Hayward, from Moffatt and Dowling 1981) and contain too much peripheral aspects (Goldstein, from Sunley and Taylor 1982), i.e. too much advice. Similarly, in the *interviews* it was recognised that "the Eurocodes appear – in some cases – between a deterministic code and a text book" (P1) and that this makes them difficult to use.

It was argued that all codes should have an appropriate balance between generalities of practice and specific design information (Bromhead, from Moffatt and Dowling 1981). It was suggested to differentiate clearly between mandatory and desirable provisions such as background, commentary and guidance (Wilby, from Moffatt and Dowling 1981; Wolchuck, from Moffatt and Dowling 1981).

Likewise, the Industry Standards Group (2012) noted that "it is not always made clear which [contents] are mandatory and which provide guidance (and are therefore open to interpretation)". The Industry Standards Group (2012) also recommended a critical review of standards to identify "the absolute minimum requirements" that are necessary for safety and efficiency reasons.

6.3.1.2 Boundaries between design standards and other documents

It does not seem to be easy to define what a design standard should provide and what instead should be given by complementary documents. In the *UK debates*, this issue was acknowledged and the importance of defining clearly the boundaries was advocated. An interesting consideration was made in the *interviews* (P3) on the value of looking at standards from multiple perspectives:

> "Good standards are a combination of why, what and how. The 'why' promotes understanding. The 'what' looks at specific requirements. The 'how' is the material that enables the 'what' to be achieved".

The 'why' is represented by compounding documents such as background information, 'what' is the requirement provided, and the 'how' is the supporting advice. It was noted that "a good commentary explaining the background and the design philosophy of the rules is indispensable for proper application of the code" (Wolchuck, from Moffatt and Dowling 1981). This can be particularly relevant when considering that (P2):

> "There are two types of engineers: know-how engineers – all they want are instructions, they don't care about background – and know-why engineers – they do care about background".

6.3.1.3 Balance between performance-based and method-based requirements

Technical provisions contained in design standards can be unduly conservative, for example when requiring the use of a specific design method which is not relevant in all cases and which instead could be presented as a recommended or permitted method, rather than as a requirement. To overcome this issue, the Industry Standards Group (2012) recommended defining outcomes or performance rather than inputs or methods.

Nevertheless, striking the balance between performance-based and method-based requirements is not an easy task. Bulleit (2012) noted that overly "explicit codes" (i.e. those providing methods and specific inputs) increase the length of documents and can stifle innovation when not leaving freedom to use alternative, more appropriate options, whereas overly "implicit codes" (i.e. those providing only high-level principles or outcomes) require users to glean directly from the their knowledge space and can decrease design consistency.

Similarly, Elms (1999) noted that "if codes are too implicit, then proper enforcement of construction requirements for safe structures can be difficult to perform and the likelihood of a structural failure may be increased". Likewise, Nethercot (2012) stated that performance-based codes encourage innovation, but they are more difficult to use since they require designers to glean from other sources to find guidance on how requirements can be met. These issues have also been recognised in the interviews (P3):

> "If that [only general principles or performance] is all you provide, then you end up with documents that are almost impossible for users to apply, so you have to do more than that, but the question is: how much more do you give users? Historically that is approached in different ways in different countries and a balance is needed".

The situation is further complicated by the fact that the concept of performance of a constructed facility is loosely defined for three main reasons: (1) there is a lack of objective data describing the performance of civil and structural engineering works; (2) it spans multiple realms including technical, financial, social and environmental aspects (Aktan et al. 2007); (3) it requires understanding of aspects which span far beyond the design phase. While (1) is a theme currently explored (see Sections 5.4.2 and 5.4.3 on the use of innovative technologies in sensors and data management), (2) and (3) would require specific investigation.

6.3.1.4 Organisation of content

As discussed in Section 2.6.2, standards' writers can choose between structure-type standards (standard for bridges, standard for buildings, etc.) or material-type standards (standard for concrete structures, standard for steel structures, etc.). In the *interviews*, the choice between structure-type standards and material-type standards was considered a "controversial topic" (P2) since compelling arguments can be produced for both.

In principle, structure-type standards seemed the most promising solution since users could find all information they needed in one document. Yet, having different standards for different structures would require repetitions of technical provisions and when one element changes, all other documents should change accordingly. Moreover, when there is interaction between different structural types (e.g. concrete and steel structures), their interfaces could be an issue.

In the *UK debates*, it was noted that the main benefit of structure-type codes is the availability of all necessary information for a specific structure in one document. On the other hand, it was argued that the behaviour of a material does not change from application to application and that organisation according to structure type leads to the duplication of information and possibly inconsistent terminology and design philosophy.

The application of XML to standards development (see Section 2.6) can solve most of the issues identified above. Through markup language and metadata, XML helps extract relevant content from the same underpinning text, and filter the information needed in terms of structural material or structure-type. Poston and Dolan (2012) suggested grouping together and bookmarking provisions for member design and detailing following the design process. This approach still implies a pdf-centric view of design standards and a static experience of the content by users. XML based content and derived products such as Eurocode PLUS (see Section 2.6) overcome these issues.

6.3.2 Human issues

6.3.2.1 Subjectivity in development

The development of a design standard is influenced by standards' writers' tacit knowledge, experience and expertise. There are different types of standards' writers: those who provide detailed provisions to help designers (particularly young engineers) in their tasks; those who assume a high level of competence by designers; those who believe that only high-level principles should be provided arguing that "design standards are not textbooks" (P4); those who "tend to promote their own expertise" (P2) by introducing complex methods; and many more.

This highly subjective process is called by Buillet (2012) "encoding" and comprises codification and sorting (see Figure 6.1). In the encoding phase, standards' writers are responsible for (i) translating their knowledge into technical provisions, (ii) selecting and organising the content in the text, (iii) balancing competing demands by different stakeholders, and (iv) taking account of legal, social and economic aspects *inter alia* as discussed below. Reflecting on the issues that may arise in standardisation committees, P3 noted the potential inconsistencies that may stem from the level of autonomy that they have and the need for "a lot of dialogue to improve clarity and consistency".

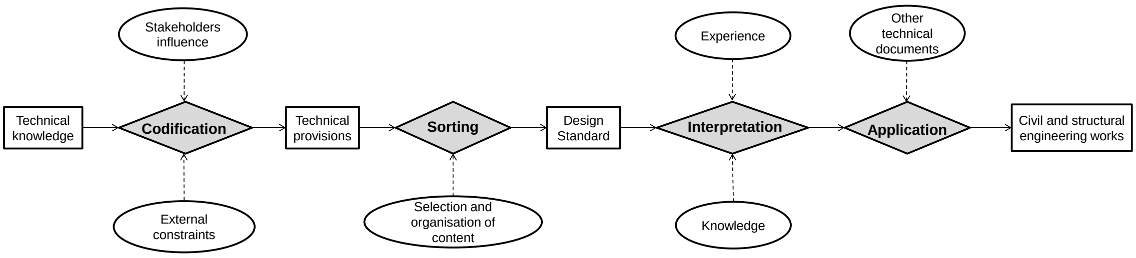

Figure 6.1 Encoding and decoding process (adapted from Bulleit 2012 and Angelino et al. 2014a)

6.3.2.2 Writing skills of standards' writers

Participants to the *interviews* and the *brainstorming sessions* observed that different standards' writers have different writing skills, which ultimately affect (positively or negatively) the quality of the text produced and its understandability. It was noted that not all experts or technical specialists are good at writing standards and that this activity requires specific skills and competence.

6.3.2.3 Users' engagement

In the *UK debates*, the concern of an uneven representation of experts and designers in the team of standards' developers was raised. This issue was also noted in the *interviews*:

> "What would be useful is to have professional engineers who sit with standards' writers and indicate what could not be acceptable to the design practice (…) The drafting teams should be carefully chosen to ensure designers representations". (P2)
>
> "Standards are produced for users, not for experts' interest". (P3)

The issue of the users' engagement and their limited participation in standardisation committees was also noted in the *interviews*. It was recognised that often people are not particularly interested in engaging in the standardisation process, or do not have enough time or money to participate, thus their needs may not be fully addressed. Nethercot (2012) noted that, whilst codes are "an easy target for complaint" by designers, it is equally true that many of them do not contribute to the standardisation process when they have the opportunity (for example when the draft of the code is published for consultation). On top of that, Nethercot also recognised that, when public comments are collected, "a disappointingly small proportion—perhaps less than 5%—of public comments are incisive and well thought through and have the potential to improve the document".

Arguably, more education on the role of standards for the engineering profession, along with more effective communication on the opportunities made available to influence the standardisation process and whether and how the feedback received have been taken on board to improve the draft, would help increase user participation while improving the quality of comments received. Introducing online collaborative tools would also beneficial to overcome geographic barriers and reduce costs.

6.3.2.4 Competing needs of stakeholders

Although in theory standardisation should be a transparent and open process of cooperation among stakeholders (see Principle 2 of standardisation in Chapter 2), this is not always the case. In such a multi-stakeholders process, actors may have diverse interests and may exert different degrees of power (or influence).

Nethercot (2012) acknowledged the different and "frequently competing" stakeholders' interests, as well as the inherent contradictions that may arise while trying to meet their needs. Allen (1992) also argued that stakeholders might contribute negatively to the standardisation process due to their competing needs, and notes that this issue may affect the usability of standards and their success. He also acknowledged that:

> "If there is too much influence from experts, the codes may become difficult to use (difficult to understand, difficult to build, etc.). If there is too much influence from a manufacturing segment, the codes may result in unfair competition or may not adequately protect people".

Similarly, Nethercot (2012) highlighted the tensions that exist between the aspirations of practitioners for greater economy, simplicity and all-embracing provisions and the desire of the research community for technically advanced provisions. In other words, the standardisation process can become "a political or economical power game although the topics discussed are mostly of a purely technical nature" (Takahashi and Tojo 1993).

6.3.2.5 Purpose of design standards

Whilst design standards fulfil specific roles (see Chapter 5), more specific expectations may be claimed by different stakeholders and be in contrast. Weiss (1991) writes that "while the stated goal of developing a viable standard may be adopted by most of the committee members, other, secondary, goals may also exist and these may be in conflict". In the *UK debates*, the need for an agreement on the purpose of design codes was advocated by many voices as presented below:

> "If the structural codes continue to be drafted as multipurpose documents, they will inevitably become more and more incomprehensible and less and less usable". (Armitage, from Sunley and Taylor 1982)

> "There are so many conflicting voices, so many people wanting to see different things in the same document, and so many different perceptions of the purpose of the document" (Watson, from Sunley and Taylor 1982)

> "The first thing any code of practice drafting committee must do is decide what purpose the code is intended to serve". (Hargreaves, from Moffatt and Dowling 1981)

6.3.3 Procedural aspects

6.3.3.1 Time for drafting and reviewing standards

Standards development typically entails numerous drafting and review cycles (see Section 2.2.4). While it was recognised that quicker standards development processes already exist, for example the Public Available Specifications produced by ISO or BSI, during the *brainstorming sessions* it was queried whether more efficient ways of drafting could be introduced to streamline the process of development and update of standards.

6.3.3.2 Resources availability

During the development stage of a standard there can be inefficiencies due to the limited resources available, both financial and human. In the *interviews* it was noted that the development of a standard is a costly process (P2) as also recognised by Allen (1992). Similarly, there may not be enough technical support or the support available relies heavily on volunteer work. According to Allen (1992) strong reliance on volunteer support can lead to "the continuance of codes which are either unsatisfactory or out of date".

6.3.4 External factors

6.3.4.1 Changes towards a smarter construction industry

As examined in Chapter 5, the construction industry is increasing recognising the potential of digital and smart technologies (building information modelling, automation, new sensor technologies, etc.), to positively impact how structures will be designed, built, managed, operated and dismantled. How design standards can drive and support these changes is still on open question as noted in Chapter 5. However, addressing this aspect would maximise the opportunities that design standards can offer and avoid making them blockers to this foreseeable future.

6.3.4.2 Political aspects

A design standard can be supported by or enforced for political reasons. As an example, at European level in 2012 the European Commission through CEN started the process of evolution of the Eurocodes (European Commission Enterprise and Industry Directorate-General 2012) in order to (i) encourage and accompany innovation taking into account "new societal demands and needs", (ii) "facilitate the harmonisation of national technical initiatives on new topics of interest for the construction sector" and (iii) "assist new entrants to the market and small- and medium-sized enterprises". Standards' writers are thus expected to translate these general public policy objectives into specific technical provisions. This can be particularly challenging when dealing with new subject areas such as sustainability (see Section 6.3.4.6).

6.3.4.3 Legal aspects

In the *UK debates* it was noted that standards' writers must always be conscious of the legal regulatory system in the background to ensure that standards are to achieve their full usefulness. The link between standards and regulations is presented in Section 2.6.

6.3.4.4 Social and cultural aspects

The development of design standards requires careful consideration of the high degree of social responsibility that the structures have and the impact that structural failures may have on safety, health and well-being of population. Different safety cultures exist in different countries, which shape the perception and evaluation of risks (Douglas and Wildavsky 1982) and their translation into design parameters. As an example, the Eurocodes explicitly provide a mechanism for European Member States to exercise their right to determine values related to regulatory matters through the National Annexes, which contain parameters that are left open for national choice (Denton et al. 2010).

6.3.4.5 Economic aspects

Safety has a cost. Faber (2007) notes that:

> "The level of safety to be guaranteed for the individual members of society is a societal decision with a strong bearing to what the society can afford; (…) society only has limited resources at hand and thus must prioritize".

Economic aspects manifest themselves in three distinct situations. First, technical provisions can be presented in a way that promotes or inhibits the design of cost-effective solutions. This can be seen in two circumstances. The first circumstance is the case of simplified design methods against more rigorous ones. The former are generally quicker to apply, but provide more expensive design solutions. Nethercot (2012) noted that generally designers want to minimise time to design in response to "the pressures of fee competition and practice economics". In such a context, having simple or – perhaps more appropriately – simplified design approaches is helpful. On the other hand, clients typically desire economic solutions and competitive results, which are generally achieved by considering more sophisticated approaches. Clearly, it is difficult to strike the balance between these rival aspects. The second circumstance is when the design standard requires fulfilling requirements that can provide substantial additional costs. As an example, Elms (1999) argued that it was not always straightforward to apply sustainability principles in a competitive market as they could add significant costs to designs. However, cost-efficiency should not be evaluated against design costs only, but looking at the life of the structure as noted in the *interviews* (see also Section 5.4.3.7).

The second aspect is that economy is an important factor when setting target reliability levels. Since higher costs are normally associated with increased safety, the calibration process of a design standard should aim at optimising factors for actions and resistances, which in turn would minimise the total cost of a civil and structural engineering work (Atkans et al. 2001). Cost optimisation approaches for code calibration typically consider the initial cost of design, a variety of costs relevant during the design life of the structure (such as construction cost, maintenance costs, future rehabilitation costs), and the cost of failure. A discount rate is generally introduced to take account of the country under consideration (for example between 2% and 4% for developing countries). An example of cost optimisation procedure for individual structural components is provided by Atkans et al. (2001).

The third economic aspect that has to be considered when developing a design standard is the impact that it may have on the choice of structural materials. Indeed, design standards are expected to support all structural materials equally (Allen 1992). A comment on this aspect was also made during the *interviews* (P2):

> "Having a single standard on basis of design enables the risk of commercial advantage of one material on another or, in other words, of an unfair competition in the market to be reduced."

6.3.4.6 Sustainability aspects

Sustainability has been examined in Sections 5.4.1 and 5.4.3.2. For the purpose of this discussion, a challenge can be seen in the potential difficulty in developing technical provisions, which provide a framework to develop sustainable civil and structural engineering works. Clear recommendations should be given to designers (i) to select materials and products that can be safely decommissioned at end of life and then re-deployed where possible, and (ii) to assess and implement measures that increase design life from early stages of the design process in order to reduce the need for future maintenance and repair.

6.4 Challenges in use

Challenges in the use of design standards are summarised in Table 6.2 and examined in detail in the following paragraphs. They have been classified into (i) those related to the content of the document, (ii) those related to human issues, and (iii) those linked to external factors. No procedural aspects emerged from this study.

Table 6.2 Challenges in use

Content	Human issues	Procedural aspects	External factors
• Increase in technical standards • Cross-references among documents • Navigation between technical provisions • Length of design standards • Degree of complexity of standards • Novelty of requirements	• Users' needs and primary audience • Subjectivity in use: users' skills and learning component	-	• Contractual aspects • Legal aspects

6.4.1 Content

Part of the work presented in this section has been published in Angelino et al. (2014a) as personal contribution of the author.

6.4.1.1 Increase in technical standards

In recent decades the construction industry has been affected by a tremendous increase in technical standards developed by organisations operating at international, regional and national level. The situation is also made challenging by client and industry standards, which are developed by independent organisations for specific products or industry sectors (see Section 2.5 for a classification of standards relevant to the construction industry). In other words, "what Freyssinet a quarter of a century ago called «a rage of regulation», continues unabated" (Harris, from Moffatt and Dowling 1981).

One of the consequences of this issue is that it may bring about challenges on how designers respond to the often-overwhelming flow of information provided in standards as well as in other companion documents in a meaningful manner. As Simon (1996) argued, “the meaning of knowing has shifted from being able to remember and repeat information to being able to find and use it”. This represents a key challenge for engineers nowadays.

6.4.1.2 Cross-references among documents

The application of systems of standards (i.e. suites of cross-referenced standards) further increases the challenge for designers. Standards not only address design requirements, but also requirements for materials and products (e.g. EN 206 on concrete, EN 1337 for structural bearings, EN 338 for structural timber) and those during execution (e.g. EN 1090 for steel structures, EN 13670 for concrete structures, and EN 14199 for micro piles).

The cross-references among standards stemming from different normative sources can cause overlapping – and sometimes conflicting – requirements or gaps, which increase the risk of misapplication. Moreover, when links between different standards are not established properly, the issue is that the reference can become obsolete. The Industry Standards Group’s (2012) report recognised this issue and recommended eliminating unnecessary duplication and conflict and, consequently, reducing the number of standards. While this work was published six years ago, this recommendation is still relevant as demonstrated by the case studies presented in Chapters 7 to 9.

This risk is further increased by the use of a wide range of documents, such as technical specifications, design guides, text books and worked examples. Nethercot (2012) noted that the increasing wealth of information provided to designers by these peripheral documents often decreases the need to use standards themselves. Nethercot (2012) also clarifies that the appropriate use of standards and accompanying documents is based upon “education, experience and understanding” of structural engineering.

6.4.1.3 Navigation between technical provisions

The increase in technical standards and the existence of cross-references among documents can make navigation challenging and have a negative impact on the text comprehension by users. However, navigation can also be difficult in one single document as noted in the *interviews*. To overcome this issue and enhance accessibility of technical provisions, P1 recommended identifying “preferential routes” within the standard to enable easier navigation among related technical provisions. Specific aids exist to help the flow of the text, which include flowcharts, hyperlinks, decision tables, diagrams, etc. In particular, decision tables were introduced in a study carried out in the US (Fenves et al. 1969) to aid standards' writers in verifying that all relevant design situations have been covered, and to support designers in identifying relevant conditions, actions and rules.

A more general recommendation to enhance navigation was made by P3, who suggested looking at the "patterns" of design standards, i.e. the way technical provisions are presented. From the interview it emerged that two types of patters may exist: (i) a hierarchical structure of the text, where information is provided sequentially according to a general design process (see Figure 6.2); (ii) a network structure, where technical provisions are linked to each other (see Figure 6.3). P3 acknowledged that the study of the patterns of design standards is a totally unexplored field.

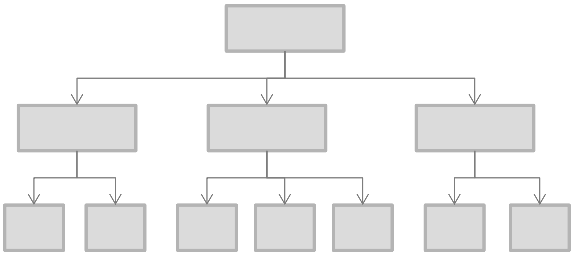

Figure 6.2 Hierarchical structure of the text

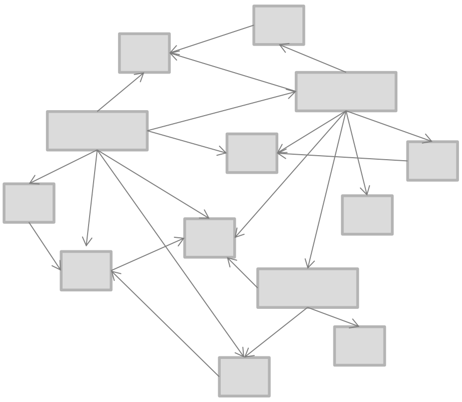

Figure 6.3 Network structure of the text

6.4.1.4 Length of design standards

With increasing technical knowledge design standards have become much longer. Dibley (1990) ascribed the increased complexity in codes of practice to their comprehensiveness and greater accuracy. In the *UK debates*, it was noted that the length and complexity of codes largely resulted from the effort by drafting committees to include as much guidance as possible "in an attempt to cover in detail the complete range of construction likely to be built to the code being prepared" (Menzies and Armer, from Moffatt and Dowling 1981).

Nethercot (2012) stated that it is not rare to hear comments about the advantages in including in codes "everything that is needed", which in turn is based on the claim that "the more we know the more we codify". This has led to the growth in the length of design standards, which according to Nethercot is not a problem, provided that the layout of the document, the system of indexing and cross-references are appropriate, and considering that in reality designers are not expected to read the entire standard, but only relevant sections. Recent developments in IT tools (see Section 2.6 on XML and DOIs) support better accessibility of the content, ease of navigation and opportunity to extract and share relevant information in an online environment (an example is Eurocodes PLUS, see Section 2.6).

Interestingly, in the *UK debates* it was acknowledged that "the increases in length and complexity of codes are an implicit attempt to remove the need for the designer's interpretation" (Menzies, from Moffatt and Dowling 1981). Nethercot (2012) also noted that brevity is generally seen beneficial. However, too short documents may appear obscure, particularly when dealing with complex topics.

6.4.1.5 Degree of complexity of standards

Design standards can span from simple to overly complicated and a balance between them is needed. The issue with simple standards (considered as "recipe books") emerged in the *interviews* (P3):

> "When users apply standards for the first time, they want something straightforward like a recipe book, but that becomes frustrating in the long term as over-simplified standards give conservative technical provisions. (…) There is a real tension between making standards simple, easy, straightforward and making them economic and flexible".

This issue was also noted in the *UK debates*. It was pointed out that simple codes, which are defined as "codes that depend on a simplistic and to that extent unrealistic formulation of structural behaviour" (Horne, from Sunley and Taylor 1982) are "limiting since structural behaviour is certainly not simple in most cases" (Rowe, Sunley and Taylor 1982).

On the other hand it was noted that "complex codes can confuse but should be written so that they do not" (from Sunley and Taylor 1982). A balance is needed between simplified and rigorous provisions due to the impact they have on the economy of the structure (see Section 6.3.4.5). An interesting difference between "simple codes" and "simple design" was noted in the *UK debates*

(Kerensky, Sunley and Taylor 1982). The former was described an "illusory phase", whereas the latter was considered not prohibited provided the right level of safety and economy was guaranteed.

A specific issue is related to their intrinsic technical complexity. Design of civil and structural engineering works can be complicated and requires specific technical knowledge. New design approaches, complex calculations such as non-linear analysis, design assisted by testing, seismic analysis, structure and ground interaction, the multiplicity of types of loading and structural systems, can all affect the complexity of design and of design standards (*UK debates*; Dibley 1990).

6.4.1.6 Novelty of requirements

There has been an increasing call for practicing structural engineers to consider new requirements (European Commission Enterprise and Industry Directorate-General 2012) such as those related to sustainability particularly to meet societal demands or enable better economy. Nethercot (2012) argued that typically any new standard is generally perceived as unfamiliar, technically more complex, difficult to use, and requiring longer time to design, particularly when the potential benefits to users are not emphasised enough. This can be particularly challenging when the new content refers to innovative solutions, methods or materials.

6.4.2 Human issues

6.4.2.1 Users' needs and primary audience

Design standards are primarily used by designers. The importance of evaluating carefully their needs was highlighted in the *interviews* (P3):

> "Generally, anyone looks at needs typically from their perspectives or the perspectives of people that work close to them and then necessarily they do not have the breadth of understanding of different needs of different users. (…) there is always the risk that people make assumptions about the needs of users which are based on their own experiences".

There are inherent complexities and dichotomies in striving to meet the needs of many users (P3):

> "In the process of optimisation of a standard for a particular users' population, there is a risk to impact negatively on other users".

Moreover, whilst all users are important, it is difficult to fulfil all their aspirations simultaneously as recognised in the *UK debates* (Kenyon from Sunley and Taylor 1982; Watson, from Sunley and Taylor 1982). This concept is not new. Bryson (2004) noted that in a multi-user environment meeting the fundamental expectations of key stakeholders is essential for a successful outcome. The choice of which stakeholders can be considered as "key" is not easy insofar as it is political, may have ethical consequences and generally involves judgement (Bryson 2004).

Defining a primary audience for the document, meeting their needs and keep the idea of the primary audience clearly in mind as drafting work continues were advocated in the *UK debates* to reduce complexity (Needham, from Sunley and Taylor 1982; Sunley and Taylor 1981; Watson, from Sunley and Taylor 1982).

6.4.2.2 Subjectivity in use: users' skills and learning component

In Section 6.3.2.1 the subjectivity in the development process of a standard was introduced. Similarly, specific knowledge and experience are required to users in a "decoding" process, which comprises interpretation and application (see Figure 6.1). Designers have diverse skills as recognised in the *UK debates*. Similarly, Nethercot (2012) reported some comments from the Chair of a standardisation committee on the development of the UK's first limit states bridge design code, who noted the different priorities of designers mainly for their diverse skills:

> "Many plead for simplicity in a code both for speed of application and to enable it to be used by Engineers with limited experience. Some expect rules to be both simple and all embracing. Others expect that they should refer to fundamental knowledge when designing major bridges and want freedom for experienced designers to work beyond the scope of a code. Those competing for worldwide markets require the code to produce the 'most economical' bridges".

Nethercot (2012) recommended allowing designers with differing degrees of skill to apply design standards as appropriate, as well as enabling skilled users to apply their knowledge without being unduly constrained. Assuming a certain level of knowledge and competence of designers was also advocated in the *UK debates*.

Participants to the *brainstorming sessions* observed that a broad category of designers with different skills and capabilities exists (from graduate engineers to experts) and that design standards, trying to meet the needs of all the categories of designers, have increased in complexity. It was also recognised that specific attention should be paid on how design standards can accommodate the needs of different categories of designers, while supporting a critical application of their content.

These considerations suggest the importance of considering users' skills and capabilities and developing design standards that explicitly recognise the importance of how different categories of designers extract information from design standards and design. Interestingly, there does not appear to be any study exploring this issue. This aspect will be examined in detail in Chapter 10.

6.4.3 External factors

6.4.3.1 Contractual aspects

In the *UK debates* it was argued that "a client expects his Engineer to follow a code that has been published by a reputed authority" (Chatterjee, from Moffatt and Dowling 1981). Design standards provide a key means to designers to fulfil a contractual obligation when explicitly required (see Section 5.5). Therefore, if design standards are incorporated in a contract, they must be used by designers.

6.4.3.2 Legal aspects

While design standards are not regulations as emphasised in Section 2.4, their legal status can vary. In some countries design standards are mandatory as referenced by regulations "exclusively". In others they assume the form of "deemed-to-satisfy" documents where referenced by regulations "indicatively". In some countries, design standards are merely advisory and optional documents. When a design standard is deemed to satisfy the requirements of statutory regulations, this may have a negative impact on the willingness of users in applying alternative documents or approaches.

6.5 Challenges in other standardisation stages

This study also reveals the existence of specific challenges in implementation, maintenance and derogation stages, which are presented below. The approval stage has not been covered as no relevant insights emerged from either literature or the qualitative study.

6.5.1 Challenges in implementation

Challenges in implementation are indicated in Table 6.3. No content-related challenges and human issues emerged from this study.

Table 6.3 Challenges in implementation

Content	Human issues	Procedural aspects	External factors
-	-	• Set appropriate withdrawal date.	• Education and support to users.

After the publication of the standard, specific attention needs to be paid to its implementation. The challenges in this stage are represented by the need for publicising it and educating users (Nethercot 2012), as well as withdrawing other conflicting standards.

Support to the profession is typically represented by guidance materials, software tools and training courses provided by a variety of sources. In the UK for example major contributions to the implementation of the Eurocodes were provided by the BSI committees, client organisations, industry bodies, professional institutions and academics as documented by Denton et al. (2010).

Withdrawing conflicting standards is relatively straightforward when dealing with single isolated standards, but can be complicated when the design standards involved are a suite of documents having large impact. As an example, the Eurocodes implementation required a coexistence period during which time both national standards and Eurocodes could be used (Denton et al. 2010). This period lasted until March 2010, when all conflicting national standards were expected to be withdrawn.

6.5.2 Challenges in maintenance

Challenges in maintenance are indicated in Table 6.4.

Table 6.4 Challenges in maintenance

Content	Human issues	Procedural aspects	External factors
Same as development stage (Section 6.3.1) • Up-to-date content	Same as development stage (Section 6.3.2)	• Same as development stage (Section 6.3.3) • Content management system	Same as development stage (Section 6.3.4)

Standards typically follow a five-year review and update process[1]. During the review stage, issues similar to those identified for the development stage (Section 6.3) may arise. In addition, there can be inefficiencies due to the inadequacy of the content management system, which does not enable the standard and associated feedback to be processed effectively. These inefficiencies can have a negative impact on the rapidity to update the standard (thus leading to out-of-date documents) and on the responsiveness of technical requirements to stakeholders' needs. While recognised standards organisations like ISO or BSI generally have established and effective processes to proactively

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[1] This is the typical timeframe for standards developed at national and European level. PAS have a shorter life (two years) as discussed in Section 2.4.2.

maintain formal standards, the organisations managing *de facto* standards may not have such effective processes as shown in the case studies in Chapters 7 and 9.

A tension between up-to-date content, usability and cost-efficiency may also emerge. Indeed, participants to the *brainstorming sessions* and the *interviews* observed that, while design standards should provide up-to-date content, having continuous changes to standards can be detrimental to their use as well as costly, because that would require continuous update to software tools and training material.

6.5.3 Challenges in derogation

Challenges in derogation are indicated in Table 6.5. No content-related issues emerged from this study.

Table 6.5 Challenges in derogation

Content	Human issues	Procedural aspects	External factors
-	• Subjective assessment of departures	• Time to review a departure • Resources availability to review a departure • Administrative errors	• Quality submissions

During the derogation stage (see Section 2.6.6 for a definition of derogation), the following inefficiencies have been identified by the Industry Standards Group (2012): (i) long time to review a departure; (ii) low level of resources available to review departures; (iii) poor quality submissions; (iv) administrative errors; (v) subjective assessment often characterised by risk aversion of receivers of departures, who may not be willing to approve the departure particularly for safety matters. These inefficiencies affect the willingness in proposing solutions that differ from those provided by the standard under consideration.

6.6 Reflections

6.6.1 A complex-socio technical system

Review of literature and the qualitative study reveal that the life-cycle of a design standard sees a strong interaction between technical and human aspects. This was also recognised by Tassey (2000), who argued that a standard aims to strike the balance between users' requirements, technology possibilities and related costs, and government constraints imposed to safeguard society. To further increase the challenge, some inherent tensions in development and use of design standards also emerged from this study (see also Bulleit 2012; Leivestad and Mehus 2012; Nethercot 2012), for example between cost effectiveness and competitiveness in design, prescription and flexibility for users, stability and the drive for the introduction of new approaches.

The life-cycle of a design standard should thus be regarded as a "complex socio-technical system" (Emery and Trist 1960), i.e. a complex system within a socio-technical framework. In line with Blockley and Godfrey (2000), a distinction can thus be made between 'hard' and 'soft' factors affecting the system of interest. Hard factors involve physical elements, i.e. the content of the standard. Soft factors involve human and social aspects, such as those related to users and stakeholders and their needs and expectations. Macro-environmental (external) factors related to political, social, legislative and procedural considerations also exist and need to be considered. Table 6.6 summarises these aspects.

The link between hard, soft and macro-environmental factors is shown in Figure 6.4, which reflects Blockley and Godfrey's (2000) consideration that every hard system is set within a soft system.

Table 6.6 Hard, soft and macro-environmental factors at different life-cycle stages

Stage	Hard (content)	Soft (human issues)	Macro-environmental (external factors and procedural aspects)
Conceptualisation and development	• Balance between advice and requirements • Boundaries between design standards and other documents • Balance between performance-based and method-based requirements • Organisation of content	• Subjectivity in development • Writing skills of standards' writers • Users' engagement • Competing needs of stakeholders • Purpose of design standards	• Changes towards a smarter construction industry • Political aspects • Legal aspects • Social and cultural aspects • Economic aspects • Sustainability aspects • Time for drafting and review • Resources availability
Use	• Increase in technical standards • Cross-references among documents • Navigation between technical provisions • Length of design standards • Degree of complexity of standards • Novelty of requirements	• Users' needs and primary audience • Subjectivity in use: users' skills and learning component	• Contractual aspects • Legal aspects
Implementation	-	-	• Education and support to users. • Set appropriate withdrawal date.
Maintenance	Same as development stage (Section 6.3.1) • Up-to-date content	Same as development stage (Section 6.3.2)	Same as development stage (Section 6.3.3 and 6.3.4) • Content management system
Derogation	-	• Subjective assessment of departures	• Quality submissions • Time to review a departure • Resources availability to review a departure • Administrative issues

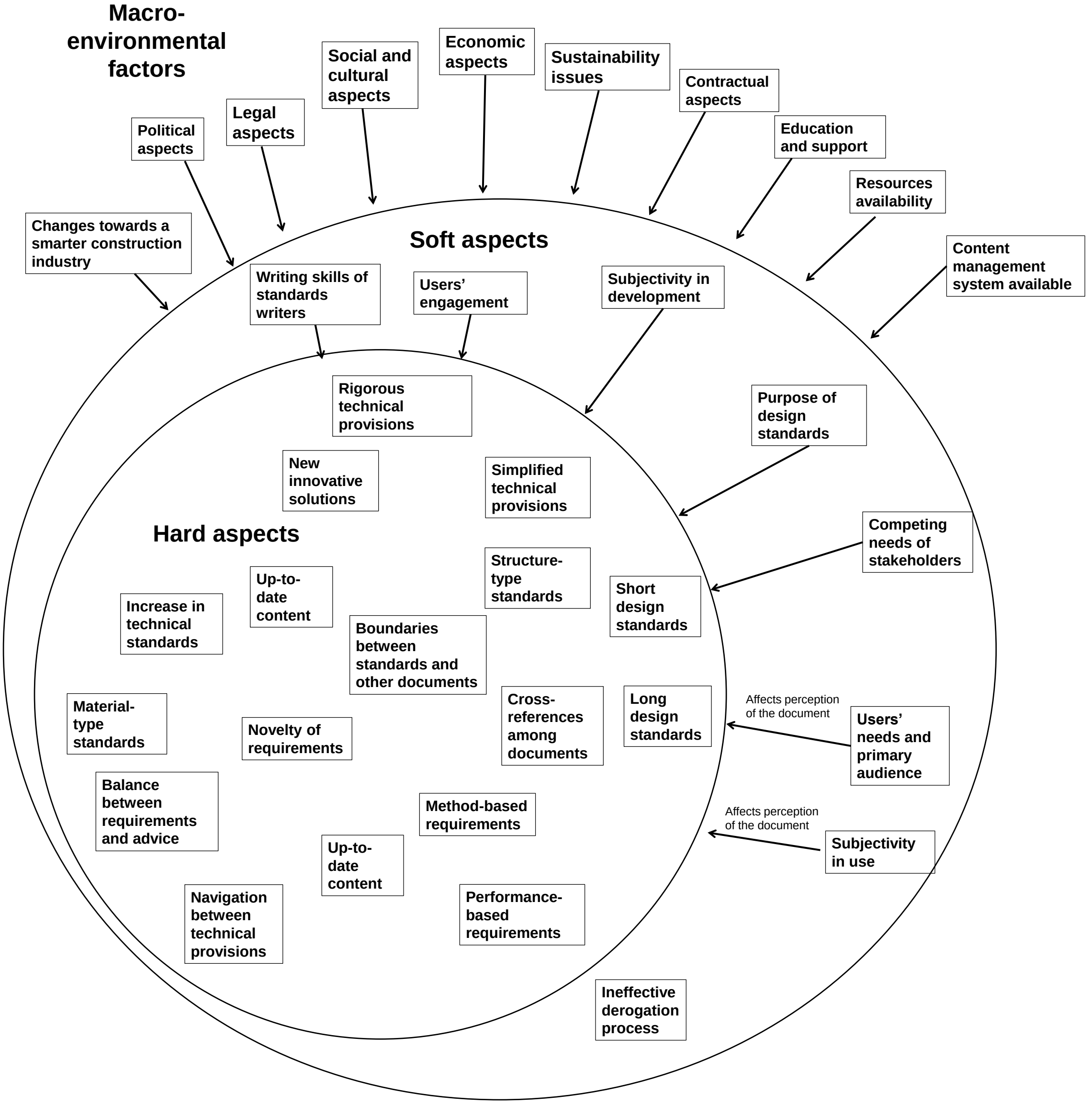

Figure 6.4 A map of challenges in design standards

Further conceptual analysis of the identified challenges reveals that some of them affect not only the life-cycles stages of the design standard, but also assets' design, specifically the flexibility to develop technical solutions and their safety, cost-effectiveness and sustainability. Their impact can be either positive or negative as illustrated in Table 6.7. It is worth noting that, where no impact is indicated in Table 6.7, it does not imply that the impact does not exist, but rather that it did not emerge from this study.

Table 6.7 Additional impact of the challenges of design standards

Specific challenge	**Areas of impact related to assets' design**			
	Flexibility to develop technical solutions	**Safety of solutions developed**	**Cost-effectiveness of solutions developed**	**Sustainability of solutions developed**
(6.3.1.1) Balance between requirements and advice	Unclear distinction has a **Negative** impact: overly conservative design.	Unclear distinction has a **Negative** impact: it may lead to unsafe solutions.	-	-
(6.3.1.3) Fully PBRs for the design of an asset	Depends on how they are presented.	Depends on how they are presented. For example, **Negative:** if codes are too high-level, safety requirements can be difficult to enforce. This leads to an increased likelihood of structural failures (Elms 1999).	**Positive** when enabling cost-effective solutions. **Negative** when leading to the development of bespoke solutions. These bring about additional design costs while discouraging competition, and may lead to human errors and failures (Industry Standards Group 2012)	**Positive** as sustainable development should not be presented as a prescribed solution, but as an open process to support the development of cost-effective solutions and provide environmental and social benefits at any given time.
(6.3.1.3) Method-based requirements	**Negative**: they stifle innovation and technology (*UK debates*) and limit mindful design thinking.	-	**Positive** when dealing with common design situations (i.e. where well-proven technology is required and used) **Negative** when dealing with innovative solutions.	**Negative** (see above for fully performance-based requirements).
(6.3.1.4) Material-type standards	-	-	**Positive**: reduce the risk of commercial advantage of one material on others.	-
(6.3.2.2) Writing skills of standards' writers	-	**Negative** when they do not have appropriate writing skills and competence as the text produced can be misinterpreted.	-	-
(6.3.2.4) Competing needs of stakeholders	-	-	**Positive** or **Negative**: it depends on the category of	**Positive** or **Negative**: it depends on the category of

Specific challenge	**Areas of impact related to assets' design**			
	Flexibility to develop technical solutions	**Safety of solutions developed**	**Cost-effectiveness of solutions developed**	**Sustainability of solutions developed**
			stakeholders exerting influence.	stakeholders exerting influence.
(6.3.2.5) Purpose of design standards	-	-	**Positive** or **Negative**: it depends on the category of stakeholders exerting influence.	**Positive** or **Negative**: it depends on the category of stakeholders exerting influence.
(6.4.1.1) Increase in technical standards	-	**Negative**: these may increase the risk of misinterpretation and misapplication and, at worst, may lead to safety issues.	-	-
(6.4.1.2) Cross-references among documents	-	**Negative** if not effective. Indeed, these may increase the risk of misapplication and, at worst, may lead to safety issues.	-	-
(6.4.1.3) Navigation between technical provisions	-	**Negative** if not effective.	-	-
(6.4.1.4) Length of design standards	Where too long, **Negative** as they may remove the need for the designer's interpretation (*UK debates*). Where short, **Positive** as leaving designers with wide freedom to develop technical solutions. However, also **Negative** when leaving too much freedom to designers and no safety net, with the consequent risk of over-conservatism in design.	-	-	-

Specific challenge	**Areas of impact related to assets' design**			
	Flexibility to develop technical solutions	**Safety of solutions developed**	**Cost-effectiveness of solutions developed**	**Sustainability of solutions developed**
(6.4.1.5) Simplified technical provisions	**Negative:** they stifle the imaginative application of advances in structural technology (*UK debates*)	-	**Negative:** they may oversimplify the design and lead to more conservative and expenses solutions.	-
(6.4.1.5) Rigorous technical provisions	Depends on their clarity. **Positive** where well thought to enable the development of innovative solutions **Negative** where over-complicated and unclear, as they do not enable the use of good practice and do not promote the development of innovative solutions (Gann et al. 1998)	**Negative** when unclear as it can lead to unsafe design.	**Positive:** typically they provide more economic design solutions.	-
(6.4.1.6) Novelty of requirements	Depends on the technical provision, for example **negative** if the technical provision is unduly prescriptive.	Depends on the technical provision, for example: **Negative** if technical provisions are not grounded on accepted research results and confirmed by sufficient experience.	Depends on the technical provision, for example: **Negative** where leading to some substantial additional design costs.	-
(6.4.1.6) New innovative solutions	Depends on how they are presented. **Positive** when presented as advice, thus leaving designers to propose other valid alternatives. **Negative** when presented as requirements as limiting the choice of designers.	Depends on the technical provision, for example **negative** if the solutions introduced are unsatisfactory (not grounded on accepted research results and confirmed by sufficient experience)	Depends on the technical provision, for example **negative**: serious technical, economic and social problems (UK debates)	-

Specific challenge	**Areas of impact related to assets' design**			
	Flexibility to develop technical solutions	**Safety of solutions developed**	**Cost-effectiveness of solutions developed**	**Sustainability of solutions developed**
(6.4.2.2) Subjectivity in use	Depends on users' skills. For example, **Negative** when designers do not have enough knowledge and experience.	Depends on users' skills. For example, **Negative** when designers do not have enough knowledge and experience.	Depends on users' skills. For example, **Negative** when designers do not have enough knowledge and experience.	Depends on users' skills. For example, **Negative** when designers do not have enough knowledge and experience.
(6.5.1) Education and support	**Negative** when not available.	-	-	-
(6.5.2) Up-to-date content	**Positive** as they typically encourage the application of best practice.	**Positive**: Users apply up-to-date provisions in conjunction with other cross-referenced documents.	**Positive** for example when supporting the development of cost-effective solutions.	**Positive** for example when supporting the development of sustainable solutions.
(6.5.3) Ineffective derogation process	**Negative:** opportunities not attempted due to the time required to process departures (Industry Standards Group 2012).	-	**Negative:** opportunities not attempted due to the time required to process departures (Industry Standards Group 2012).	-

The impact of the challenges in design standards on flexibility, safety, cost-effectiveness and sustainability is shown in Figure 6.5. It exhibits that multiple challenges may affect the same aspect, meaning that the development of a design standard requires taking a holistic perspective to minimise the unintended consequences that may arise when focusing on one aspect without appreciating the big picture. The figure thus reinforces the concept of complex socio-technical system applied to the life-cycle of a design standard. Figure 6.5 also shows the boundaries of the system of interest of this thesis.

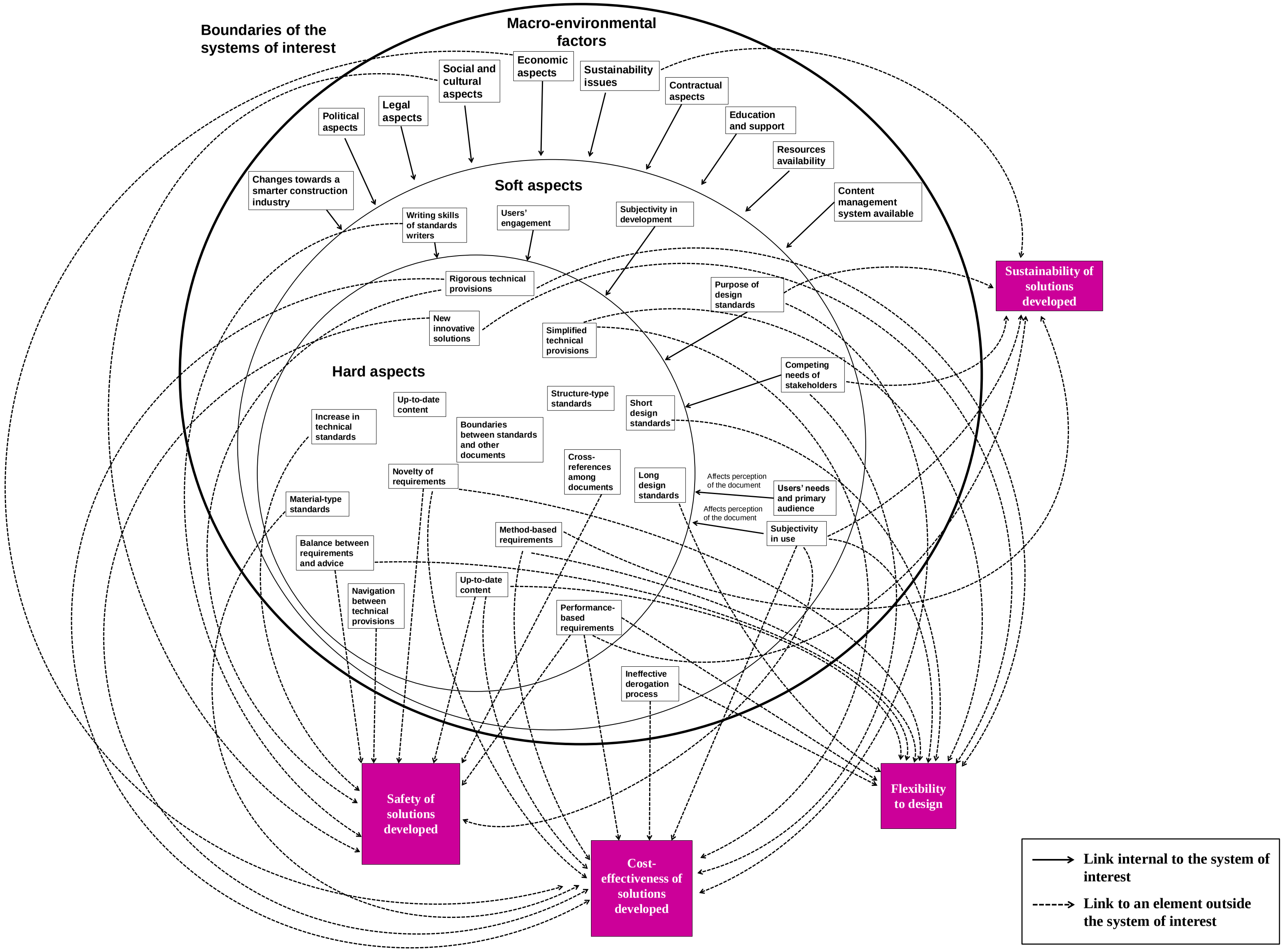

Figure 6.5 Impact of the challenges in design standards

There are four key implications of considering this as a complex socio-technical system.

1. Having a clear appreciation of both technical aspects and human issues is fundamental to understand the functionality of the system as a whole (Blockley and Godfrey 2000). Hence, to develop better design standards, hard, soft and macro-environmental factors and their links need to be understood first.

2. When dealing with complex problems, understanding the problem and the solutions that might be suitable to different people can be part of the problem (Bryson and Crosby 1992). Therefore, managing stakeholders' expectations, addressing users' needs and overcoming human issues are essential aspects of problem solving. This can be demanding as shown in the previous sections.

3. When dealing with complex problems, applying simplistic solutions might solve and improve some aspects, but may also have adverse consequences on the whole system of interest (see impact of the challenges in Figure 6.5). For example, while 'simplification' is largely claimed as the way forward, it requires careful thoughts: simplified technical provisions are generally easy to apply, but may affect negatively the flexibility to develop alternative and cost-effective technical solutions.

4. Complex socio-technical problems cannot be 'solved' as traditional engineering problems. Rather, they should be 'managed' in order to reduce complexity (see Section 4.2.1 on wicked problems).

6.6.2 Emerging features of better design standards

Having identified the key challenges affecting development and use of design standards, it can be argued that managing those challenges would help develop better design standards. Drawing together the findings of this chapter and the roles and attributes of good and easy to use design standards explored in Chapter 5, some initial features of better design standards have been identified. They are listed in Table 6.8 and are set around:

i. Hard aspects (content of the design standard);
ii. Soft aspects (human issues);
iii. Macro-environmental aspects (procedural aspects and external factors).

Real case studies have been used to test the features of better design standards contained in Table 6.8, identify additional ones as relevant and investigate specific strategies for their management. They are examined in the following chapters.

Table 6.8 Preliminary features of better design standards

(i)	**Hard aspects**
1.	Better design standards provide a clear distinction between requirements and advice.
2.	Better design standards have clear boundaries with other accompanying publications.
3.	Better design standards have the right balance of performance and methods.
4.	Better design standards have clear interfaces with other linked standards.
5.	Better design standards are easy to navigate.
6.	Better design standards have a length appropriate to communicate requirements in an understandable way.
7.	Better design standards are not unduly complex and provide the right balance of simplified and rigorous approaches
8.	Better design standards are up-to-date.
9.	Better design standards enable safe solutions to be developed, which in turn reflect risks levels acceptable for the country in which they operate.
10.	Better design standards support the design of cost-effective civil and structural engineering works.
11.	Better design standards support the design of sustainable civil and structural engineering works.
(ii)	**Soft aspects**
12.	Better design standards minimise subjectivity in the development process.
13.	Better design standards are developed by appropriate skilled standards' writers.
14.	Better design standards address users' needs.
15.	Better design standards address key stakeholders' expectations.
16.	Better design standards fulfil clear defined purposes.
17.	Better design standards focus on a target audience.
18.	Better design standards support users' skills and their learning process.
(iii)	**Macro-environmental aspects**
19.	Better design standards are the product of a streamlined development process.
20.	Better design standards are supported by sufficient financial and human resources.
21.	Better design standards are managed by an efficient content management system.
22.	Better design standards are challenged by means of an effective derogation process.
23.	Better design standards support and drive the changes expected in the construction industry.
24.	Better design standards enable public policy objectives to be achieved.
25.	Better design standards do not inhibit innovation and provide a framework to innovate.

6.7 Conclusions

There exist specific challenges at different life-cycle stages of design standards. They have been identified and classified into three categories: (i) hard challenges, (ii) soft challenges and (iii) macro-environmental challenges, which reflect basic components of complex systems.

Hard challenges mainly relate to technical provisions, their length and complexity, the balance between advice and requirements, the balance between methods and performance, and the structure of the text. Soft challenges mainly relate to stakeholders, users and their competing needs and expectations. Soft challenges strongly affect the content of design standards and may be difficult to overcome. Macro-environmental challenges mainly refer to political, economic and procedural aspects. The identified challenges affect not only development, use, implementation, maintenance and derogation from the standard, but also the flexibility to design and the cost-effectiveness, safety and sustainability of the solutions developed.

The challenges in design standards are intertwined and make the development of design standards a complex socio-technical problem. Hence, applying focused, simplistic solutions might solve and improve some aspects, but may also have adverse consequences on the whole system of interest. A key conclusion that has been drawn from this chapter is that managing the identified challenges would help reduce complexity and aid the development of better design standards. A list of features of better design standards has been derived and will be tested against real case studies in the next chapters.

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Chapter 7

Development of design standards: cases studies

7.1 Introduction

The author has been involved in five live projects, which contributed to the exploration of what good design standards are and how they can be developed in practice. Figure 7.1 summarises the characteristics of the five real projects examined in this thesis in terms of timing and types of standards. Three of them are presented in this chapter, specifically:

- Project 1: Client technical specifications
- Project 2: Interim advice on design of structural bearings
- Project 3: BSI PAS 8812 Design of temporary works to European Standards

For each project, background information, key activities, findings and challenges are provided ("within-case analysis", see Chapter 4 on case study research). Lessons emerged to develop better standards are also examined.

Project 4 on the Structural Eurocodes and Project 5 on the Design Manual for Roads and Bridges (DMRB) are examined in Chapter 8 and Chapter 9 respectively. These two projects represent a key focus of this thesis due to their high degree of complexity in terms of size of documents, number of stakeholders involved and impact on design practice.

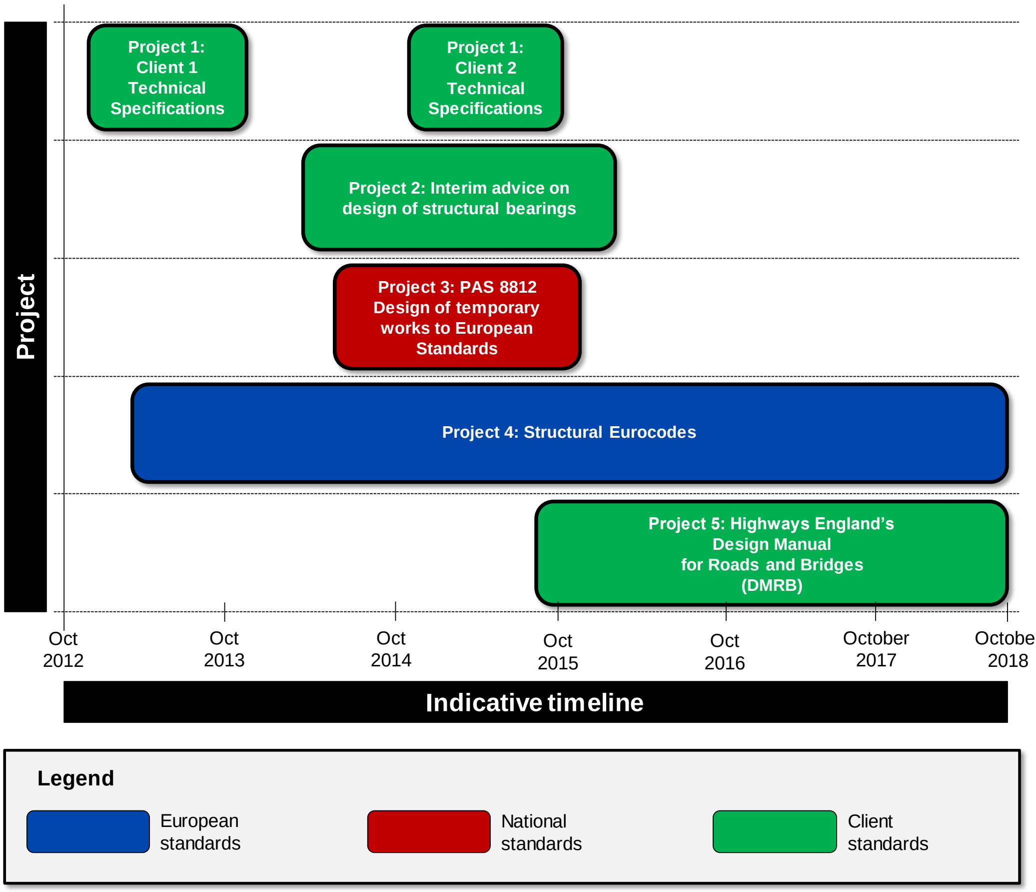

Figure 7.1 Real projects examined in this thesis

7.2 Project 1: Client technical specifications

7.2.1 Background

In 2007 the first generation of the Eurocodes was published and by the end of March 2010 all conflicting national standards were expected to be withdrawn in the European Member States. In the UK the British Standards Institution withdrew the UK National Standards conflicting with the Eurocodes, which then became the official structural design standards for the UK. The implementation of the Eurocodes demanded a lot of effort from standards makers and users. The Institution of Structural Engineers (2004) considered this as the "biggest change in codified structural design ever experienced in the UK".

Clients were expected to implement the Eurocodes into their own specifications (see Denton et al. 2010 for UK implementation of the Eurocodes). In 2013 the author's host organisation was appointed by a UK client to manage the integration of the Structural Eurocodes into their technical specifications (10 interrelated documents). In 2016 the author’s host organisation was appointed by another UK client to undertake a similar task on a set of interrelated technical specifications. For confidentiality requirements the names of the clients are not mentioned. The technical specifications covered client-specific requirements for design, construction and testing of relevant civil and structural engineering works. The topics treated are not specified for confidentiality requirements.

7.2.2 Key activities

The author was responsible for reviewing and redrafting some of the clients’ technical specifications to align those to the Eurocodes and other relevant European standards. The scope of the review included relevant parts of BS EN 1990 – 1997 & 1999, the respective National Annexes, and other non-contradictory complementary information (NCCI) such as BSI Published Documents (PDs). The same approach was adopted for both projects as they differed only in terms of the technical topics covered.

7.2.3 Challenges

The first challenge of these projects was to produce a working document where (i) changes made to the technical specification could be easily identified, (ii) new requirements were traceable, and (iii) any decision or assumption was recorded and visible to control scope creep. In addition, the document had to be manageable so that the right quantity of requirements was held at the right level and was easy to use for communication with the client. The Word table reproduced in Table 7.1 was proposed to the client and accepted as fit for purpose.

Table 7.1 Extract from a client technical specification (Project 1)

Clause no.	Original clause and proposed amendment	Commentary	Review comments
1.1.1	*The “Specification for the design, construction and testing of civil and structural works” is made up of a suite of five separate Specifications.* ~~and their respective, separate appendices~~ *It provides design and construction requirements for all new works and modifications to existing assets which include* ~~aspects of civil and structural engineering,~~ the structural design of buildings and civil engineering works, as well as geotechnical aspects.	Deletion of the reference to the appendices which have been deleted. Insertion for consistency with EN 1990, 1.1(2)	
Legend: *Original clause* ~~Deletions~~ Insertions Client to review			

Another specific challenge was to understand which information had to be provided so as to develop clear, complete and concise requirements. To tackle this issue, the general principle of '3Ws' and '1H' was applied[1]:

(i) What requirement has to be verified
(ii) Why that specific requirement is needed (background)
(iii) How requirements can be verified (specific method)
(iv) Where other relevant information can be found (cross-referencing)

The fourth 'W' (i.e. who is responsible to meet the requirement) was not included to make the document contract-neutral and provide freedom to define roles and responsibilities in the contract phase. Indeed, making reference to specific roles such as designers or constructors can lead to disputes between supply chain parties over who has responsibility for delivering the product or service under different types of contracts.

(i), *(iii)* and *(iv)* were provided in the client specifications; *(ii)* was recorded in the working document under the column 'Commentary' (see Table 7.1). While background information was not intended to be published, it represented a fundamental part of the audit trail of the document as it explained the rationale behind technical provisions and additional relevant information to support the client for future claims.

The client specifications were interconnected. They also made reference to other external standards and technical publications. Introducing effective cross-references was therefore a vital step in redrafting the specifications. This was done by reducing duplication from other documents to a minimum while providing clarification of how the referenced requirements were interpreted by the client.

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[1] This follows the comment made by one of the interviewees on the fact that "good design standards are a combination of why, what and how" (see Section 6.3.1.2).

7.3 Project 2: Interim advice on structural bearings design

Part of the work presented in this section has been published in Angelino et al. (2014a) and Parsons Brinckerhoff (2015) as personal contribution of the author.

7.3.1 Background

In 2014 the author's host organisation was appointed by a UK client to provide recommendations for interim national guidance on design of bridge bearings. The author was responsible for exploring ambiguities in current European and National standards for bearings design and developing recommendations to address these.

The Structural Eurocodes are the main suite of standards for design of structural and civil engineering works. However, they do not comprehensively cover the design of bridge bearings and reference should be made to a set of separate European Product Standards (see Section 2.5 for a definition), i.e. EN 1337, which also give technical provisions for the design of structural bearings. However, these provisions are not fully aligned to the Eurocodes' terminology and design approach. Clarification was therefore required.

7.3.2 Key activities

The project started in June 2014 with the final report issued in December 2015. Key activities included: (i) identifying overlapping requirements and gaps; (ii) carrying out comparative analyses of actions on bridge bearings and their movements; (iii) defining the format of the bearing schedule.

The following steps were carried out:

- review of the content of the documents listed in Table 7.2;
- identification of issues and inconsistencies in technical provisions;
- identification and comparison of potential options for resolution of the identified issues considering the main benefits and limitations;
- recommendations for interim national guidance on design of bridge bearings.

Table 7.2 Documents relevant for design of bridge bearings (Project 2)

Document	Title
BS 5400-2:2006	"Steel, concrete and composite bridges. Part 2: Specification for loads" (superseded, withdrawn)
BS 5400-9.1	"Steel, concrete and composite bridges. Bridge bearings. Code of practice for design of bridge bearings" (superseded, withdrawn)
BS EN 1990:2002+A1:2005 + National Annex	"Basis of design"
BS EN 1991-1-5:2003 + National Annex	"Actions on structures. Part 1-5: General actions. Thermal actions"
BS EN 1993-2:2006 + NA	"Design of steel structures. Part 2: Steel bridges"
BS EN 1337-1:2000	"General design rules "
FprEN 1337-1:2011	"General design rules" (draft for comment)
BS EN 1337-2:2004	"Sliding elements"
BS EN 1337-3:2005	"Elastomeric bearings"
BS EN 1337-4:2004	"Roller bearings"
BS EN 1337-5:2005	"Pot bearings"
BS EN 1337-6:2004	"Rocker bearings"
BS EN 1337-7:2004	"Spherical and cylindrical PTFE bearings"
BS EN 1337-8:2007	"Guide bearings and restraint bearings"
PD 6703:2009	"Structural bearings. Guidance on the use of structural bearings"
NA to DIN EN 1990-A1, Annex E (German annex)	"Technical specifications and requirements for the design of bearings of bridges"
SCI P406	"Determining design displacements for bridge movement bearings"

7.3.3 Issues identified

From hands-on application on a real project related to structural bearings design and review of the standards in Table 7.2, the lack of clarity emerged on:

(i) thermal actions acting on bearings and relevant partial factors (γ) and combination factors (ψ) in the Eurocodes terms;

(ii) relevant actions to calculate the friction forces in sliding bearings;

(iii) actions and combinations of actions to calculate bearing reactions using relevant combination of actions at the ultimate limit states (ULS) and/or serviceability limit states (SLS) in the Eurocodes terms;

(iv) bearing movements using relevant combination of actions at ULS and/or SLS;

(v) bearing schedule and its content.

As an example, Table 7.3 provides a summary of the equations to calculate the maximum expansion and contraction ranges according to different documents.

Table 7.3 Comparison of equations to calculate maximum expansion and contraction ranges (Project 2)

<table>
<thead>
<tr><th rowspan="2">Source</th><th rowspan="2">Expansion</th><th rowspan="2">Contraction</th><th rowspan="2">ΔT_1</th><th rowspan="2">ΔT_2</th><th colspan="2">γ_{T1} or γ_{T2}</th><th rowspan="2">Design Movement range</th></tr>
<tr><th>ULS</th><th>SLS</th></tr>
</thead>
<tbody>
<tr><td colspan="8">Approach 1</td></tr>
<tr><td>SCI P406</td><td>$\Delta T_{d,exp,bearing} = \gamma_T \cdot (T_{e,max} - T_0)$</td><td>$\Delta T_{d,con,bearing} = \gamma_T \cdot (T_0 - T_{e,min})$</td><td>Not relevant – uncertainty in the positioning of the bearing is modelled as a tolerance</td><td>-</td><td>1.45⁽¹⁾</td><td>1.00</td><td>$\Delta L_{d,exp,bearing} = L \cdot \alpha_T \cdot \Delta T_{d,exp,bearing}$ + tolerance on length from the fixed bearing
$\Delta L_{d,con,bearing} = L \cdot \alpha_T \cdot \Delta T_{d,con,bearing}$ + tolerance on length from the fixed bearing</td></tr>
<tr><td colspan="8">Approach 2</td></tr>
<tr><td>General expression</td><td>$\Delta T_{d,exp,bearing} = \gamma_{T2} \cdot [\gamma_{T1} \cdot (T_{e,max} - T_0) + \Delta T_1] + \Delta T_2$</td><td>$\Delta T_{d,con,bearing} = \gamma_{T2} \cdot [\gamma_{T1} \cdot (T_0 - T_{e,min}) + \Delta T_1] + \Delta T_2$</td><td></td><td></td><td>1.55
1.45⁽¹⁾</td><td>1.00</td><td rowspan="8">$\Delta L_{d,exp,bearing} = L \cdot \alpha_T \cdot \Delta T_{d,exp,bearing}$
$\Delta L_{d,con,bearing} = L \cdot \alpha_T \cdot \Delta T_{d,con,bearing}$</td></tr>
<tr><td>EN 1991-1-5 Case A</td><td>$\Delta T_{d,exp,bearing} = \gamma_{T1} \cdot (T_{e,max} - T_0) + \Delta T_1$</td><td>$\Delta T_{d,con,bearing} = \gamma_{T1} \cdot (T_0 - T_{e,max}) + \Delta T_1$</td><td rowspan="2"><table><tr><th>Case</th><th>Installation of bearings</th><th>Safety term</th></tr><tr><td>1</td><td>The temperature at which the bearings and expansion joints are set is not specified</td><td>20°C</td></tr><tr><td>2</td><td>The temperature at which the bearings and expansion joints are set is specified</td><td>10°C</td></tr></table></td><td rowspan="2">-</td><td rowspan="2">1.55
1.45⁽¹⁾</td><td rowspan="2">1.00</td></tr>
<tr><td>EN 1991-1-5 Case B</td><td>$\Delta T_{d,exp,bearing} = \gamma_{T2} \cdot [(T_{e,max} - T_0) + \Delta T_1]$</td><td>$\Delta T_{d,con,bearing} = \gamma_{T2} \cdot [(T_0 - T_{e,max}) + \Delta T_1]$</td></tr>
<tr><td>EN 1993-2 Case C</td><td>$\Delta T_{d,exp,bearing} = (T_{e,max} - T_{e,min})/2 + \Delta T_1 + \Delta T_2$</td><td>$\Delta T_{d,con,bearing} = (T_{e,max} - T_{e,min})/2 + \Delta T_1 + \Delta T_2$</td><td rowspan="2"><table><tr><th colspan="3">Table A.4: Numerical values for ΔT_0</th></tr><tr><th>Case</th><th>Installation of bearings</th><th>ΔT_0 [°C]</th></tr><tr><td>1</td><td>Installation with measured temperature and with correction by resetting</td><td>0</td></tr><tr><td>2</td><td>Installation with estimated temperature and without correction by resetting with bridge set as $T_0 \pm 10$°C</td><td>15</td></tr><tr><td>3</td><td>Installation with estimated temperature and without correction by resetting and also one or more changes in the position of the fixed bearing</td><td>30</td></tr></table></td><td rowspan="2">5°C</td><td rowspan="2">1.55
1.45⁽¹⁾</td><td rowspan="2">Cannot be defined as this equation is only applicable to ULS limit states</td></tr>
<tr><td>EN 1993-2 Case D</td><td>$\Delta T_{d,exp,bearing} = (T_{e,max} - T_0) + \Delta T_1 + \Delta T_2$</td><td>$\Delta T_{d,con,bearing} = (T_0 - T_{e,min}) + \Delta T_1 + \Delta T_2$</td></tr>
<tr><td>FprEN 1337-1 Case E</td><td>$\Delta T_{d,exp,bearing} = [\gamma_{T1} \cdot (T_{e,max} - T_{e,min}) + \Delta T_1]/2$</td><td>$\Delta T_{d,con,bearing} = [\gamma_{T1} \cdot (T_{e,max} - T_{e,min}) + \Delta T_1]/2$</td><td rowspan="3"><table><tr><th colspan="5">Table G.2 - Recommended values for ΔT_0</th></tr><tr><th colspan="5">ΔT_0 [°C]</th></tr><tr><th>Case</th><th>Installation of bearings</th><th>Steel bridges</th><th>Steel-concrete bridges</th><th>Concrete bridges</th></tr><tr><td>1</td><td>Installation with measurement of mean structural temperature and, if necessary, with correction by resetting</td><td>0</td><td>0</td><td>0</td></tr><tr><td>2</td><td>Installation with temperature estimate for mean structural temperature T_0 and without correction</td><td>7.5</td><td>5</td><td>5</td></tr><tr><td>3</td><td>Installation with estimated temperature T_0 without correction and with one or several possible changes of the fixed bearing's position</td><td>20</td><td>15</td><td>15</td></tr></table></td><td rowspan="3">-</td><td rowspan="3">1.55
1.45⁽¹⁾</td><td rowspan="3">1.00</td></tr>
<tr><td>FprEN 1337-1 Case F</td><td>$\Delta T_{d,exp,bearing} = [\gamma_{T1} \cdot (T_{e,max} - T_{e,min})] /2 + \Delta T_1$</td><td>$\Delta T_{d,con,bearing} = [\gamma_{T1} \cdot (T_{e,max} - T_{e,min})] /2 + \Delta T_1$</td></tr>
<tr><td>FprEN 1337-1 Case G</td><td>$\Delta T_{d,exp,bearing} = \gamma_{T1} \cdot (T_{e,max} - T_0) + \Delta T_1$</td><td>$\Delta T_{d,con,bearing} = \gamma_{T1} \cdot (T_0 - T_{e,max}) + \Delta T_1$</td></tr>
<tr><td>NA to DIN EN 1990 - Case H</td><td>$T_{ed,max} - T_0 = \gamma_F \cdot (T_{e,max} - T_0) + \Delta T_1$</td><td>$T_0 - T_{ed,min} = \gamma_F \cdot (T_0 - T_{e,max}) + \Delta T_1$</td><td><table><tr><th colspan="5">Table E.4 - Recommended values for ΔT_0</th></tr><tr><th>Case</th><th>Installation of bearings</th><th colspan="3">ΔT_0 [°C]</th></tr><tr><th></th><th></th><th>Steel bridges</th><th>Composite bridges</th><th>Concrete bridges</th></tr><tr><td>1</td><td>Installation with measurement temperature and with correction by</td><td>0</td><td>0</td><td>0</td></tr><tr><td>2</td><td>Installation with estimated temperature T_0 and without correction by resetting with bridge set at T_0</td><td>7.5</td><td>5</td><td>5</td></tr><tr><td>3</td><td>Installation with estimated temperature T_0 and without correction by resetting and also one or more changes in position of the fixed bearing</td><td>20</td><td>15</td><td>15</td></tr></table></td><td>-</td><td>1.35
(German value)</td><td>1.00</td></tr>
<tr><td colspan="3">Assumptions: γ_{T2} and γ_{T1} have the same value, but they are mutually exclusive
γ_{T2} (or γ_{T1}) and ΔT_2 are mutually exclusive</td><td colspan="5">NOTES: ⁽¹⁾ A reduced value of γ may be used when the duration of the relevant design situation is taken into account directly using BS EN 1991-1-5, A.2.</td></tr>
</tbody>
</table>

7.3.4 Challenges

While the specific technical results of this review are not relevant to this research, it is worth presenting two key challenges encountered.

Overlapping and conflicting requirements represent the first challenge. The existence of provisions not provided in directly relevant standards or clauses, as well as inconsistent requirements, result in ambiguity, inefficiency in design and misunderstanding of technical provisions. Inconsistent requirements can be seen primarily in the calculation of: the uncertainty in the positioning of the bearing at the reference temperature T_0 (either as a tolerance or as an additional temperature change); the uncertainty in temperature difference in the bridge (either as a fixed temperature or as a partial factor); the reference temperature T_0, which is introduced in some standards with two values (one for expansion and one for contraction) rather than a single value (there can be only one value for the reference temperature from which the thermal expansion and contraction due to temperature change are determined); the design temperature change and design movements of bearings (see Table 7.3); the content of the bearing schedule. Overcoming the issue of overlapping and conflicting requirements is not easy as, in practice, it stems from either an ineffective communication between different drafting teams within a standardisation organisation (see Section 2.3.5.1), or from ineffective liaison between different organisations (see Section 2.3.5.4).

This project also showed significant challenges in the use of terms and definitions. Same terms were applied in different standards with different meanings (for example the reference temperature T_0) or were introduced using different formulae (see Table 7.3 for the calculation of the temperature ranges according to different standards). This led to difficulty in comparing the requirements of standards, incompatibilities in design, and ultimately diverse results in design of bridge bearings. To overcome these issues, the author started from basic principles of design of bridge bearings to derive general expressions (see Table 7.3). These were then used to compare the terms and factors provided in different standards.

7.4 Project 3: PAS 8812 on Temporary Works Design

Part of the work presented in this section has been published in Harris and Angelino (2017) and in PAS 8812:2016 as personal contribution of the author. Work done in collaboration with others is indicated as such.

7.4.1 Background

The British Standards Institution (BSI) was appointed by High Speed 2 (HS2) to facilitate the development and publication of two Publicly Available Specifications (PAS) specific to temporary works:

- PAS 8811, *Code of Practice for temporary works – Client procedures* (co-sponsored by HS2 and the Temporary Works Forum), to give recommendations for the UK infrastructure client procedures with respect to temporary works construction projects;
- PAS 8812 *Guide to the application of European Standards in temporary works design* (co-sponsored by HS2 and the Temporary Works Forum) to provide guidance on the application of the European Standards to the design of temporary works in the UK.

The author's host organisation was appointed to develop the guidance document PAS 8812 [17], which represents the subject of this section. The author was one of the two technical authors of PAS 8812. The purpose of PAS 8812 was to produce a user-orientated guide, i.e. a navigation tool that promotes consistency in the design approach to temporary works. In particular, PAS 8812 aimed at providing (from PAS 8812, Section 1 "Scope"):

(i) high-level guidance on the application of European Standards to the design of all types of temporary works in the UK;
(ii) clarification of the relationship between the Eurocodes and other European Standards specifically associated with temporary works; and
(iii) clarification of design requirements for identified groups of temporary works.

7.4.2 Key activities

The project was sponsored by HS2 and the Temporary Works forum (TWf) and facilitated by the BSI. A steering group was created to support the activities of the technical authors, which comprised representatives of key UK consultancy firms, contractors and public clients such as AECOM, CH2M, Crossrail, Highways England, Institution of Civil Engineers, London Underground, Mott MacDonald, and Network Rail.

The work covered a period of one year (from November 2014 to November 2015) including: (i) the work to produce the draft versions of the document; (ii) the steering group meetings; (iii) the consultation period; (iv) the finalisation of the document in response to the comments received. PAS 8812 was published in January 2016.

7.4.3 Issues identified

Three main issues, which affect the application of the European Standards to temporary works design, were jointly identified with the steering group (see also PAS 8812).

The first issue involves the scope of application of the Eurocodes. Although they focus on the design of permanent works, they give principles and requirements for structural safety, serviceability and durability, which are also relevant to temporary works. However, it is important to recognise that temporary works can be subjected to risks and challenges that might not apply to permanent works. These include (see PAS 8812 Section 0.3 “Typical features of temporary works and associated risks” for more details):

- short timescale for the use of temporary works;
- reused components;
- less redundancy and lower stiffness than permanent works;
- susceptible to initial imperfections.

Due to their specific features, the application of the Eurocodes to the design of temporary works needs to be considered carefully[2].

The second issue concerns the existence of little published guidance on the application of the Eurocodes specific to temporary works (see PAS 8812 Section 0.5 “European Standards for temporary works design”). Most of the available guidance is equally valid to both permanent and temporary works. However, only a limited amount is specific to the

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[2] Structural design to the Eurocodes, including for temporary works, requires a limit state design approach to be used. The full implementation of the Eurocodes in 2010 was accompanied by the withdrawal of conflicting British Standards. This resulted in a degree of apprehension within parts of the industry as to how temporary works solutions should be designed in the context of European standards. Historically, temporary works in the UK have been designed to British Standards and have relied on permissible stress design approaches, with a key standard being BS 5975.

development of temporary work solutions and in particular how to apply a limit state design approach to temporary works.

The last issue is related to the scope of application of the European Product and Execution standards written specifically for temporary works (see PAS 8812 Section 0.5 "European Standards for temporary works design"). Examples are BS EN 12810 "Façade scaffolds made of prefabricated components" and BS EN 12812 "Falsework". Generally, these standards provide simplified approaches that are likely to produce more conservative designs than those resulting from the use of the Eurocodes alone. Although these simplified approaches are likely to be valid for common applications such as falsework systems carrying in situ slabs and beams, they might not be appropriate for complex systems (such as those where there is an interaction with permanent works or geotechnical structures) and can lead to the design of unsafe solutions.

7.4.4 Challenges

While the content of PAS 8812 and the technical issues connected with the design of temporary works are outside the scope of this thesis, it is worth presenting the key challenges encountered in the drafting work. The content of this section reflects the view of the author only and do not necessarily represent the perspective of BSI, HS2 and the Temporary Works forum.

The first challenge was to agree the purpose of the guide. While the intended purpose of PAS 8812 (i.e. a navigation tool, see Section 7.4.1) had been initially discussed with the steering group, during one of the meetings it was challenged by some members of the group. Specifically, it was suggested to focus on a specific category of temporary works, rather than on a variety of different solutions, as well as including working examples. The proposals would have made the document either too focussed on a specific category of temporary works, or too long when trying to cover working examples too, and were in contrast with the original intended purpose of the document.

The second challenge was to achieve a consensus on the scope of the sections of the document. The issue was to balance the needs of temporary works designers (represented by the Temporary Works forum) with the wider interests of the steering group members and the technical direction given by the document authors. Before starting the drafting process, the authors identified specific objectives for each section of the document, as well as the themes that were intended to be addressed or not. The table produced was circulated within the steering group members and comments were collected. This step helped provide transparency, set clear expectations among stakeholders on the content of the document, address future queries, and minimise scope creep.

The third challenge was to define the target audience for the document. Discussion during the steering group meetings showed the need for introducing a criterion to focus the drafting effort while avoiding the introduction of textbook material. The recognition that the design of temporary works requires specific skills and technical knowledge led the steering group to a specific discussion on the audience for the document. The result of this discussion was incorporated into PAS 8812 as a key assumption for the use of the document, and is reproduced below:

> "It has been assumed in the preparation of this PAS that the execution of its provisions will be entrusted to appropriately qualified and experienced people, for whose use it has been produced",

The fourth challenge was to provide the right level of guidance. The '3Ws' and '1H' approach adopted in Project 1 was not relevant in this context because the PAS 8812 did not provide requirements, only advisory material to support navigation between existing standards and guidance documents associated with the design of temporary works. While in many cases cross-referencing was enough for readers to navigate the content, in some situations inconsistencies between standards existed, and specific guidance had to be provided to help users overcome them. The authors recognised the value of introducing some principles to guide the drafting process, which proved to be essential to maintain and improve coherence in the way the clauses were developed. The principles were formulated by the author and are reproduced below:

1) Where information provided by product and execution standards was supplementary to the Eurocodes without inconsistences, it could be accepted and referred to without further explanation.
2) Where small inconsistences existed between product and execution standards and the Eurocodes, these had to be flagged only.
3) Where more than one alternative approaches or methods existed, explanation on how to make a decision on the appropriate one had to be provided.
4) Where contradictions, incompatibilities or ambiguity existed between product and execution standards and the Eurocodes, a "warning" had to be provided (for example by using the following sentence "*Although* <…> *could be interpreted* <…>, *there are a*

number of reasons for not using <…>") and advice on how to overcome incompatibilities had to be given.

The existence of overlapping and conflicting requirements between European Standards was another challenge. The governing drafting principles listed above helped overcome this issue. However, more effective liaison between technical committees within one standards organisation (in this case CEN, see Section 2.3.5.1) would be needed to mitigate this problem.

The last challenge was to clarify the terminology. Some of the terms presented in the Eurocodes might represent a change from traditional UK practice in temporary works design (for example the concept of design situations) and merited clarification to avoid potential misinterpretation. Similarly, some terms used traditionally for temporary works cannot be directly compared to those provided in the Eurocodes (e.g. the concept of safe working load). PAS 8812 Annex B was developed to provide clarified versions of terms and definitions and help users better understand the Eurocodes terminology.

7.5 Discussion

A comparison between the three projects is summarised in Table 7.4 in terms of purpose, document author(s) and peer reviewer(s) involved, and audience of the document produced.

Table 7.4 Similarities and differences between Projects 1, 2 and 3

Theme	Project 1	Project 2	Project 3
Purpose of the work	Development of client technical specifications	Recommendations on how specific technical and usability issues identified in existing standards could be overcome	Development of a public available specification
Document author(s)	The author	The author	The author and a colleague
Peer reviewer(s)	A colleague of the author; the client	A colleague of the author; the client.	Steering group
Audience	Designers dealing with the design of specific civil and structural engineering assets	Designers of bridge bearings	Permanent works designers dealing with temporary works

A key difference between the three projects resides in the fact that Projects 1 and 3 deal with the development of a standard (be it in the form of client technical specifications or public available specification), whereas Project 2 entails the development of recommendations to overcome gaps and conflicting requirements in existing standards. Lessons drawn from these projects on how to enhance the content of the standard and the standardisation system are examined in the following paragraphs.

7.5.1 Content of the standards

7.5.1.1 Understanding purpose, scope and audience of the document

Project 3 revealed the value of defining purpose, scope and target audience of the document. This is helpful for two main reasons: (i) to focus drafting effort and provide the right balance of advisory content (particularly textbook material, which is generally helpful for less experienced designers); (ii) to provide transparency, set clear expectations among stakeholders on the content of the document, address future queries, and minimise scope creep. Defining purpose, scope and target audience is a well-established concept in standardisation organisation (see for example BS 0:2016). However, their value seems to be underestimated[3] and more attention should be paid to them.

7.5.1.2 Balancing continuity in best practice and innovation

Ensuring continuity in best practice was a key driver in the development of PAS 8812 to ensure that levels of reliability and safety, which had been previously considered appropriate to the design of temporary works, were not eroded. The steering group recognised the importance of preserving the knowledge gained during many years of research and experience in the field of temporary works and the significant improvements in industry practice following a series of temporary works failures in the 1970s (Bragg 1975).

Ensuring continuity in best practice should be a key driver for design standards. However, where best practice moves on, requiring the application of specific best practice may restrict innovation. This tension between achieving continuity in best practice and supporting the development of innovative solutions has to be recognised and managed by standards' writers.

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[3] For the sake of clarity, this project was undertaken after the Eurocodes project (see Chapter 8), which also revealed the importance of clearly defining purpose, scope and target audience of the standard.

7.5.1.3 Approaches to provide appropriate level of information

Projects 1 and 3 showed different approaches to provide appropriate level of information. In the former, the author introduced the concept of 3Ws and 1H to balance requirements and advisory content. In the latter, governing principles were used to guide the reader and overcome overlapping and conflicting requirements. In either case, the result was a more complete, concise and coherent document.

7.5.1.4 Making appropriate use of cross-references

Arguably, providing all relevant information in one standard by duplicating information from other documents can be helpful to users. However, there are three main disadvantages of this approach: (i) the standard can become enormously long; (ii) selecting only a certain type of information could be misleading as users could assume that the information provided is all they need to know and apply; (iii) the standard developed can become out of date and obsolete when the duplicated documents are updated.

Effective cross-referencing is thus needed. In principle, text should not be duplicated from relevant standards or documents, only reference to them should be made avoiding where possible to cite specific clauses. This helps reduce the need for future changes. This approach however makes it difficult for users to find information unless they are familiar with the referenced document and knows where to find relevant clauses.

There is therefore a tension between having easier to use information (when specific clauses are mentioned), and reducing the need for future changes thus extending the life of the standard (achievable when general cross-references are introduced).

7.5.1.5 Enhancing consistency in terminology

Projects 2 and 3 revealed the existence of issues in the use of terms and definitions. These may have different meanings in different standards (e.g. maximum expansion and contraction ranges for the design of structural bearings, see Table 7.3) as well as diverse implications in different technical contexts (e.g. the concept of safe working load in the context of temporary works design, and the characteristic value of an action for design of permanent works). To develop better design standards, consistency in terminology should be enhanced.

7.5.2 Standardisation system

7.5.2.1 Introducing smarter authoring platforms

In Project 1 a Word document was developed to manage clauses, changes, commentary and discussion between document author and client (see Table 7.1). While this table was fit for its purpose, one limitation deserves mention. In Project 1 the list of users of the table was rather straightforward (i.e. the author, a colleague of the author reviewing the work, and the client). Where the review and approval processes are characterised by numerous stakeholders like in Project 3, multiple copies and different versions of the same document are circulated leading to confusion and sometimes re-work.

XML format is increasingly used by standards organisations to manage the publication stage and provide smarter outputs that can improve the user's experience from the information given in a document (see Section 2.6). However, standards continue to be authored in Microsoft Word (work on Projects 1 and 3 supports this claim). Similarly, the audit trail of decisions made during the committee stage along with the background commentary of the document are typically developed and maintained in Microsoft Word. Online collaborative authoring systems should be used to enable easier and quicker access and smart editing. This aspect has been explored in the DMRB project presented in Chapter 9.

7.5.2.2 Enhancing interfaces between standards organisations

Projects 2 and 3 revealed the need to enhance liaison within and between different standardisation organisations mainly to overcome the problem of overlapping and conflicting requirements. Within a single organisation ineffective liaison can be minimised by introducing internal mechanisms that cross-check work in progress against existing and new documents. It is more difficult to manage the work effectively that involves different standardisation organisations, particularly when dealing with interfacing topics such as structural bearings, where material properties and design can be closely coupled.

7.5.3 Lessons learned

Lessons drawn from these projects are summarised in Table 7.5. The projects are indicated with P1, P2 and P3 as relevant.

Table 7.5 Summary of lessons emerged from Projects 1, 2 and 3

Topic	Lesson learned
Purpose, scope and audience of the standard	Defining a clear high-level purpose, specific objectives and a target audience for the standard helps focus drafting effort and minimise scope creep, while. Achieving consensus among stakeholders may be complicated. Exploring their concerns and needs, as well as showing how their needs can be addressed or why they cannot be, is essential to set clear expectations among stakeholders and provide transparency in the decisions taken. (P3)
Continuity in best practice	Ensuring continuity in best practice and not losing the knowledge gained in many years of research and practical work are crucial to avoid introducing unsafe methods or approaches. On the other hand, attention should be paid to not restrict the development of innovative solutions. (P3)
Approaches to provide appropriate level of information	To develop complete and concise requirements the principle of 3W and 1H (what, why, where, and how) can be applied. It allows clarifying: What requirement has to be verified; Why that specific requirement is needed (background); Where other relevant information can be found (cross-referencing); and How requirements can be verified (specific method). The fourth W (i.e. who is responsible to meet the requirement) should be avoid to ensure contract-neutral requirements. (P1) To enhance coherence in the way content is provided, introducing governing principles can be beneficial. (P3)
Effective cross-referencing	Cross-references should be made to documents rather than specific clauses. Yet, there is a tension between reducing the need for future changes (achievable when cross-references to documents are introduced) and having easier to use information (when specific clauses are mentioned). (P1)
Consistency in terminology	Improving consistency in terminology among different standards is a fundamental step to minimise the risk of misinterpretation and human error (P2). This can be particularly relevant when dealing with the same terms used in different contexts with different meanings (P3).
Smarter authoring platforms	Online collaborative authoring systems should be adopted to enhance the drafting process. (P1; P3)
Interfaces between standards	The interfaces between standards need to be managed more effectively. This can be done by enhancing liaison either within a standardisation organisation or between different organisations. (P2; P3)

7.6 Conclusions

In this chapter three projects have been presented to explore what better design standards are and how they can be developed. Project 1 (P1) concerned the integration of the Structural Eurocodes into client technical specifications and represented a preliminary attempt to standards development by the author. Project 2 (P2) involved the development of recommendations to overcome ambiguities in current formal standards for design of bridge bearing and dealt with overlapping and conflicting requirements and with the inherent technical complexity of provisions. Project 3 (P3) referred to the development of a new publicly available specification (PAS) to provide a means of navigating the diverse landscape of existing standards and guidance documents associated with the design of temporary works. Lessons have been drawn from these projects to enhance both the content of the standards and the standardisation system, and will be used in Chapter 11 for the framework development.

Chapter 8

Usability of the Structural Eurocodes

This chapter contains collaborative work carried out by the author as nominated member of a European team called 'Chairman's Advisory Panel on the ease of use of the Eurocodes' (hereinafter called CAP) of CEN/TC250, the European Committee with the overall responsibility of the Structural Eurocodes. The author fulfilled the role of facilitator of the activities carried out by the CAP in collaboration with the Chair of the CAP and the Chairman of CEN/TC 250. Parts of the work presented in this chapter has been published in CAP on ease of use (2014a; 2014b) and Breitschaft et al. (2014). The content of these publications presented in this chapter represents a personal contribution of the author. Work done in collaboration with others is indicated as such.

This chapter also contains work carried out by the author since being appointed as M/515 Technical Reviewer for the second generation of Eurocodes and member of the CEN/TC 250 Management Group.

8.1 Introduction

The Structural Eurocodes are the main suite of design standards in Europe and in several countries outside Europe for civil, structural and geotechnical design. In 2010 the European Commission started the process of evolution of this international suite of standards towards the second generation with a major focus on enhancing their "user-friendliness". Research towards interpreting what "user-friendliness" might mean in the context of the Eurocodes had to be taken.

This chapter reports on the project carried out to understand the concept of usability in the context of the Structural Eurocodes and to help define the recommendations to enhance their ease of use. This project has been selected and examined in this thesis for its high degree of complexity in terms of size of documents, number of stakeholders involved and impact on design practice.

The chapter is structured as follows. In Section 8.2 background information is provided to understand the Eurocodes' history and their nature. An overview of the work on the first generation of Eurocodes is provided. Latest developments in the Eurocodes evolution are presented with a focus on the structure of the technical committee responsible for the Eurocodes' development (i.e. CEN/TC 250), the work programme, and the development process of the Eurocodes. The issue of the usability of the first generation of Eurocodes is illustrated in Section 8.3. The methodology applied is examined with a focus on objectives, research methods adopted and the stages of the work. The role of the Chairman's Advisory Panel (CAP) on Ease of Use of the Eurocodes is clarified. A distinction has been made between the collaborative work carried out within the CAP, the activities undertaken as appointed Technical Reviewer of the Eurocodes, and the personal and independent contribution of the author as a researcher. The guidelines developed to enhance the ease of use of the Eurocodes are also illustrated. Critical reflections on the limitations of the research programme are given in Section 8.4. Emerging themes relevant to the discussion on the quality of design standards are examined in Sections 8.5, 8.6 and 8.7. Key lessons learned are summarised in 8.8.

8.2 Background on the Eurocodes

8.2.1 First generation

The development of the first generation of the Structural Eurocodes was a remarkable accomplishment. It stemmed from the ambitions of the Commission of the European Communities (today called European Commission) to foster harmonisation and eliminate technical barriers to trade across the European Member States. Nowadays, the Eurocodes are used by professional engineers across the EU and European Free Trade Association (EFTA) Member States. In addition, there is considerable interest in using the Eurocodes by other countries outside Europe (see Figure 8.1).

A detailed description of the 40-year drafting work and collaborative international effort carried out for the first generation of the Eurocodes is provided by Johnson (2009). He claims that the aim of the first generation of the Eurocodes was a "three-way harmonisation across countries, structural materials and types of structure with the widest scope practicable". Johnson (2009) also notes that harmonisation is only one of the achievements of the first generation of the Eurocodes, which include: (i) wide scope; (ii) most provisions based on research and conceptual models, rather than rules of thumb; (iii) exploitation of the availability of software for analysis; (iv) essential reference to product standards; (v) account of geographical differences by means of nationally determined parameters (NDPs).

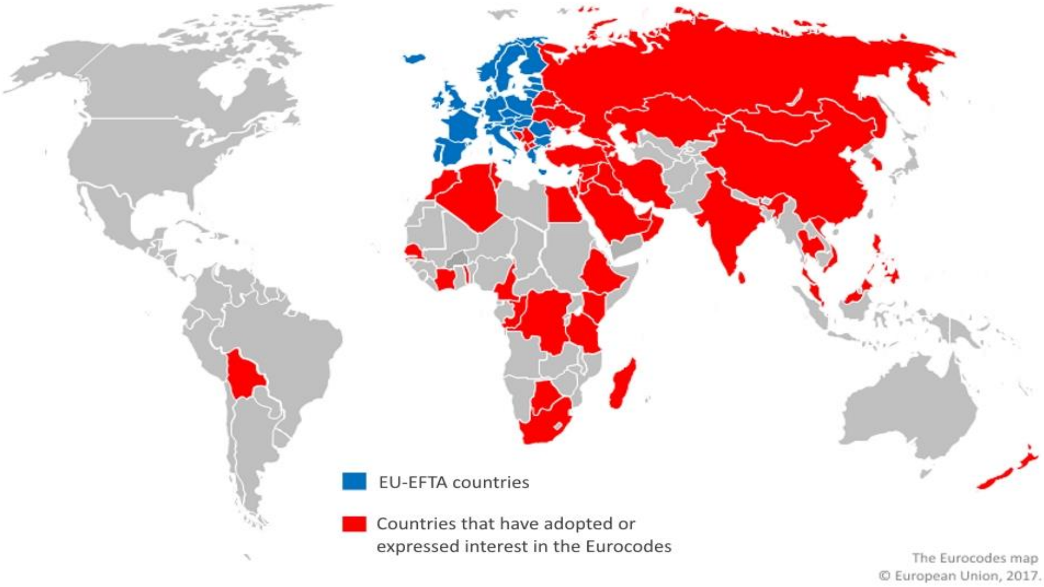

Figure 8.1 Countries that have expressed interest or have adopted the Eurocodes (reproduced from http://eurocodes.jrc.ec.europa.eu/)

8.2.2 Second generation

The process of evolution of the Eurocodes towards the second generation initiated in 2010 with the Programming Mandate M/466 (2010) issued by the European Commission Enterprise and Industry Directorate (EC-EID) to CEN, followed by Mandate M/515 (2012). This process aimed to take on board market developments (particularly new methods and materials), new societal needs, innovation and research, as well as to enhance their ease of use. After around three years of technical work and discussion, in 2013 a technical reply to the mandate was unanimously approved by CEN/TC 250 (CEN/TC 250 Decision 315) and transmitted to the EC-EID (2013a).

8.2.2.1 CEN/TC 250 structure

CEN/TC 250 is the Technical Committee with the "overall responsibility for structural design rules in the building and civil engineering field" (Resolution BTS1 11/1992). In this capacity, CEN/TC 250 is responsible for development and maintenance of the Structural Eurocodes. The CEN/TC 250 structure includes a Management Group, Coordination Group, 9 Subcommittees (SC), 7 first tier Work Groups (WG) that report directly to TC 250, two Horizontal Groups (HG) and 97 subordinate Working Groups and Task Groups. Current CEN/TC 250 Structure is represented in Figure 8.2.

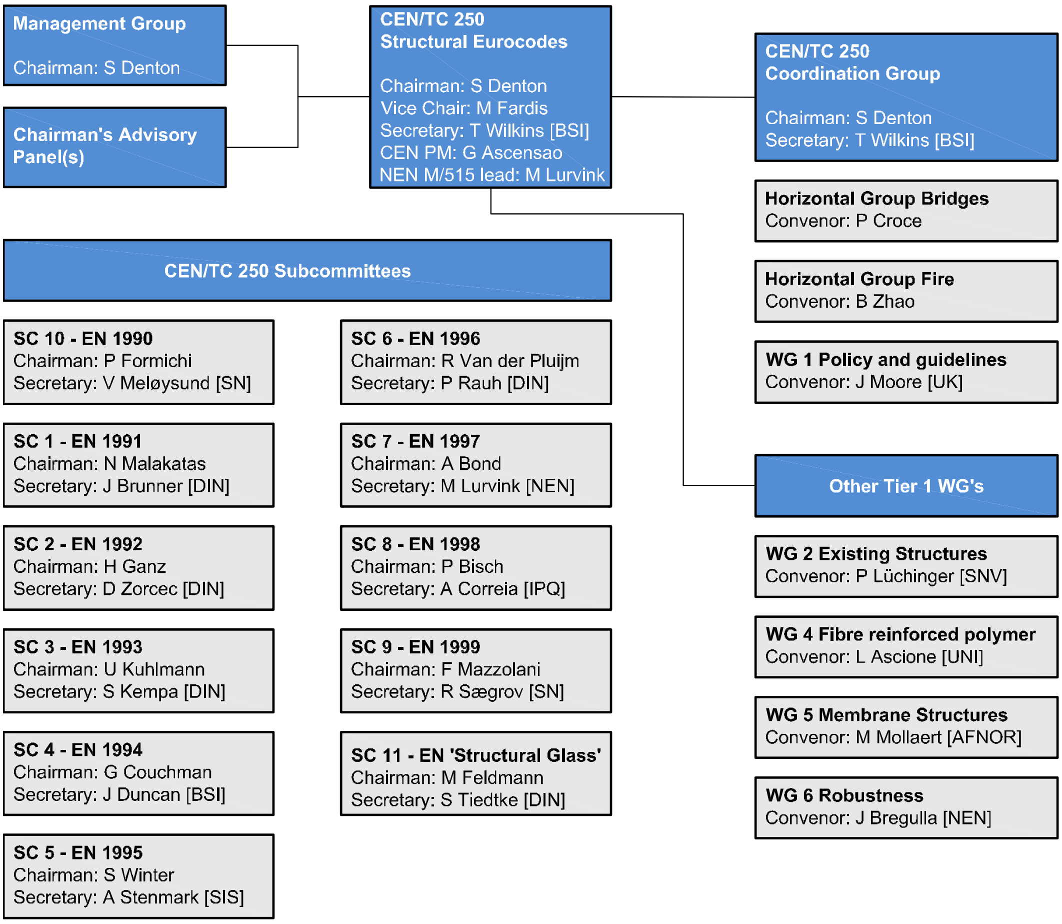

Figure 8.2 Current CEN/TC 250 Structure at November 2018 (excluding subordinate Working Groups and Task Groups), reproduced from CEN/TC 250 (2018)

8.2.2.2 CEN/TC 250 work programme

The full CEN/TC 250 work programme was structured to comprise 77 discrete tasks in four overlapping phases, with Phase 1 including those parts of the programme upon which other activities were dependent for reasons of overall coordination or technical scope. The deliverables of the four phases comprise:

- revised EN Eurocode parts;
- additional or modified clauses / sections to EN Eurocode parts, which have then to be combined by the relevant SCs or WGs into EN Eurocode parts;
- new EN Eurocode parts for example on structural glass structures;
- new CEN TS (technical specification, see Section 2.4.1) covering assessment of existing structures, fibre reinforced polymers (FRP) structures and membrane structures.

The European Commission expressed positive feedback on the technical proposal for the development of the second generation of the Eurocodes in 2014. However, a comprehensive mandate response (quotation) comprising both technical and financial proposals was required for the European Commission to fully assess the proposals. The quotation for Phase 1 of the proposed CEN/TC 250 work programme was formally agreed by the European Commission in 2014 awarding a grant agreement for EUR 4.5M. The quotation for Phase 2 worth EUR 3.29M was accepted in 2016, and the single combined quotation for Phases 3 and 4 worth EUR 3.6M was accepted in 2018. The total funding required from the European Commission to fulfil the full objectives of mandate M/515 through the execution of all four phases of the CEN/TC 250 work programme is thus approximately EUR 11.4M, and represents the largest funding amount ever allocated for a standardisation programme by the European Commission.

The calls for experts for Phase 1, Phase 2, and Phases 3 and 4 of the work programme were launched in April 2015 (January 2017 for the Technical Reviewer role, see Section 8.3.1), December 2016 and December 2017 respectively (details can be found at https://www.nen.nl/Normontwikkeling/Eurocodes-2020.htm). The purpose of these procurements was to appoint experts to form the Project Teams for the 29 tasks in Phase 1, 22 tasks in Phase 2, 26 tasks in Phases 3 and 4, and the appointment of the Technical Reviewer.

The project teams for the delivery of the four phases of the work programme (which comprised one Project Team Leader and four or five Project Team Members) started to work in September 2015 for Phase 1 (June 2017 for the Technical Reviewer role), June 2017 for Phase 2, June 2018 for Phase 3 and November 2018 for Phase 4.

A summary of the Eurocodes evolution is represented in Figure 8.3, including the four overlapping phases.

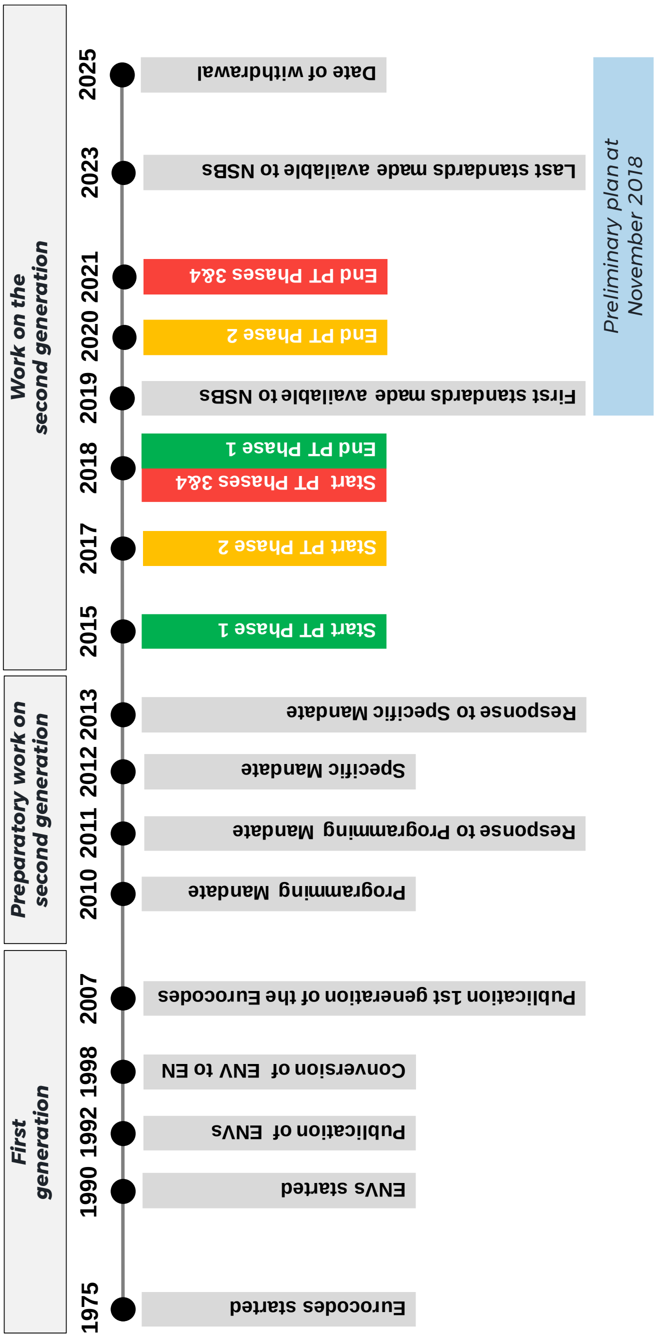

Figure 8.3 Timeline of the Eurocodes evolution

8.2.2.3 Development process

The development process of the Eurocodes is based on the CEN Internal Regulations (CEN/CENELEC 2017, 2018) and is outlined in Figure 8.4. The work of the appointed Project Teams entails: the production of three drafts reviewed by the relevant Sub-Committee (SC) or Working Group (WG); a commenting period (informal enquiry) by National Standards Bodies (NSBs) to collect initial views on the deliverables produced by the Project Teams, and the preparation of the final deliverable taking into account comments from the NSBs.

The responsibility to finalise a EN Eurocode part is then transferred to the relevant SC or WG, potentially incorporating inputs from several project teams working in the same phase of the work programme or in different phases. Once a EN Eurocode part has been compiled, it is submitted to CEN-CENELEC Management Centre (CCMC) for first editing and subsequently to DIN (German NSB) and AFNOR (French NSB) for translation. The Eurocode part is then ready for CEN formal enquiry. At this stage, the NSBs may start drafting their National Annexes although further work may be needed after CEN enquiry.

The relevant SC or WG review and resolve comments from CEN enquiry and finalise the standard. CCMC carries out the relevant administrative tasks and makes further editorial changes to the document as needed. Formal vote is then launched (see Chapter 2 for voting policy of EN and CEN TS). There may be cases where a translation period is also requested by DIN and AFNOR during the previous enquiry procedure.

Following a positive result of the formal vote, CCMC publication unit makes final editorial changes to the document produced, and distributes the definitive text of the approved European Standard (EN) in the available language version(s) (English, French and German) to the NSBs. CEN Members implement the Eurocode part at national level by giving it the status of a national standard and are expected to withdraw any national standards conflicting with the EN within a specific timeframe (see Chapter 2). It is expected that the co-existence period of the first and second generation of Eurocode parts will be handled at national level.

The SCs and WGs are currently reviewing the Phase 1 deliverables. Six of them are draft Eurocode parts, two are draft CEN TS, the remaining are additional or modified clauses to EN Eurocode parts. The latter will be used by relevant SCs or WGs to compile draft Eurocode parts using the deliverables that will be developed in other phases of the work programme. Work is also ongoing to develop a preliminary plan for the publication of the second generation of Eurocodes.

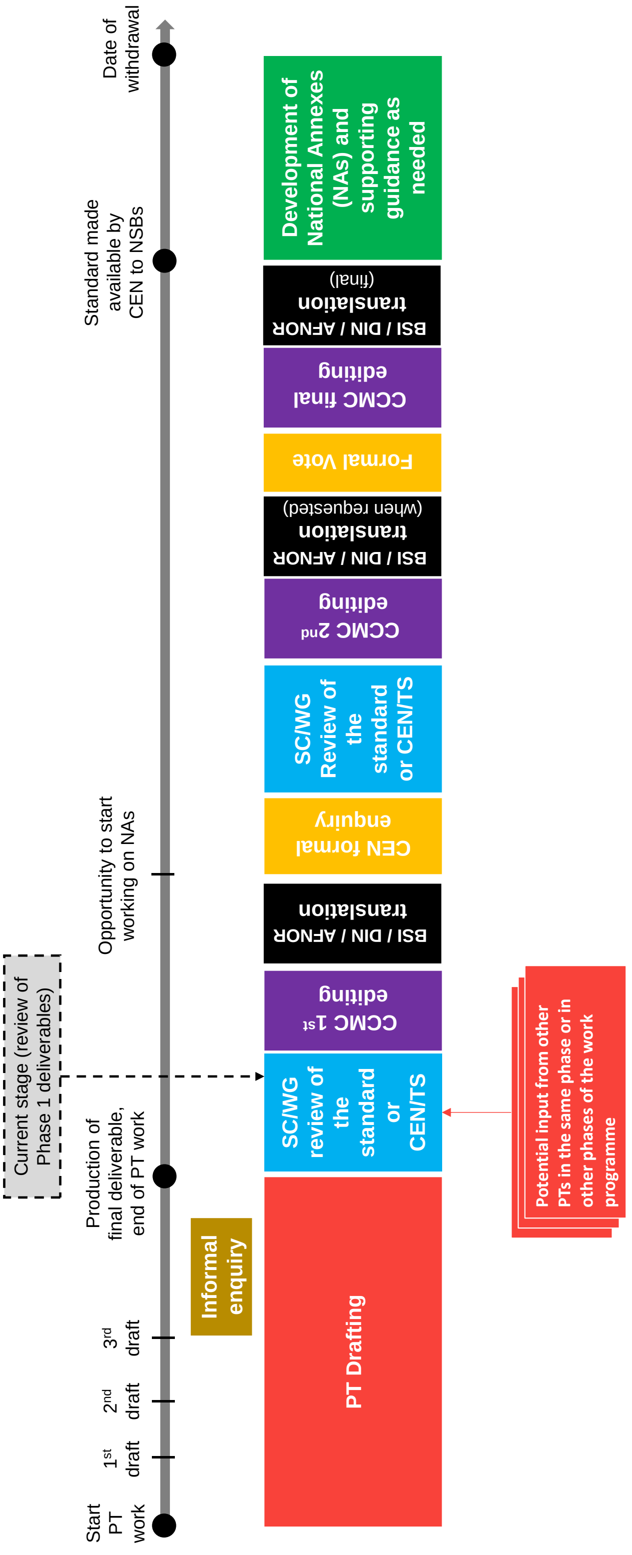

Figure 8.4 Example of development process of a Eurocode part

8.3 Enhancing the ease of use of the Eurocodes

8.3.1 Overview

A notable focus of the work programme is on enhancing the ease of use of the Eurocodes for users (CEN/TC 250 2013a). Accomplishing this task required a clear understanding of what 'usability' means in the context of the Eurocodes first and then how it can be enhanced in practice. Over recent years the issue of their usability has been discussed at some length by CEN/TC 250 and its subcommittees, and has become of significant interest and concern in many CEN member countries.

The first formal commitment of CEN/TC 250 to improving the ease of use of these documents was in 2010 through Decision 280, by which CEN/TC 250 agreed to work on this challenging task. To support this effort, in 2013 CEN/TC 250 agreed to create a Chairman's Advisory Panel (CAP) to develop recommendations for the approach to be taken to enhance the ease of use of the Eurocodes (CEN/TC 250 2013b).

To sustain the recommendations developed by the CAP and provide support to the Project Teams working on the evolution of the Eurocodes, the role of the Technical Reviewer was subsequently introduced. Following international competitions, the author has been appointed Technical Reviewer for all phases of the work programme.

The work undertaken by the author within the CAP and as Technical Reviewer to explore the strategies to enhance the ease of use of the Eurocodes is presented in the next sections.

8.3.2 Multi-methodology

8.3.2.1 Action Case Research

Action Case Research (ACR) was adopted by the author as the overall research framework to explore the strategies to enhance the ease of use of the Eurocodes and identify the challenges to be addressed (see Section 4.3.5 for more details on ACR). Ten spirals of observing, reflecting, planning and acting were followed as illustrated in Figure 8.5:

- Spiral 1 refers to the initial exploration carried out as personal initiative of the author.
- Spirals 2 to 7 illustrate the collaborative work carried out by the CAP.
- Spiral 8 refers to CEN/TC 250 activities for the development of the position paper.

- Spirals 9 and 10 refers to personal work of the author as nominated Technical Reviewer of Phases 1 to 4 of the work programme.
- Spirals 2 to 8 lasted over 17 months (from October 2013 to March 2015). From March 2015 to June 2017 the projects teams of Phase 1 of the work programme have been working on the deliverables identified in the relevant task specifications. Spirals 9 and 10 refer to the Technical Reviewer work started in June 2017 (over 16 months).

The spirals have been grouped into five stages discussed in detail in the following sub-sections in terms of purpose, data collection, analysis procedures and key outcomes:

- Stage 1: The problem situation unstructured (comprising spiral 1)
- Stage 2: The problem situation expressed (comprising spiral 2)
- Stage 3: Argumentative process (comprising spirals 3-5)
- Stage 4: Reaching consensus (comprising spirals 6-7)
- Stage 5: Synthesis (comprising spiral 8)
- Stage 6: Implementation (comprising spiral 9)
- Stage 7: Monitoring (comprising spiral 10)

Action Case research has been used in conjunction with two research methods presented in detail below, i.e. *Stakeholders Analysis* and the *Issue-Based Information System (IBIS)* rhetorical method.

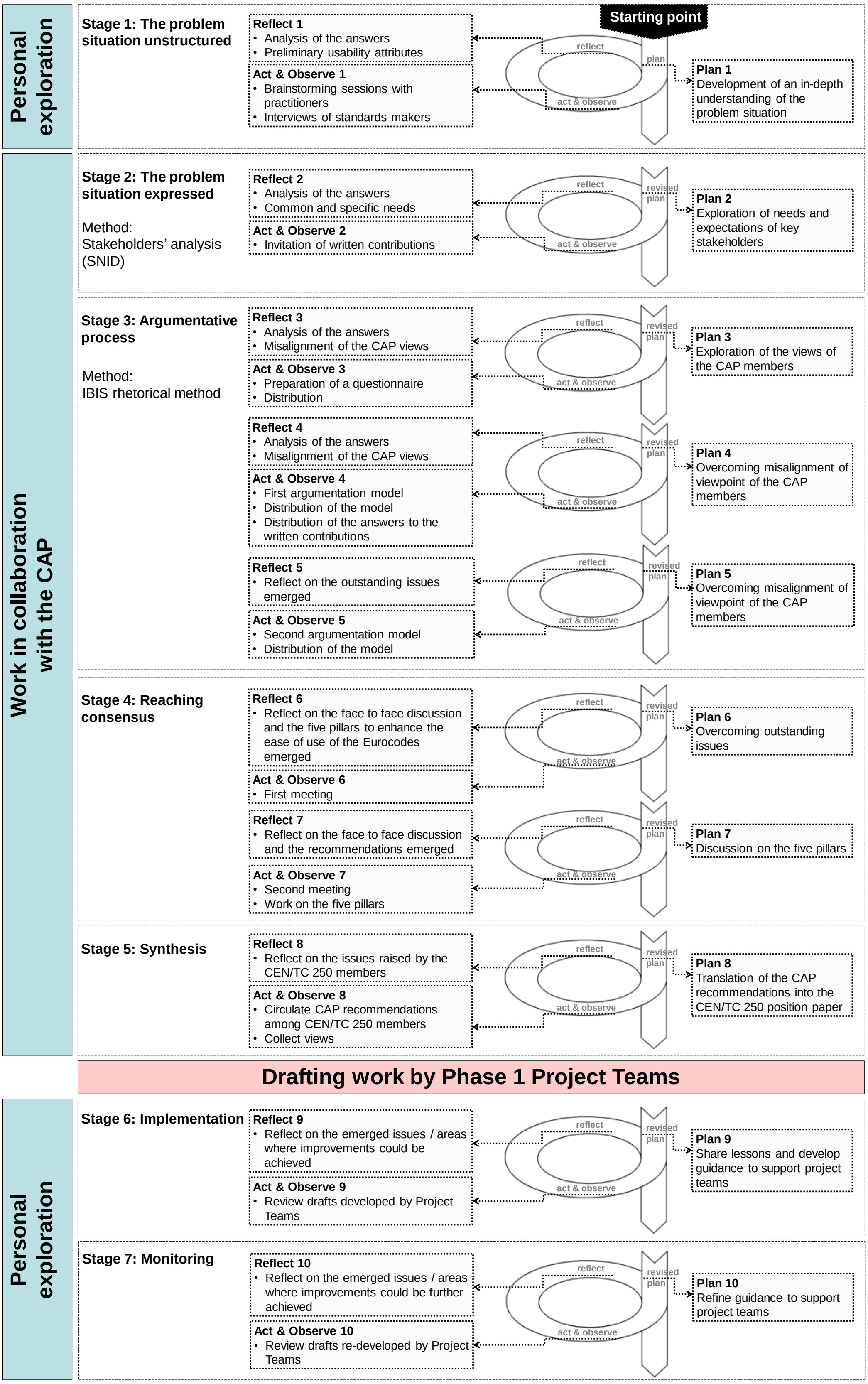

Figure 8.5 Overview of the research programme for the Eurocodes project

8.3.2.2 Stakeholders' analysis

The first objective of this project was to appreciate the needs and priorities of different categories of stakeholders on the second generation of the Eurocodes, and assess potential tensions.

A wide range of stakeholders identification and analysis techniques exist (Hermans and Thissen 2009). In this project a modified version of the 'Stakeholder-Issue Interrelation Diagram' (SIID) (Bryson 2004) has been adopted. The classical SIID develops further the power/interest matrix (Mendelow 1981) to (i) identify issues relevant to different categories of stakeholders, (ii) show how stakeholders might be linked through their relationships with the stated issues and (iii) suggest actual and potential areas of cooperation and conflicts among stakeholders.

The modified SIID adopted in this project contained needs rather than issues[1] as illustrated in Figure 8.6, and it has been called 'Stakeholder-Need Interrelation Diagram' (SNID). Through SNID it is possible to identify both common needs among different categories of stakeholders and specific needs. Common needs were clustered to identify shared goals and reduce the categories of actors to deal with. On the other hand, specific needs were isolated: this contributed to identify and assess potential tensions among different needs.

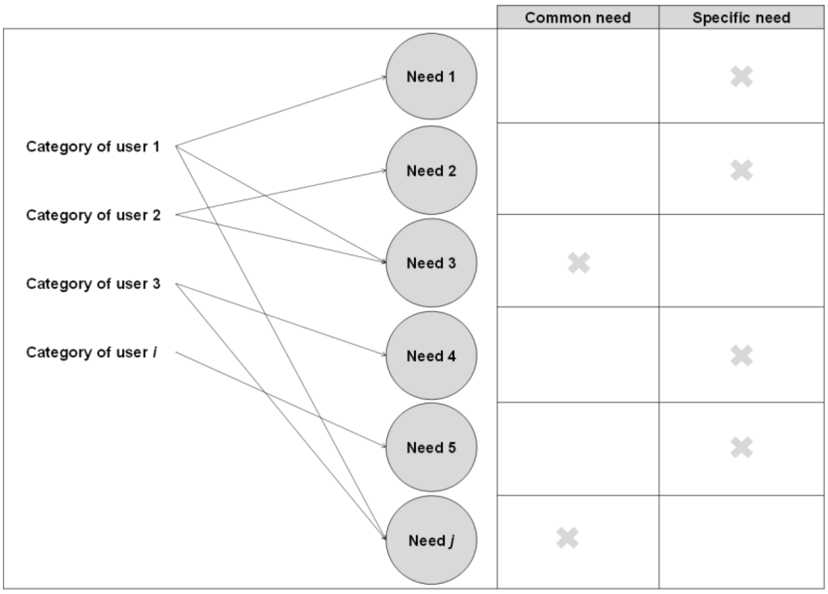

Figure 8.6 Stakeholder-Need Interrelation Diagram for the Eurocodes project

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[1] It is worth noting that issues are often needs and, as the literature shows (Eden and Ackermann 1998), give rise to the identification of goals in action.

8.3.2.3 IBIS rhetorical method

Decision making typically requires discussion and negotiation among stakeholders, which may be supported by different techniques depending on the issue to be tackled. As noted in Section 8.3.1, one of the objectives of the research programme was to develop a shared understanding among decision makers whilst exploring and externalising areas of disagreement. Within the reasoning, logic and argumentation research areas, the Issue-Based Information System (IBIS) rhetorical method can be used to tackle this kind of situations.

Based on the early ideas of Kunz and Rittel (1970), the IBIS method is a structured way to facilitate discussion whilst expressing and linking *issues* (i.e., questions or problems), *positions* (i.e., possible options for resolution of a specific issue), and *arguments* (i.e., pros and cons of alternative positions). The IBIS method develops further the theory of argumentation presented by Toulmin (1958), which can be particularly relevant when dealing with policy making and more in general wicked or messy problems as noted by Mitroff et al. (1982). This links to what was discussed in Chapter 4 on the importance of following an argumentative process for messy problems, which involve participants and evolves during the research activity.

From a practical point of view, the IBIS method starts with the formulation of a specific issue. Different positions are then proposed by the participants. After that, arguments in favour of and against each position are put forward. Through this structured process a better understanding among participants is developed. This may relate to alternatives available or more promising options in a specific context for a stated issue. The IBIS method thus results in explicit “capture, articulation, representation and use of the rationale” (Lewkowicz and Zacklad 2002). At the end of this process a map is typically produced, which links issues, positions and arguments. Tools such as Compendium (Selvin et al. 2001) exist that enable IBIS maps to be developed.

There are three features of the IBIS method which can potentially be considered limitations when using it. First, personal participation and interaction in meetings are important aspects. Indeed, Mackenzie et al. (2006) argue that the IBIS method “is intended to support joint problem solving and to encourage helpful, collaborative conversation around the wicked problem”. Second, the IBIS method is not meant to provide the source of the issue, position and argument: in other words, it does not require the name of the participant making that specific statement or posing that specific issue. Third, the IBIS method treats each issue separately, thus it does not enable dependent relationships between different issue resolutions to be showed as also recognised by McCall (1979). In cases where (i) opportunities for participation and interaction are restricted (for example due to geographical reasons), (ii) the name of participant stating an issue is required for transparency reasons and to facilitate the sharing of ideas, and (iii) answering one issue often depends on how other issues are answered, the IBIS method requires a degree of modification or adaptation. A modified IBIS has been adopted in this project to overcome these issues. The modified IBIS has been called I$\widehat{\mathrm{BI}}$S and is presented in Section 8.3.5.

8.3.3 The CAP on ease of use

The fifteen members of the Chairman's Advisory Panel on Ease of Use (CAP) of the Eurocodes were selected from those nominated by CEN/TC 250 members from different European countries. They were an expert and informed team with a balance between practitioners, academics and experts experienced in standards development. Their backgrounds covered all aspects of civil and structural engineering, including concrete, steel, composite, and masonry structures design, bridge design, seismic design, geotechnical design. The CAP members had long-lasting experience in standards drafting. Specifically:

- five members from the United Kingdom (including the Chairman of CEN/TC 250), all practitioners experienced in standards development (two of them with over 40 years of experience, one over 25 years), two members also fulfilling academic roles;
- four members from Germany (including the Chair of the CAP), all practitioners experienced in standards development (two of them over 30 years of experience), one member fulfilling an academic role, and one with a strategic role in the public sector (technical approval authority);
- one member from Spain, practitioner;
- one member from Greece, practitioner with over 40 years of experience in standards development, and also fulfilling an academic role;
- one member from France, experienced in standards development;
- one member from Italy (the author), practitioner and experienced in standards development;
- one member from Norway, practitioner with over 40 years of experience in standards development, and also fulfilling an academic role;
- one member from Sweden, practitioner and working for a client authority.

The CAP was intended to be an advisory panel whose recommendations had to be ratified by CEN/TC 250. The objectives of the CAP were to:

(i) appreciate the needs and priorities of users and different categories of stakeholders on the second generation of the Eurocodes, and assess potential tensions;
(ii) explore and externalise areas of disagreement among decision makers (i.e. the CAP members); and
(iii) develop a shared understanding and obtain the most reliable consensus between decision makers.

The CAP went through a rigorous process to support decision making and provide a robust and auditable rationale for the decisions taken for widespread dissemination to users of the Eurocodes and to the Project Teams (PTs) engaged in drafting the second generation of the Eurocodes.

The author fulfilled the role of "process facilitator" in Miranda and Bostrom's (1999) terms working closely with the Chair of the CAP and the Chairman of CEN/TC 250. Key responsibilities included: proposal of relevant research methods; data assessment and modelling; identification of emerging themes.

8.3.4 Stage 1: The problem situation unstructured

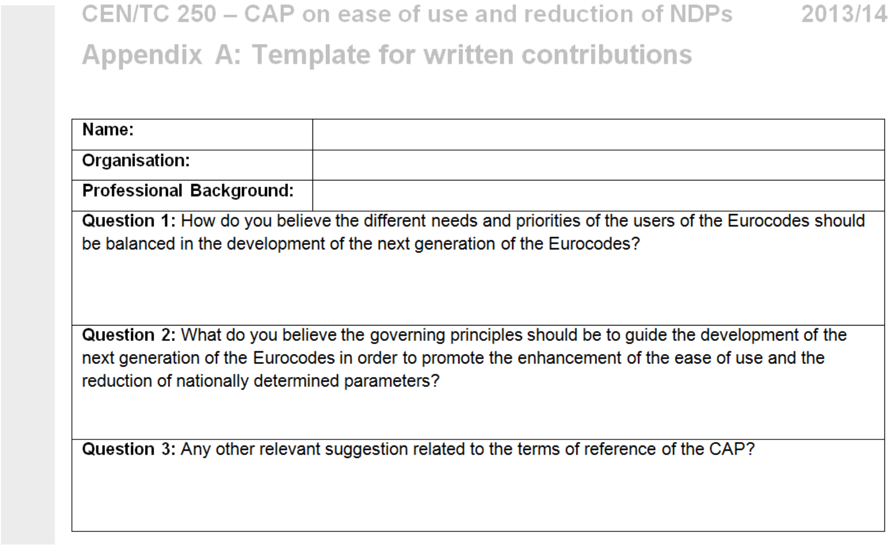
The purpose of Stage 1 was to develop an in-depth understanding of the problem situation. The author reviewed relevant documents and carried out brainstorming sessions with practitioners and semi-structure interviews of standards' writers, which have been introduced in Sections 4.3.2 and 4.3.3, respectively. As a result, general needs of practicing engineers and standards' writers were identified, which formed the basis for Stage 2 of the programme. The preliminary list of usability attributes presented in Table 5.3 was adopted.

8.3.5 Stage 2: The problem situation expressed

The formal collaborative process with the CAP members started in the second spiral. The purpose was to identify and categorise key stakeholders, and to investigate their needs and expectations for the second generation of the Eurocodes. A stakeholders' analysis was carried out and a preliminary list of twenty-one target audiences was developed.

8.3.5.1 Written contributions

Subsequently, an invitation for written contributions was sent to the National Standards Bodies of all European Member States (CEN/TC250 2013c) to collect information about the needs of the Eurocodes' audiences and specifically: (i) to investigate common needs valid for diverse audiences; (ii) to appreciate specific needs; (iii) to start investigating the feasibility of the users' expectations; (iv) to identify contrasting views. Contributions were invited from any organisation or individual who wished to contribute to the CAP work. Three questions were asked and a specific template was provided requiring name, organisation and professional background of the contributing author to contextualise the responses (see Figure 8.7).



CEN/TC 250 – CAP on ease of use and reduction of NDPs 2013/14

Appendix A: Template for written contributions

Name:	
Organisation:	
Professional Background:	
Question 1: How do you believe the different needs and priorities of the users of the Eurocodes should be balanced in the development of the next generation of the Eurocodes?	
Question 2: What do you believe the governing principles should be to guide the development of the next generation of the Eurocodes in order to promote the enhancement of the ease of use and the reduction of nationally determined parameters?	
Question 3: Any other relevant suggestion related to the terms of reference of the CAP?	

Figure 8.7 Template for written contributions (CEN/TC250 2013c)

Sixteen detailed responses were collected from different European Member States (eleven from the UK, two from Germany, one from Belgium, one from Finland, and one from Italy). Disappointingly, the number of responses was not as high as expected considering the number of stakeholders involved in the Eurocodes evolution. Nevertheless, the response covered key categories of users including practitioners, clients, product manufacturers, standard makers, regulators, educators and researchers.

Responses addressed a wider range of topics than those required by the questions and were categorised into the following themes:

- Problems in the current generation of the Eurocodes

  Responses showed typical issues experienced by the Eurocodes' users. Difficulty in navigation and dispersion of information were two recurrent issues. The Eurocodes are a big suite of design standards made up of 58 volumes containing technical provisions on all structure and material types. They comprise more than 5,200 pages, which in turn require the National Annexes to be implemented in different European countries. Perceived complexity stemming from the inherent text complexity, the novelty of the content, different drafting styles, and the attempt to find a compromise between different design traditions and cultures also emerged from the responses. The Eurocodes are developed and used by CEN National Members (see Chapter 2) characterised by specific technical, political, economic, cultural and legal issues. Johnson (2009) acknowledged these aspects and noted that those delayed the work of drafting committees and panels for the development of the first generation of the Eurocodes, and made the entire process extremely challenging.

- Stakeholders' expectations

  A huge number of stakeholders are affected by the Eurocodes' evolution, not only designers (around 500,000 professional engineers across the CEN National Members only plus thousands of other users outside Europe), meaning that significant people-oriented issues exist due to the variety of needs and expectations. Responses to the written contributions showed different needs of different categories of stakeholders. However, respondents also acknowledged the importance of focusing on practitioners – not necessarily experts – as the primary audience.

- Governing principles for the next generation of the Eurocodes

  Responses to the written contributions acknowledged, *inter alia*, the need to:

  - enhance clarity by using easier and plain language, avoiding ambiguity, improving editorial and technical consistency between the Eurocode parts;
  - enhance navigation by providing a logical sequence of technical provisions;
  - improve consistency with other European standards;
  - ensure that the Eurocodes are understandable to qualified practitioners who have not participated in the drafting process;
  - focus on practitioners' needs and bear in mind that they have different skills;
  - control the length of documents;

- limit the change in the structure of the Eurocodes to avoid confusion;
- avoid drastic simplification;
- maintain basic technical concepts;
- provide more harmonisation by avoiding too many alternative rules, particularly when leading to negligible differences.

Responses have been summarised into the factors affecting the usability of the Eurocodes, which are indicated in the Ishikawa diagram illustrated in Figure 8.8.

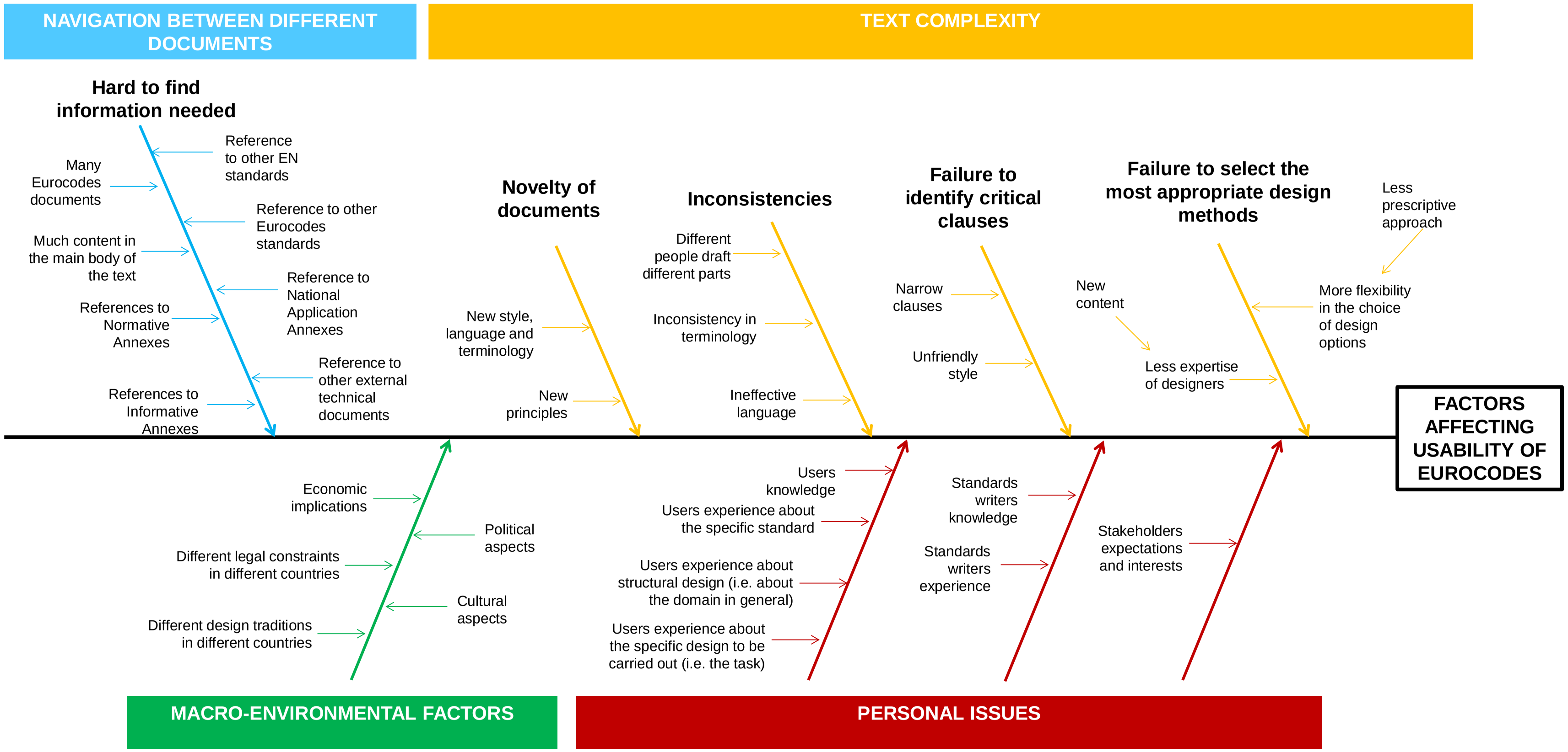
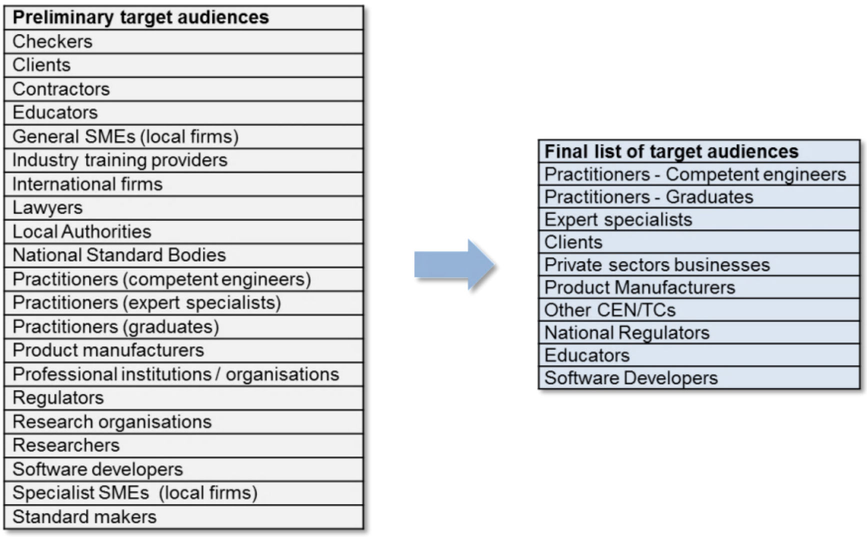


Figure 8.8 Factors affecting the usability of the Eurocodes (Ishikawa diagram)

8.3.5.2 Target audiences

A stakeholder-need interrelation diagram (SNID) was then prepared using data gathered from the written contributions and Stage 1 to investigate similarities and divergences among stakeholders' needs. The diagram enabled both common and specific needs to be identified. As a result, the categories of stakeholders were reduced from the initial twenty-one to ten as shown in Figure 8.9. A report containing the results of this study was produced and circulated among the CAP members during Stage 3 presented in the next section.



Preliminary target audiences
Checkers
Clients
Contractors
Educators
General SMEs (local firms)
Industry training providers
International firms
Lawyers
Local Authorities
National Standard Bodies
Practitioners (competent engineers)
Practitioners (expert specialists)
Practitioners (graduates)
Product manufacturers
Professional institutions / organisations
Regulators
Research organisations
Researchers
Software developers
Specialist SMEs (local firms)
Standard makers

Final list of target audiences
Practitioners - Competent engineers
Practitioners - Graduates
Expert specialists
Clients
Private sectors businesses
Product Manufacturers
Other CEN/TCs
National Regulators
Educators
Software Developers

Figure 8.9 Categories of stakeholders reproduced from CAP on ease of use (2014a, 2014b)

8.3.6 Stage 3: Argumentative process

8.3.6.1 Initial exploration of the CAP views

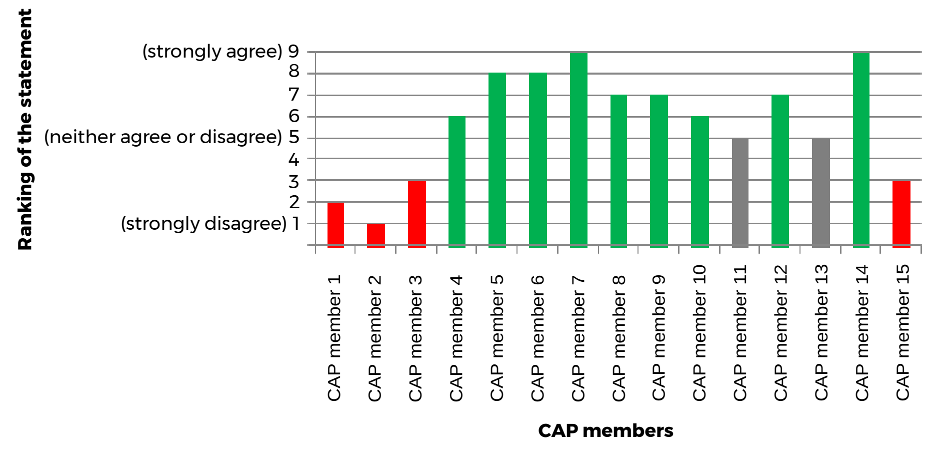
The purpose of Stage 3 was to develop a shared understanding among the CAP members and externalise areas of misalignment in their viewpoints on the strategies to enhance the ease of use of the Eurocodes. The aim was to explore potential conflicts and avoid latent disagreement, which may affect future decisions. The argumentative process started with the preparation of a questionnaire made up of two tables.

Forty-four statements were prepared based on the results of the interviews and the brainstorming sessions carried out by the author in Stage 1 (see Table A in Annex A). Some statements overlapped for consistency check of the responses. A Likert scale 1-9 was proposed, with (1) strongly disagree, (5) neither agree or disagree, (9) strongly agree. A column for comments was also provided.

The attributes of easy to use design standards derived by the author and presented in Table 5.3 were used to create a list of key performance indicators (KPIs) of user-orientated design standards (see Table B in Annex A). The KPIs were expected to be ranked by the CAP members in order of importance to the user-friendliness of the Eurocodes.

Due to the small sample size (15 responses, one for each CAP member), the author did not carry out statistical calculations to analyse responses. The answers were simply compared looking at the ranking of the responses, with 1 denoting strong disagreement and 9 strong agreement with the statement. Bar charts were used to compare them as shown in Table 8.1. Comments and name of the respondent were included for transparency reasons and to speed up the process of exploration and externalisation of the areas of disagreement among the CAP members.

Table 8.1 Example of a table used to summarise CAP responses



No	Statement	Outcome	Comments from the CAP members
9	*The number of pages will be a key factor affecting the ease of use of the Eurocodes after 2020*	*Need to externalise reasons for misalignment*	*CAP Member No. 2: The volume must be right to cover the content that is needed – leaving out rules to reduce volume will not make the codes easier to use.* *CAP Member No.11: Navigating in plenty of pages is not easy for designers. However, cutting the number of pages is not the solution to improve the ease of use of the Eurocodes since the deleted information has to be allocated somewhere else (unless it is useless).*

Results from Table A of the questionnaire showed good alignment of views on some key governing principles for the next generation of the Eurocodes such as:

- the role of the designers as the most important users of the Eurocodes;
- the importance of not inhibiting the freedom of expert practitioners to work from first principles;

- the need to minimise potential for misinterpretation;
- the necessity of providing simplified routes through the Eurocodes;
- the need for more consistency.

Yet, results from Table A also showed areas of misalignment of the CAP views on:

- the role of simplified methods and alternative application rules;
- the inclusion of rules for product performance;
- the number of pages;
- the role of informative annexes;
- the inclusion of detailed design methods for specific applications.

Similarly, results from Table B of the questionnaire showed a good alignment on the order of importance of the KPIs, but also inconsistencies internally (i.e. within the answers to Table B) as well as externally (i.e. with the responses from Table A), meaning that further discussion was needed.

Due to the small sample size, it was not possible to infer any valid correlation between the answers and features of the CAP members (see Section 8.3.3) such as years of experience, country of origin, field of interest, etc. The answers were seen as a combination of personal beliefs and values, experience of specific technical traditions, knowledge, and external influences.

8.3.6.2 Exploration of areas of misalignment in the CAP viewpoints

To explore and externalise the areas of misalignment in the viewpoint of the CAP members, the author suggested the adoption of the IBIS method (see Section 8.3.2.3). It was applied in the form of a table reproduced in Figure 8.10.

<table>
<tr><td>Issue</td><td colspan="2">Comment
[Collected from the questionnaire]</td></tr>
<tr><td></td><td colspan="2"></td></tr>
<tr><td colspan="3">Q1: Why do you think there is misalignment among participants’ view on this issue?</td></tr>
<tr><td colspan="3"></td></tr>
<tr><td colspan="3"></td></tr>
<tr><td colspan="3"></td></tr>
<tr><td colspan="3">Q2: What options exist to address this misalignment?</td></tr>
<tr><td>Option 1</td><td>Pros:</td><td>Cons:</td></tr>
<tr><td>Option 2</td><td>Pros:</td><td>Cons:</td></tr>
<tr><td>Option (…)</td><td>Pros:</td><td>Cons:</td></tr>
<tr><td>Option <i>i</i></td><td>Pros:</td><td>Cons:</td></tr>
</table>

Figure 8.10 IBIS table for the CAP members

The CAP members were asked to: provide opinions on the potential reasons for disagreement on specific statements of the questionnaire; suggest options for resolution; and propose arguments in favour and against each option taking the responses to the invitation for written contributions in consideration. The IBIS table was circulated and one month was given to provide answers.

The reasons for choosing this "asynchronous argumentation" (Guerrero and Pino 2009) were twofold: (1) for geographical reasons, as the CAP members were from different CEN Member States, hence opportunities for face to face meetings were very limited; (2) to give the CAP members more time to read and reflect on the answers in line with Kanselaar et al.'s (2003) considerations on asynchronous argumentation.

The analysis of the responses to the IBIS table revealed that some areas of misalignment of the CAP views needed to be shared and discussed in person. It also showed that disagreement does not always stem from a real conflict among participants. Indeed, a few statements were felt ambiguous and misunderstood, thus responses were led by different interpretations of these statements. In some cases, misunderstanding was due to geographical, lexical or cultural barriers. In other cases, it was clear that the responses to the questionnaire stemmed from an incomplete or partial view of the problem situation. Some answers were led by an ideal and desirable outcome, rather than an achievable one.

Moreover, a few responses seemed to be influenced by the field of interest (e.g. seismic or geotechnical engineering) of the CAP members. Some answers were affected by the diverse legal status design standards have in different countries (indeed, where design standards are enforced by regulations, their roles become much more restricted than in counties where they are not mandatory by law). A few responses were led by the specific engineering practice in the countries of origin. On top of that, political and economic considerations also affected (and in some cases constrained) responses from the CAP members.

To further explore controversial issues, another table as reproduced in Figure 8.11 was developed. It is different compared to the one in Figure 8.10 as it is comprised of the name of the CAP member against the issue and the related arguments. This modified IBIS table has been called $\mathrm{I}\widehat{\mathrm{BI}}\mathrm{S}$. Related issues were grouped together to reduce the work load on the CAP members. The $\mathrm{I}\widehat{\mathrm{BI}}\mathrm{S}$ table was circulated ahead of the first face-to-face meeting of the CAP to share views and give the opportunity to reflect on the answers of the other participants.

Issue	**Comment** [Collected from the questionnaire]		**Name**
			Participant 1
			(…)
			Participant *i*
Q1: Why do you think there is misalignment among participants' view on this issue?			
			Participant 1
			(…)
			Participant *i*
Q2: What options exist to address this misalignment?			
Option 1-1:	Pros:	Cons:	Participant 1
Option 1-1:	Pros:	Cons:	Participant 1
Option (…)-1:	Pros:	Cons:	(…)
Option *i*-1:	Pros:	Cons:	Participant *i*
Option *i*-2:	Pros:	Cons:	Participant *i*
Option *i*-3:	Pros:	Cons:	Participant *i*

Figure 8.11 Modified IBIS table ($\widehat{\text{IBIS}}$) for the CAP members

8.3.7 Stage 4: Reaching consensus

The purpose of Stage 4 was to reach consensus on the outstanding issues emerged from Stage 3. Once the areas of misalignment in the CAP views were shared among participants and the risk of "premature consensus" (Janis 1972) was mitigated (i.e. situations where consensus is achieved before all alternative positions have been explored and evaluated), the consensus process was pursued. This aligns to Fisher's (1980) argument that greater consensus results when the group in charge of decision goes through significant disagreement and express and resolves conflicts during the decision-making process before reaching consensus.

Two face-to-face meetings were organised with the CAP members. They were carefully planned in the pre-meeting phase, in the meeting itself with its "divergent" (exploration and development part) and "convergent" (concluding) phases (Guerrero and Pino 2009), and in the post-meeting phase.

8.3.7.1 First CAP meeting

In line with Ackermann (1996), during the pre-meeting phase the issues to be discussed in the meeting itself, the approach to be taken, venue and time scales were defined. At the beginning of the meeting a clear set of objectives was provided, along with an overview of the key issues to discuss.

The divergent part of the meeting included: a presentation of the answers to the written contributions and to the questionnaire, the facilitation of the discussion between the CAP members with an emphasis on the areas of misalignment, and the documentation of the comments from the CAP. The author was in charge of documenting contrasting views, specific concerns and proposals in her role of 'participant-as-observer' (Gill and Johnson 2010).

The concluding part of the meeting aimed at summarising the emerging themes and clarifying areas where further discussion was needed. After the meeting detailed minutes were produced and circulated. These included not only agreed actions, but also the debate that had led to them.

The first meeting enabled areas of misalignment to be clarified and allowed participants to converge towards five pillars that collectively serve to enhance the ease of use of the Eurocode (CAP on ease of use 2014a, 2014b):

1. Users and their needs
2. Principles and related priorities
3. Examples and/or guidance
4. Measurements and associated targets
5. Management, governance and support

The pillars emerged from the following considerations. First, the discussion in the CAP and the findings from the written contributions had shown diverse perspectives between different categories of target users of the Eurocodes, as well as conflicting needs. Having clarity of expectations and target users were identified as key aspects to support the drafting effort of the Project Teams (PTs) involved in the development of the second generation of the Eurocodes.

Second, the existence of diverse expectations and contrasting views of some specific areas shed light into a general need for agreed high-level principles, which could be used by the PTs to base their decisions during the drafting process. When these principles were in conflict, a prioritisation was needed and the value of defining "principles and related priorities" emerged. Importantly, it was clarified that the focus was not on 'how' those principles and priorities had to be applied, but rather 'why'.

Examples and/or guidance were introduced because having real examples of the application of the principles was useful. Similarly, identifying measurements of success and associated targets was considered an important aspect to understand whether the objectives are achieved. Finally, management, governance and support were introduced as general management activities relevant to every project activities.

8.3.7.2 CAP activities between the first and second meeting

After the first meeting specific work was carried out by the author in collaboration with the Chair of the CAP and the Chairman of CEN/TC 250 to provide a more extensive definition of the pillars, as well as to translate them into actions. The results of this work were shared with the CAP members. Time was allowed to the CAP to provide comments.

8.3.7.3 Second CAP meeting

The second meeting followed the same structure and process as the first one. The outcomes were the clarification of the five pillars, which could then be translated into recommendations to CEN/TC 250. The content of the final CAP report to CEN/TC 250 was also discussed.

8.3.7.4 Final CAP activities

A draft recommendation report was circulated among the CAP members to collect comments and observations. As a result, six recommendations were produced for the approach to be taken to enhance the ease of use of the second generation of the Eurocodes (CAP on ease of use 2014a, 2014b). These are reproduced in Table 8.2.

Table 8.2 CAP recommendations reproduced from CAP on ease of use (2014a, 2014b)

Recommendation 1	The overall framework for enhancing the ease of use of the second generation of the Eurocodes should be based upon the five pillars presented in Figure 1*.
Recommendation 2	In developing the second generation of the Eurocodes the primary target audience for the standards should be "Competent civil, structural and geotechnical engineers, typically qualified professionals able to work independently in relevant fields". The commitment to this group and to nine other groups of users should be as presented in Figure 3*.
Recommendation 3	The principles set out in Table 2* should provide the focus for efforts to enhance the ease of use of the next generation Eurocodes. Where in conflict, primary principles should take precedence over secondary ones.
Recommendation 4	As a first step, Sub-Committees (SCs) and Working Groups (WGs) should be instructed by CEN/TC 250 to identify areas in their standards that present opportunities for enhancing ease of use following the principles in Table 2 (i.e. up to 12 examples in total). Where possible, tentative illustrations of how such improvement can be achieved should also be presented. Furthermore, early action should be taken on aligning the structures of the documents and common text under the coordination of WG1.
Recommendation 5	SCs and WGs should monitor and report their progress in applying the recommendations contained in this report and enhancing the ease of use of the Eurocodes.
Recommendation 6	The CEN/TC 250 management group should establish arrangements to assure that the recommendations of this report are implemented appropriately by SCs, WGs and PTs. In support of this, issues of ease of use should be included in the SC/WG report template and agenda for CG meetings to enable good practices and lessons learned to be shared and to promote consistency of implementation of the ease of use recommendations.

* See CAP on ease of use 2014a, 2014b

8.3.8 Stage 5: Synthesis

The purpose of Stage 5 was to translate the six CAP recommendations into a CEN/TC 250 position paper on the strategies to enhance the usability of the second generation of the Eurocodes. Firstly, the CAP recommendations were shared with the CEN/TC 250 members to receive feedback and comments. The responses from the CEN/TC 250 members were analysed by the author. They provided relevant insights and enabled the CAP recommendations to be enriched.

Specific actions were taken to address the concerns expressed by the CEN/TC 250 members and develop the position paper. The emerging actions log was prepared by the author in collaboration with the Chairman of CEN/TC 250 and circulated among the CEN/TC 250 members. This document supported transparency and provided clarity on the modifications made to the CAP recommendations.

In conjunction with the actions log, the Chairman of CEN/TC 250 issued the position paper containing the overall vision, approach and specific aspects of guidance for enhancing the ease of use of the Eurocodes (CEN/TC 250 2015). These were based on the CAP five pillars and related recommendations, as well as the responses from the CEN/TC 250 members. The position paper was approved with positive votes of the representatives of the European Member States unanimously in March 2015. Details of the guidelines are provided in the following sections.

8.3.8.1 Statements of intent to meet users' needs

The first guideline refers to users and recognises the importance of focusing the drafting effort on a primary target audience represented by *Practitioners – Competent designers* (defined as "competent civil, structural and geotechnical engineers, typically qualified professionals able to work independently in relevant fields"), whilst defining clear statements of intent to address key needs of the other audiences. The statements of intent developed are reproduced in Figure 8.12.

CATEGORIES OF EUROCODES' USERS	CEN/TC 250 STATEMENTS OF INTENT
Practitioners – Competent engineers [Primary target audience]	**We will aim to produce Standards that are suitable and clear for all common design cases without demanding disproportionate levels of effort to apply them**
Practioners – Graduates	We will aim to produce Eurocodes that can be used by Graduates where necessary supplemented by suitable guidance documents and textbooks and under the supervision of an experienced practitioner when appropriate
Expert specialists	We will aim not to restrict innovation by providing freedom to experts to apply their specialist knowledge and expertise
Product Manufacturers	Working with other CEN/TCs we will aim to eliminate incompatibilities or ambiguities between the Eurocodes and Product Standards
Software developers	We will aim to provide unambiguous and complete design procedures. Accompanying formulae will be provided for charts and tables where possible
Educators	We will aim to use consistent underlying technical principles irrespective of the intended use of a structure (e.g. bridge, building, etc.) and that facilitate the linkage between physical behaviour and design rules
National regulator	We will endeavour to produce standards that can be referenced or quoted by National Regulations
Private sectors businesses	We will continue to promote technical harmonization across European markets in order to reduce barriers to trade
Clients	We will produce Eurocodes that enable the design of safe, serviceable, robust and durable structures, aiming to promoting cost effectiveness throughout their whole life cycle, including design, construction and maintenance
Other CEN/TCs	We will engage proactively to promote effective collaboration with those other CEN/TCs that have shared interests

Figure 8.12 Guideline No. 1 reproduced from CEN/TC 250 (2015)

8.3.8.2 Principles and related priorities

The second guideline refers to the governing principles to facilitate the drafting of a more user-orientated generation of the Eurocodes. The principles largely resulted from the argumentative process in Stage 3 and are reproduced in Table 8.3. Draft objectives and possible actions to satisfy each principle were developed by the author, discussed with the CAP members and incorporated into the full CAP recommendations report (CAP on ease of use 2014b).

Table 8.3 Principles and related priorities in the evolution of the Eurocodes reproduced from CEN/TC 250 (2015)

General principles (primary)	
1	Improving clarity and understandability of technical provisions of the Eurocodes
2	Improving accessibility to technical provisions and ease of navigation between them
3	Improving consistency within and between the Eurocodes
4	Including state-of the-art material the use of which is based on commonly accepted results of research and has been validated through sufficient practical experience
5	Considering the second generation of the Eurocodes as an "evolution" avoiding fundamental changes to the approach to design and to the structure of the Eurocodes unless adequately justified
Specific principles (secondary)	
6	Providing clear guidance for all common design cases encountered by typical competent practitioners in the relevant field
7	Omitting or providing only general and basic technical provisions for special cases that will be very rarely encountered by typical competent practitioners in the relevant field
8	Not inhibiting the freedom of experts to work from first principles and providing adequate freedom for innovation
9	Limiting the inclusion of alternative application rules
10	Including simplified methods only where they are of general application, address commonly encountered situations, are technically justified and give more conservative results than the rigorous methods they are intended to simplify
11	Improving consistency with product standards and standards for execution
12	Providing technical provisions that are not excessive sensitive to execution tolerances beyond what can be practically achieved on site

8.3.8.3 Examples

The third guideline refers to the need for illustrating the application of the governing principles through relevant examples. This guideline required the teams involved in drafting the second generation of the Eurocodes (i) to identify areas in their standards that could be enhanced by following the principles in Table 8.3 and (ii) to present tentative illustrations of how such improvement can be achieved.

8.3.8.4 Strategic performance measures

The fourth guideline refers to relevant performance measures and aims to provide confidence that CEN/TC 250 ambitions for enhancing ease of use of the Eurocodes are being achieved. This was a challenging task because some principles (e.g. clarity or understandability) are difficult to measure in a rigorous and systematic way. Suggestions for possible performance measures were provided in the full CAP recommendations report CAP on ease of use 2014b) These included trial applications on international projects involving the contribution of different countries, and small groups of experts who have not closely participated in the subject being examined.

8.3.8.5 Management, governance and support

The fifth guideline requires establishing specific arrangements to assure that the first four guidelines were implemented appropriately by the Project Teams (PTs) involved in the drafting phase. In support of this, CEN/TC 250 agreed to include issues of ease of use in the report template of the Project Teams to enable good practices and lessons learned to be shared and to promote consistency of implementation of the recommendations. Subsequently, the role of the Technical Reviewer was introduced (see Section 8.3.9).

8.3.8.6 Link between guidelines

The five guidelines are inter-connected. The statements of intent to meet users' needs were translated into a series of governing principles. The application of these principles was expected to be illustrated through relevant examples. Performance measures were introduced to assure that the intended objectives for enhancing ease of use of the second generation of the Eurocodes were achieved. Finally, central management, governance and support were established to ensure that a focus on ease of use was sustained, interdependencies were recognised and responded to, and that emergent issues were addressed.

8.3.9 Stage 6: Implementation

All tasks in the work programme included a requirement to improve the ease of use of existing Eurocode parts and ensure that new parts were drafted with an emphasis on ease of use:

> "Sub-task 2: Enhance ease of use by improving clarity, simplifying routes through the Eurocode, avoiding or removing rules of little practical use in design and avoiding additional and/or empirical rules for particular structure or structural-element types, all to the extent that it can be technically justified whilst safeguarding the core of essential technical requirements." [*From the tasks specification, Volume 3 of the calls for experts*]

To support this effort, in 2017 CEN/TC 250 agreed to create the Technical Reviewer role to provide feedback to the Project Team on improving ease of use. This aimed to achieve a high degree of technical coordination and promote consistency between Eurocode parts, particularly in terms of cross-cutting technical approaches, notation, terminology, document structures, and drafting styles. Key responsibilities of the Technical Reviewer included [from the tasks specification, Volume 3 of the calls for experts]:

- follow the CEN/TC 250's guidelines for enhancing the ease of use of the Eurocodes;
- scrutinize reports and draft technical deliverables and make recommendations to enhance consistency between different Eurocode parts and improve ease of use;
- develop guidance materials and briefings to support the work of CEN/TC 250 and the Project Teams;
- maintain an overall library of notation and terminology usage and highlight areas where consistency could be enhanced.

Following the calls for tenders for a Technical Reviewer in response to Mandate M/515 (see Section 8.2.2), the author was appointed Technical Reviewer for Phases 1 to 4 of the work programme. The Technical Reviewer was expected to work closely with, and under the direction of the CEN/TC 250 Management Team (see Figure 8.2).

The first activity undertaken by the author as Technical Reviewer was to carry out a preliminary review the April 2017 drafts (interim deliverables) produced by the Phase 1 Project Teams. These consisted of 38 documents with over 2,200 pages. The drafts were expected to comply with the CEN Internal Regulation No. 3 (IR 3:2017) and the specific CEN/TC 250 rules provided in document N 1250.

In order to apply the CEN/TC 250 governing principles (see Table 8.3), the checklist provided in Figure 8.13 was created and adopted. It provides the key questions considered when reviewing the drafts from a usability perspective, as well as a list of activities that should be carried out to ensure that the governing principles were met. As such, the checklist could also be used by the Project Teams to assess the ease of use of the drafts produced.

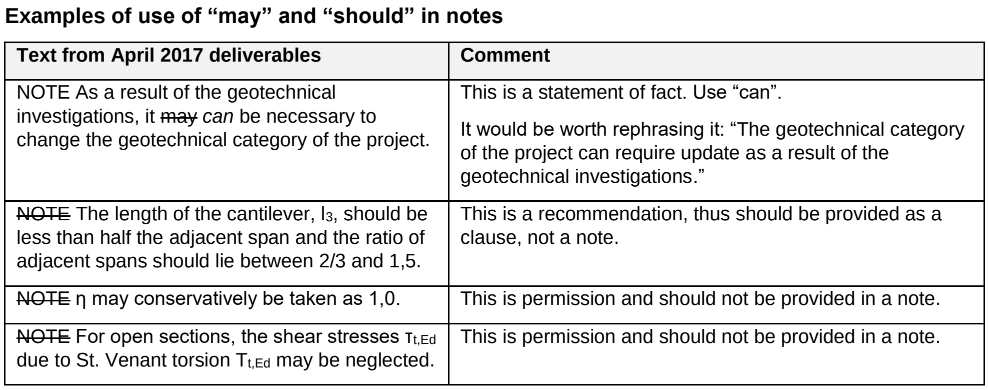
Figure 8.13 Checklist to review deliverables produced by the Project Teams

General principles (primary)		Key questions in terms of ease of use	Relevant activities
1	Improving clarity and understandability of technical provisions of the Eurocodes	• Is the final outcome (i.e. what we want the designer to do) unambiguous, clearly presented and easy to understand? • Is it clear how the identified outcome is expected to be achieved?	1.1 Clarify the status of each clause (including formulae and tables) by using the appropriate verbal forms for requirements (shall), recommendations (should), permissions (may) or statements of facts (can). 1.2 Clearly define scope and limitations in the application of the clauses. 1.3 Use language that can be easily understood by competent engineers (i.e. the target audience). 1.4 Make clauses as independent as possible, i.e. avoid readers to read an entire section to understand a concept.
2	Improving accessibility to technical provisions and ease of navigation between them	• Can relevant information be found easily and quickly? • Is linked information provided in one place?	2.1 Follow the document structure of Eurocodes provided by N1250. 2.2 Say things once and at the right place by grouping together linked topics and introduce relevant subheadings. 2.3 Develop a clear, coherent and logical structure of clauses by avoiding contradictory clauses, and putting most general concepts first and then more specific ones. 2.4 Make use of flowcharts to guide readers where relevant.
3	Improving consistency within and between the Eurocodes	• Is the sequence of sections provided consistently? • Are terms, definitions, symbols and verbal forms used consistently? • Is reference to other clauses and documents (especially to national annexes) made consistently? • Are the recommendations provided by HG-B and HG-F taken on board by relevant Projects Teams?	3.1 Follow the requirements provided by N1250 with a specific focus on sequence of sections, terms, definitions and symbols, verbal forms, cross-references and introduction of national choice. 3.2 Adopt recommendations provided in the HG reports.
4	Including state-of the-art material the use of which is based on commonly accepted results of research and has been validated through sufficient practical experience	• Has state-of the-art material been used?	[Outside Technical Reviewer's scope]

5	Considering the second generation of the Eurocodes as an "evolution" avoiding fundamental changes to the approach to design and to the structure of the Eurocodes unless adequately justified	• Have fundamental changes to the approach to design been made?	[Outside Technical Reviewer's scope] 5.1 Make changes to the approach to design only where adequately justified, for example to review unsafe or obscure rules, provide a more economic design, or increase the efficiency of the design process.
		• Have changes non-compliant with N1250 been made to the structure of the Eurocodes?	5.2 Follow the document structure of Eurocodes provided by N1250.
Specific principles (secondary)		**Key questions in terms of ease of use**	**Relevant activities**
6	Providing clear guidance for all common design cases encountered by typical competent practitioners in the relevant field	• Have common design cases been presented clearly?	6.1 Apply guidance provided for the general principles to common design cases.
7	Omitting or providing only general and basic technical provisions for special cases that will be very rarely encountered by typical competent practitioners in the relevant field	• Have special cases presented in detail?	The principle is self-explanatory of the activity to be carried out.
8	Not inhibiting the freedom of experts to work from first principles and providing adequate freedom for innovation	• Have unduly prescriptive requirements been provided?	8.1 Clearly define the high-level requirements to be achieved. 8.2 Provide methods to satisfy the identified high-level requirement as appropriate, and clearly present them as advice. 8.3 Provide clear and consistent statements of principles underpinning important elements of the Eurocodes.
9	Limiting the inclusion of alternative application rules	• Are alternative application rules clearly presented in terms of scope and limitations? • Where alternative application rules are provided in different parts of the document, is their link clear?	9.1 Review current alternative application rules, assess the reasons for their introduction and consider the necessity of using them. 9.2 Check whether alternative application rules: a. Aim to satisfy the same requirement(s), but lead to negligible differences in the final results (thus simply compete) b. Aim to satisfy the same requirement(s), but provide significant differences in the final results c. Each of them fulfil particular/specific requirement(s) In case *a*, rationalise and eliminate those not relevant. In case *b*, review and rationalise them. In case *c*, highlight scope and limitations of each method.
10	Including simplified methods only where they are of general application, address commonly encountered situations, are technically justified and give more conservative results than the rigorous methods they are intended to simplify		The principle is self-explanatory of the activity to be carried out.
11	Improving consistency with product standards and standards for execution	• Are there inconsistencies between the Eurocodes and relevant product standards? • Are there inconsistencies between the Eurocodes and relevant standards for execution?	CEN/TC 250 *Ad hoc Group on the Interaction with product standards and Eurocodes* + Technical Reviewer to ensure consistency of application in the AHG recommendations

Initial review of the April 2017 deliverables showed some common issues related to the document structure, selection of the appropriate verb form to introduce requirements and advice, use of terms, definitions and symbols, accessibility to technical provisions and navigation, presentation of alternative application rules.

The identification of these issues prompted the development of a technical note (CEN/TC 250, 2017) to suggest areas where improvements could be achieved, present the inconsistencies encountered and develop guidance to support the Project Teams. Key part of the technical note were the examples provided, which could be used by the Project Teams to review their drafts (see Figure 8.14). It is worth noting that developing examples was one of the pillars of the recommendations of the CAP and of the CEN/TC 250's position paper (see Section 8.3.8.3).



Examples of use of "may" and "should" in notes

Text from April 2017 deliverables	Comment
NOTE As a result of the geotechnical investigations, it ~~may~~ *can* be necessary to change the geotechnical category of the project.	This is a statement of fact. Use "can". It would be worth rephrasing it: "The geotechnical category of the project can require update as a result of the geotechnical investigations."
~~NOTE~~ The length of the cantilever, l_3, should be less than half the adjacent span and the ratio of adjacent spans should lie between 2/3 and 1,5.	This is a recommendation, thus should be provided as a clause, not a note.
~~NOTE~~ η may conservatively be taken as 1,0.	This is permission and should not be provided in a note.
~~NOTE~~ For open sections, the shear stresses $\tau_{t,Ed}$ due to St. Venant torsion $T_{t,Ed}$ may be neglected.	This is permission and should not be provided in a note.

Figure 8.14 Example of correct use of verb forms in the 2017 Technical Reviewer note

The Technical Reviewer note was made available to the Project Teams and was used to develop the October 2017 drafts (interim deliverables).

8.3.10 Stage 7: Monitoring

Review of the October 2017 drafts (interim deliverables) revealed that, where the Technical Reviewer note had been embraced by Project Teams, significant improvements were achieved. It is worth noting that the Project Teams had limited time to review the 2017 Technical Reviewer note (less than a month) and apply the guidance provided due to the tight timescale for the delivery of the October 2017 drafts.

Understandability of clauses and ease of navigation / accessibility of provisions were two areas with particular opportunities for improvements. Specific issues emerged from the detailed review of the October 2017 drafts, which affected the consistency within a Eurocode part and between different Eurocode parts, attained to:

(i) general aspects relating to the content of sections and annexes (e.g. the European Foreword, the Basis of Design sections, and Informative Annexes);
(ii) specific aspects on the content of the clauses (e.g. project-specific criteria, contract neutrality, and alternative application rules).

The identified issues were illustrated into a new Technical Reviewer note with relevant examples (CEN/TC 250, 2018), and discussed with WG1 members and the Coordination Group (see Figure 8.2 for a clarification of their role). The 2018 note was used to refine the CEN/TC 250 guidance document N1250 and for the preparation of the April 2018 drafts (final deliverables). These had also to take into account comments from the NSBs produced during the informal enquiry period (see Figure 8.4).

In parallel, the author provided the Project Teams with detailed comments and recommendations to enhance the ease of use of each draft. The CEN/TC 250 Vice Chair also contributed to the review process and provided valuable comments and feedback. Face-to-face meetings and conference calls were held with specific Project Teams to discuss opportunities for improving the ease of use and supporting further harmonisation between different parts.

Review of April 2018 drafts showed a significant improvement in the drafts. The level of engagement and positive attitude demonstrated by the Project Teams and related SC chairs and WG convenors greatly streamlined the process. Very positive feedback was also expressed by the Project Teams, SCs and WGs, who recognised the value of the suggestions made by the Technical Reviewer and the support received.

8.4 Limitations

Six limitations of this work warrant mention. They reflect the view of the author only.

The first refers to the limited number of professionals and experts involved in the brainstorming sessions and interviews (Stage 1), in particular if compared with the large number of stakeholders involved in the Eurocodes' evolution. However, this initial qualitative study was carried out as a personal initiative of the author in her role of researcher to start exploring the problem, not to derive final conclusions for the Eurocode project. Moreover, in qualitative research the principle of saturation (Glaser and Strauss 2009) is well recognised. This suggests the importance of understanding the phenomenon more than finding its statistical validity. Indeed, as the study progresses, new data provide more information but may not shed any further light on the issue under investigation. The brainstorming sessions and the interviews enabled a good preliminary understanding of the problem to be gained. The invitation of written contributions sought to triangulate the findings by involving a higher number of people from different background.

Linked to this, the second limitation is the small number of written contributions received and, thus, there may be a lack of representativeness to describe the needs of the Eurocodes' stakeholders. This aspect attains to a larger issue of inadequate participation of stakeholders in the standardisation process. Are all stakeholders really interested in engaging? If not, why? If a larger number of stakeholders provide their contributions, is it really helpful? These are some of the questions that should be answered. As noted in Chapter 6, Nethercot (2012) reported that experience in the UK showed that only a small proportion of public comments are relevant and can be used to improve the standard. It would have been desirable to have more contributions. However, the responses received were submitted by influential practitioners, researchers, public clients, product manufacturers and software developers, which represent the most relevant audiences of the Eurocodes.

The third limitation is about the methodology adopted and its effectiveness. Arguably other methods could be adopted. Mingers and Rosenhead (2004) acknowledge the difficulty in making a general evaluation of the effectiveness of a multi-methodology (i.e. a mix of methods like the one presented in Section 8.3.2) and suggest the value of exploring its "perceived effectiveness". Set against this context, the author does not claim that the methodology adopted in this project was the only and best possible, but rather that it was practical and effective against the objectives of the CAP set out in Section 8.3.3 and the responsibilities of the Technical Reviewer presented in Section 8.3.9.

It can also be argued that the findings of this project depend upon the methodology adopted or – in other words – that the adoption of different methods could potentially lead to different recommendations and ultimately different guidelines. This forth limitation attains to the more general issue of the quality of results in qualitative research and, specifically, to the dependability and credibility of results (see Chapter 4). In order to demonstrate the dependability of results, in this chapter details were provided, including the methods adopted, time scale for the project, steps followed and their rationale, data collection and analysis, people involved, key challenges faced and relevant lessons learned as recommended by Yin (2009). The accuracy in the process of generation and presentation of research findings has been checked by considering some of the strategies suggested by Creswell (2014) such as: (i) a detailed description of the setting, including different perspectives about a theme (rich description); (ii) the immersion of the author in the research field for a prolonged time to gain an in-depth understanding of the problem (around 6 years); (iii) the immersion of the other CAP members in the research field for a prolonged time (they were practitioners and experts with many years of experience in standards development); (iv) the request of feedback from both the CAP and the CEN/TC 250 members (member checking); (v) self-reflection and critical comments on limitations of the project presented in this section (clarity on researcher's bias).

A fifth limitation can be seen in the limited implementation of the guidelines presented in Section 8.3.8. Literature (Connell 2001) shows situations where the process is successful, consensus is achieved, but the recommendations are not successfully implemented for a number of reasons, for example due to the lack of commitment among participants. In this study the guidelines have been applied by the Projects Teams working in Phase 1 and by the Technical Reviewer for the review of their deliverables. The subsequent phases of the work programme will be finalised in 2022, hence several years would be needed to assess the final results. This is not feasible considering the timescale of this research project. Nevertheless, the CAP recommendations have provided a common basis for discussion of CEN/TC 250 objectives amongst all those engaged in the development of the Eurocodes. Thus, although the project is not yet in a stage where it is possible to assess final outcome metrics, the preliminary results (improved deliverables and positive feedback received by the Phase 1 Project Teams) are encouraging.

The last limitation is on the transferability of the guidelines, which are clearly context-specific. However, as discussed in Chapter 4 what is meant to be transferable are not the specific recommendations, but rather the learning from the methodology adopted and the general themes emerged, which are discussed in the next section.

8.5 Emerging themes related to the content of design standards

The themes emerged from the project are grouped into those related to the content of design standards and those related to the standardisation system, which mirror the classification presented in Chapter 6. The discussion reflects the views of the author only.

8.5.1 Length

The reduction of the length of the Eurocodes was considered a key issue at the beginning of the research programme and much debated in the CAP. As a result of the argumentation process, enhancing the content in terms of clarity and accessibility was considered more relevant than seeking to reduce the length of documents, which instead was seen a possible outcome of the revision process, but not the driver. Indeed, in some cases longer text is beneficial for clarity.

8.5.2 Simplified and rigorous provisions

The introduction of simplified methods was another key issue in the CAP debate. It was recognised that, although simplified methods can reduce design time and cost and provide a valuable sanity check on rigorous methods, they typically provide more conservative results, can stifle innovation and structural development, and could affect negatively construction and maintenance cost.

If two methods of design are given, i.e. one simplified and one more accurate, their locations in the main text (or in an annex) should be defined. It was observed that, if only a simplified method is given and a more accurate method is deleted, a safe and technically justified simplified method should be provided. It was also noted that simplified methods should not be regarded as routine provisions, but as an opportunity for designers.

Whilst recognising the value of simplified methods, the CAP (2014a, 2014b) recommended introducing simplified methods only when satisfying the following conditions: (i) they are of general application; (ii) address commonly encountered situations; (iii) are technically justified; and (iv) give more conservative results than the rigorous methods they are intended to simplify.

Experience gained working as the technical reviewer of the Eurocodes showed the importance of checking how alternative application rules (particularly simplified methods) are presented looking at:

- whether their scope of application and limitations are clearly indicated (see Figure 8.15);
- whether methods that aim to satisfy the same requirement(s) lead to negligible differences in the final results, thus simply compete without any technical justification.

In the former case the author recommended clarifying their conditions of use; in the latter case, the author suggested rationalising or eliminating simplified application rules. Work is ongoing to address these issues.

Text from October 2017 deliverables	Comment
Creep relaxation of forces or stresses due to differential settlements or shrinkage obtained by linear elastic analysis may be reduced by dividing them by (…)	It is not clear when the simplified method can be applied as the scope is not stated.
As a simplification, λ_V may be calculated for the concordant design values of the bending moment and shear: $\lambda_V = M_{Sd} / (V_{Sd} d)$	Scope and limitations of this simplification is not clarified.

Figure 8.15 Example of unclear scope of simplified methods

8.5.3 Navigation and accessibility of technical provisions

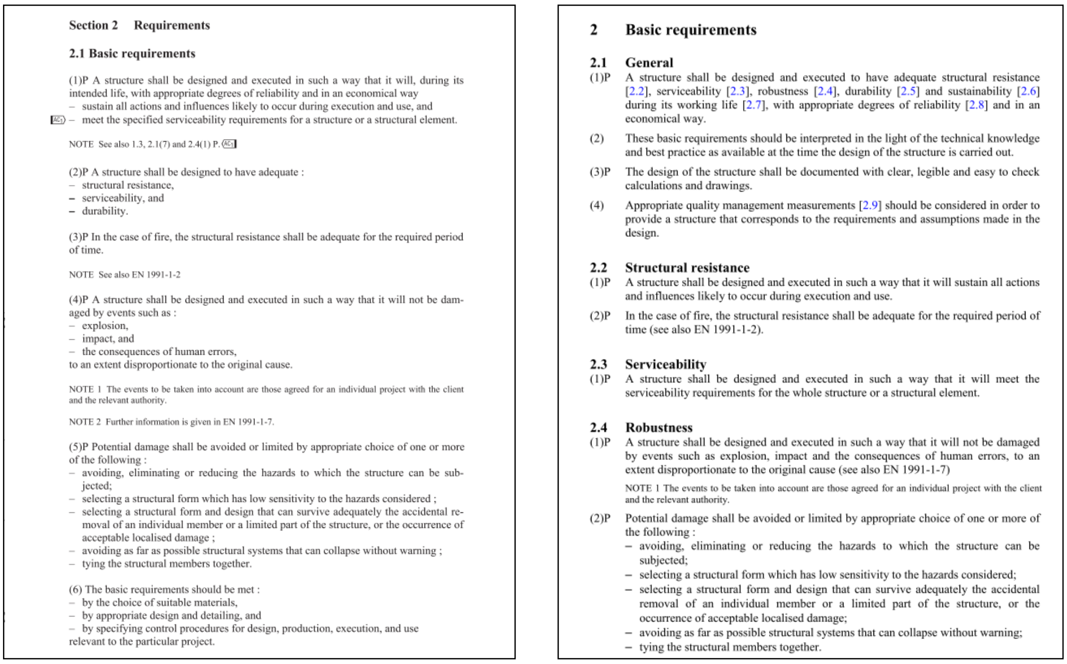
Navigation plays an important role in the discussion on user-orientation of the Eurocodes. The cross-references among the Eurocode parts make them a network of information (see Section 6.4.1.3). Jain (2010) argues that organising data into functional groupings is a key aspect for understanding and learning. Cluster analysis or data clustering is a method for grouping of data or patterns into clusters based on their similarity (Jain et al. 2000). Clustering is a fundamental step in data analysis as it enables to (i) understand the underlining structure of data, (ii) identify the degree of similarity among different data, and (iii) organise and summarise it (Jain 2010).

The author suggested cluster analysis as a structured way to analyse the pattern of a specific standard in the current suite of the Eurocodes in terms of relevant 'key words', define global and local measures of the index of navigation of the document, and potentially optimise the network of information. The author carried out a specific study to enhance accessibility and navigation of EN 1990, which is generally referred to as the "head" Eurocode insofar as it establishes the requirements to be applied and the overall framework of principles used to draft the other Eurocode parts (Denton et al. 2010).

A three-step approach was adopted to enhance navigation in EN 1990:

1. identification of key words for each clause;
2. re-organisation of clauses to link key words;
3. creation of clusters of related provisions with relevant sub-headings.

As a result of this work, a new structure of EN 1990 was developed. An example of comparison between current and new structure is provided in Figure 8.16.



EN 1990 – current version

Section 2 Requirements

2.1 Basic requirements

(1)P A structure shall be designed and executed in such a way that it will, during its intended life, with appropriate degrees of reliability and in an economical way
– sustain all actions and influences likely to occur during execution and use, and
– meet the specified serviceability requirements for a structure or a structural element.

NOTE See also 1.3, 2.1(7) and 2.4(1) P.

(2)P A structure shall be designed to have adequate :
– structural resistance,
– serviceability, and
– durability.

(3)P In the case of fire, the structural resistance shall be adequate for the required period of time.

NOTE See also EN 1991-1-2

(4)P A structure shall be designed and executed in such a way that it will not be damaged by events such as :
– explosion,
– impact, and
– the consequences of human errors,
to an extent disproportionate to the original cause.

NOTE 1 The events to be taken into account are those agreed for an individual project with the client and the relevant authority.

NOTE 2 Further information is given in EN 1991-1-7.

(5)P Potential damage shall be avoided or limited by appropriate choice of one or more of the following :
– avoiding, eliminating or reducing the hazards to which the structure can be subjected;
– selecting a structural form which has low sensitivity to the hazards considered ;
– selecting a structural form and design that can survive adequately the accidental removal of an individual member or a limited part of the structure, or the occurrence of acceptable localised damage ;
– avoiding as far as possible structural systems that can collapse without warning ;
– tying the structural members together.

(6) The basic requirements should be met :
– by the choice of suitable materials,
– by appropriate design and detailing, and
– by specifying control procedures for design, production, execution, and use
relevant to the particular project.

EN 1990 – modified version

2 Basic requirements

2.1 General

(1)P A structure shall be designed and executed to have adequate structural resistance [2.2], serviceability [2.3], robustness [2.4], durability [2.5] and sustainability [2.6] during its working life [2.7], with appropriate degrees of reliability [2.8] and in an economical way.

(2) These basic requirements should be interpreted in the light of the technical knowledge and best practice as available at the time the design of the structure is carried out.

(3)P The design of the structure shall be documented with clear, legible and easy to check calculations and drawings.

(4) Appropriate quality management measurements [2.9] should be considered in order to provide a structure that corresponds to the requirements and assumptions made in the design.

2.2 Structural resistance

(1)P A structure shall be designed and executed in such a way that it will sustain all actions and influences likely to occur during execution and use.

(2)P In the case of fire, the structural resistance shall be adequate for the required period of time (see also EN 1991-1-2).

2.3 Serviceability

(1)P A structure shall be designed and executed in such a way that it will meet the serviceability requirements for the whole structure or a structural element.

2.4 Robustness

(1)P A structure shall be designed and executed in such a way that it will not be damaged by events such as explosion, impact and the consequences of human errors, to an extent disproportionate to the original cause (see also EN 1991-1-7)

NOTE 1 The events to be taken into account are those agreed for an individual project with the client and the relevant authority.

(2)P Potential damage shall be avoided or limited by appropriate choice of one or more of the following :
– avoiding, eliminating or reducing the hazards to which the structure can be subjected;
– selecting a structural form which has low sensitivity to the hazards considered;
– selecting a structural form and design that can survive adequately the accidental removal of an individual member or a limited part of the structure, or the occurrence of acceptable localised damage;
– avoiding as far as possible structural systems that can collapse without warning;
– tying the structural members together.

Figure 8.16 Comparison of current and modified structure of EN 1990

Hyperlinks were temporarily introduced to ensure that the fundamental requirements of the chapter indicated in the initial "General" section (see modified version in Figure 8.16) were linked with the following clauses and had not been missed.

To test the effectiveness of the new structure, a brainstorming session was carried out with practitioners in the author's host organisation. They were asked to compare the current version of EN 1990 with the modified one in terms of accessibility of technical provisions and how intuitive it was. The overall feedback was very positive.

The approach presented in this section helped eliminate duplications and enhance accessibility of content. As such, this work represents a first step to optimise the network of information in the context of design standards. More work should be done to analyse the pattern of a standard in a structured way, define global and local measures of the index of navigation of the document, optimise the network of information, and integrate cluster analysis with the work currently done to support semantic search in the context of new content editing and publishing tools such as XML (see Section 2.6).

Interestingly, review of the latest version of prEN 1990 developed in Phase 1 of the work programme shows that the approach proposed in this section has been followed, with the consequent improved accessibility of the content.

8.5.4 Stable provisions

As noted in Section 8.3.5, respondents to the written contributions recognised the importance of limiting the change in the structure of the Eurocodes to avoid confusion. The work on the second generation of the Eurocodes was thus expected to be an "evolution" rather than a "revolution". The need for stability was a significant constraint in the identification of the strategies to enhance the usability of the Eurocodes.

8.6 Emerging themes related to the standardisation system

8.6.1 Primary target audience and competence of users

Defining the boundaries of what should be provided in a design standard was a challenging task. This project showed that identifying a primary target audience and related skills (Pillar 1) is a fundamental step to address this issue because it avoids the development of multi-purpose documents, which try to satisfy the needs of multiple users characterised by different skills and competences and which eventually become unduly long and difficult to use.

Knowing the level of competence expected by the designers helped understand the level of detail to be provided in the Eurocodes. Interestingly, different professional expectations existed on the significance of competence between the CAP members, which emerged in the diverse perception of the statements of intent to meet users' needs (Pillar 1) and on the governing principles (Pillar 2). This is not surprising as the CAP members were from different European countries, where different educational traditions and working environments exist, as well as different processes to demonstrate that specific competence levels have been achieved.

8.6.2 Competence of standards writers

Experience working as Technical Reviewer revealed the importance of providing *ad hoc* support and training to the standards writers. Being an expert in a technical field does not necessarily imply that the person has the ability and skills needed to write good standards, particularly if new to this field. Equally, experts experienced in standards drafting may not have had specific training and their approach, although based on a long-lasting experience, may not be consistent with the latest requirements or expectations. In this case, changing established mindsets can be challenging.

Education about standardisation is necessary. That was demonstrated by the requests received by the author to support some Project Teams, the fruitful discussions held on the fundamental principles of standards drafting, and the positive feedback received. Of great value were also the meetings with the Project Teams Leaders a few months after the start of their activities to explain expectations and provide initial training.

8.6.3 Exploration of stakeholders' expectations and users' needs

Providing confidence that the variety of different stakeholders' expectations and specifically users' needs had been effectively assessed and considered was a critical outcome of the research programme. This objective was successfully achieved through:

(i) the rigorous analysis of the qualitative data collected in Stage 1;

(ii) the careful assessment of stakeholders' needs in Stage 2;

(iii) the involvement of CEN/TC 250 members in Stage 5.

The stakeholder-need interrelation diagram (SNID) was a powerful tool as it enabled key needs for each category of stakeholders to be extracted and ultimately clear statements of intent for each category to be defined. This transparent activity also assisted in realising an additional gain: to assure all participants (i.e. the CAP members, the CEN/TC 250 members and the Eurocodes' users) that their contributions were a valid resource to achieve a common goal, i.e. to make a more user-orientated second generation of the Eurocodes.

8.6.4 Overcoming competing expectations and needs

Overcoming different and sometimes competing expectations and needs of different categories of stakeholders was not straightforward. Indeed, although highly desirable, addressing the needs of all categories of stakeholders is simply not feasible. The benchmarking exercise undertaken by the CAP was useful to tackle this issue and indicated that focus groups or similar techniques should be applied in such cases. The CAP recommended defining a high-level statement of intent relevant to the primary target audience as well as clear statements of intent to address the key expectations of the other categories of stakeholders (Pillar 1, see Section 8.3.8.1).

The statements of intent were not meant to be a limitation to the application of the Eurocodes by stakeholders; rather, they were developed to respond to their 'key' expectations and to enable Project Teams (PTs) involved in the development of the second generation of the Eurocodes to focus the drafting effort. The term 'key' has been used to emphasise that, whilst recognising the variety of stakeholders' expectations, only the key ones have been considered.

8.6.5 Achieving consensus among decision makers

An important lesson learned from this project was the value of structuring argumentative processes carefully in order to reduce the risk of unexpressed and latent disagreement among decision makers. As noted earlier, the concept of usability in the context of the Eurocodes had to be defined and from discussion it emerged that it was very much dependent upon the perspective of different people. Without a structured approach to explore areas of disagreement, the risk of latent conflict would have been high and difficult to manage in subsequent phases of the programme, thus undermining the entire process.

The IBIS method played an important role in that respect (see Stages 3 and 4). It enabled three specific benefits to be gained:

(1) clarification of the rationale behind disagreement – indeed, not always disagreement stems from a real conflict among participants (see Section 8.3.5 for details);

(2) stronger group consensus concerning the decision outcome, i.e. the recommendations – after significant discussion the CAP members supported the emerged recommendations unanimously;

(3) greater member satisfaction – this was particularly evident at the end of the first meeting.

8.6.6 Building international consensus

One of the overarching objectives for the evolution of the Structural Eurocodes established by CEN/TC 250 is to achieve exemplary levels of international consensus, evidenced through positive votes from CEN members. This objective has become a central theme with the finalisation of the Phase 1 drafts (currently ongoing), when having in place a mechanism to navigate differences of opinions and help standards writers build consensus is essential to deliver the work programme. A recommended path to resolve issues of concern was developed by the CEN/TC 250 Chairman in collaboration with the author and is reproduced in Figure 8.17.

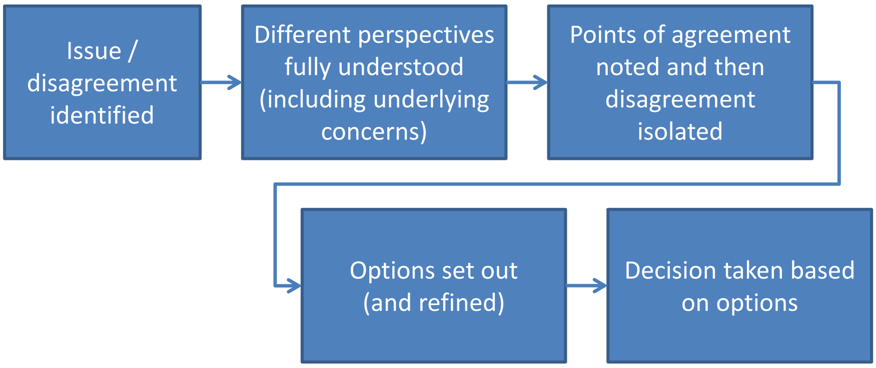


Figure 8.17 Recommended path to resolve issues of concern (reproduced from CEN/TC 250, Chairman's briefing note 2017/4)

The success of these steps relies on the right behaviours including:

1. Listening to and respecting one another's perspectives and trying to expose the root causes of differences among parties.
2. Expressing points of disagreement fully and in a timely manner.
3. Presenting national positions, not personal preferences.
4. Seeking proposals that would lead to mutually acceptable outcomes regardless of starting assumptions.

8.6.7 Liaison between technical committees

The Eurocodes are part of the wider European standardisation family in the construction industry, which also is comprised of product standards and standards for execution (see

Figure 2.7 in Chapter 2). Proactive liaison and effective collaboration between standardisation committees in CEN having shared interests was an important step to eliminate incompatibilities and ambiguities as acknowledged in one of the statements of intent contained in CEN/TC 250 Guideline 1 (see Section 8.3.8.1).

8.7 Innovation, execution tolerances and tensions

Innovation emerged as an important theme complementing hard and soft factors, which is summarised in the governing Principle No. 8 (see Table 8.3): "*Not inhibiting the freedom of experts to work from first principles and providing adequate freedom for innovation*." Guidance on how the Eurocodes can provide freedom for innovation was not provided. This attains to a wider issue of the lack of exploration into the role of design standards in the context of innovation.

Another topic emerged from discussion in the CAP was about the importance of considering more explicitly sensitivity issues in execution tolerances. Although buildability is a topic more pertinent to execution standards than design standards, consideration should be given to execution issues when writing design standards.

The results from the written contributions and the discussion in the CAP also showed the existence of a number of potential tensions such as those between improving clarity and accessibility and avoiding fundamental changes to the Eurocodes, between the need to support common design cases and leave enough freedom to develop innovative solutions, or as mentioned earlier between up to date provisions and stability. To overcome them, governing principles were identified (see Section 8.4.2), and were classified into 'General Primary Principles' and 'Specific Secondary Principles' to emphasise the precedence of the general principles on the specific principles in case of conflict between them.

8.8 Lessons learned

General lessons drawn from this project are listed in Table 8.4. They reflect the views of the author only and do not necessarily represent the perspective of WSP, the CAP and CEN/TC 250.

Table 8.4 Summary of lessons emerged from the Eurocodes project

Topic	General lessons learned
Length	Reducing length should not be the driver, but the outcome of the standardisation process. In some cases, longer text is beneficial for clarity.
Simplified and rigorous provisions	While simplified methods can reduce design time and cost, they typically provide more conservative results, can stifle innovation and structural development, and could affect negatively construction and maintenance cost. Simplified methods should not be regarded as routine provisions, but as an opportunity for designers. They should be introduced only when satisfying specific pre-established conditions.
Navigation and accessibility of technical provisions	Organising information into functional groupings is a key aspect for understanding and learning. Cluster analysis can potentially be used to enhancing navigation and accessibility of technical provisions.
Stable provisions	Limiting the change helps avoid confusion. However, there is a real tension between having up-to-date provisions and providing stability to users.
Primary target audience and competence of users	Defining a primary target audience and related skills is a fundamental aspect to focus drafting effort. Professional expectations on the significance of competence are affected by a variety of factors, including educational traditions and specific working environments. Knowing the level of competence expected by the users helps understand the level of detail to be provided in the document.
Competence of standards writers	Education about standardisation is necessary. Technical expertise in a field does not imply necessarily ability and skills to write good standards. Equally, the approach of experts experienced in standards drafting may may not be consistent with the latest requirements or expectations.
Exploration of stakeholders' expectations and users' needs	It is important to have in place an appropriate stakeholders' management strategy, which enables to identify key stakeholders, involve them in the process, and collect and assess their needs.
Overcoming competing expectations and needs	Defining which (key) needs are going to be addressed for different categories of stakeholders is an important part of the stakeholders' management strategy and is essential to focus drafting effort. Identifying statements of intent can be useful. The choice of statements is context-specific.
Achieving consensus among decision makers	Achieving consensus among stakeholders can be challenging and requires specific attention. Structuring argumentative processes among decision makers carefully (for example by using specific 'conflict-enhancing' approaches) is beneficial to clarify areas of disagreement, gain stronger consensus and greater acceptance of the group decision and, ultimately,

Topic	General lessons learned
	greater member satisfaction.
Building international consensus	To build consensus, it is necessary to identify points of agreement first, and then understand where differences among parties lie and why (root causes of disagreement), expressing and examining alternative options, evidencing pros and cons of alternatives, and being open minded in seeking a consensus path. This can be challenging.
Liaison between technical committees	Proactive liaison between different standards committees should be established to avoid gaps or overlapping requirements between different standards, as well as to eliminate incompatibilities and ambiguities.
Usability measures	To provide confidence that a standard is easy to use, usability measures need to be introduced. While these typically require users' engagement to assess the usability of the document produced, it is appreciated that this may require significant effort with resources not always available.
Innovation	While design standards should set out clear first principles to not inhibit innovation, a specific exploration is needed to fully understand the role of design standards in the context of innovation.
Buildability	Design standards should provide technical requirements that are not excessively sensitive to execution tolerances.
Tensions	Tensions in the drafting process can emerge. Developing high level governing principles (and possibly defining their priorities) is helpful to overcome them.

8.9 Conclusions

The Eurocodes are an exceptional example of a complex socio-technical system of design standards and represent a unique case study to work on. Understanding what usability means in their context was not an easy task. The scale and complexity of this undertaking required the application of a structured approach to support decision making and provide a robust and auditable rationale for the decisions taken. More than 1,000 experts are involved in the drafting work of the second generation of the Eurocodes; hence, transparency in the decisions taken is required.

A rigorous methodology was employed, which enabled to: (i) appreciate the needs and priorities of different categories of stakeholders and assess potential tensions; (ii) explore and externalise areas of disagreement between decision makers (i.e. the CAP members); (iii) develop a shared understanding and obtain the most reliable consensus between decision makers; and (iv) prepare recommendations to enhance the ease of use of the Eurocodes.

The recommendations produced by the CAP and used to develop the CEN/TC 250's position paper have been implemented across the four phases of the work programme to develop the second generation of Eurocodes. The author fulfilled the role of Technical

Reviewer and gained valuable insights into practical challenges associated with the enhancement of the usability of an existing suite of design standards. These included both hard and soft aspects, which reflect those identified in Chapter 6, while introducing new ones in terms of competence of standards writers and building international consensus. Lessons have been drawn from the Eurocodes project to enhance both the content of the standards and the standardisation system, and will be used in Chapter 11 for the framework development.

Chapter 9

Usability of the UK Design Manual for Roads and Bridges

This chapter is based on the work carried out by the author to support the Highways England's task on enhancing usability, structure and content of the Design Manual of Roads and Bridges (DMRB).

Part of the work presented in this chapter has been published in the white paper Denton and Angelino (2017), in the industry report issued by WSP Parsons Brinckerhoff (2016a) and in the publications issued by Highways England (2017a, 2017b; 2018a, 2018b, 2018c). The content of these documents presented in this chapter represents a personal contribution of the author. Work done in collaboration with others is indicated as such.

9.1 Introduction

In Chapter 8 the work to enhance the usability of an international suite of design standards (i.e. the Structural Eurocodes) was presented. This chapter focuses on the work carried out to improve the ease of use of a national suite of *de facto* standards with international adoption, i.e. the Design Manual of Roads and Bridges (DMRB).

The scope of the DMRB is broader than that of the Eurocodes, which are limited to design only. The DMRB is a proprietary set of client requirements (see Chapter 2) for the appraisal, design, management and disposal of the UK motorway and all-purpose trunk roads under the responsibility of the UK Overseeing Organisations, i.e. the highways or roads authorities represented by Highways England, Transport Scotland, Welsh Government and the Department for Infrastructure Northern Ireland. Although not written for local authorities, the DMRB is widely used by them throughout the UK. It is also adopted elsewhere in the world, including Republic of Ireland, China, South Africa and the Middle East.

In England, motorway and all-purpose trunk roads were traditionally managed by the Highways Agency. On 1 April 2015 Highways Agency became Highways England, a government company. While Highways England is in charge of motorway and all-purpose trunk roads operating in England only, they are also responsible for the development and maintenance of the DMRB. Highways England's obligations are described in a Protocol Agreement issued by the UK Department for Transport (2015). One of the obligations on Highways England was about the DMRB, specifically:

> "To undertake an initial review of the usability, structure and content of DMRB by April 2016, and depending on the conclusions of the review and advice from the Design Panel, develop a work programme to refresh the DMRB during the first Road Period [i.e. April 2020] so that it reflects the needs of its users". *Department for Transport (2015)*

The author's host organisation was appointed by Highways England to carry out a consultation with key stakeholders of the DMRB, help define the recommendations to enhance its usability, structure and content, and translate those recommendations into practical actions for the development of a more user-orientated future DMRB.

The purpose of this chapter is to report on this project. In Section 9.2 background information on the DMRB is presented. In Section 9.3 the research programme employed is examined. Critical reflections on the limitations of this work are given in Section 9.4. Emerging themes relevant to the discussion on the quality of design standards are examined in Sections 9.5, 9.6 and 9.7.

9.2 Background on the DMRB

The DMRB is a set of documents originally created from a number of separate documents previously published by the UK Overseeing Organisations. It includes standards, advice notes and other published documents relating to the UK motorway and all-purpose trunk roads. The current range of documents covers highways works, geotechnics, road schemes, pavements, traffic signs and lighting, and traffic control and communications, as well as environment aspects.

9.2.1 Governance of document development

The development process of Highways England's requirements and advice documents (RADs), including the DMRB, is overseeing by the Technical Assurance and Governance Group (TAGG). It is based on nine stages (see Figure 9.1), which have been mapped against the stages of the development process of *de facto* standards provided in Figure 2.3.

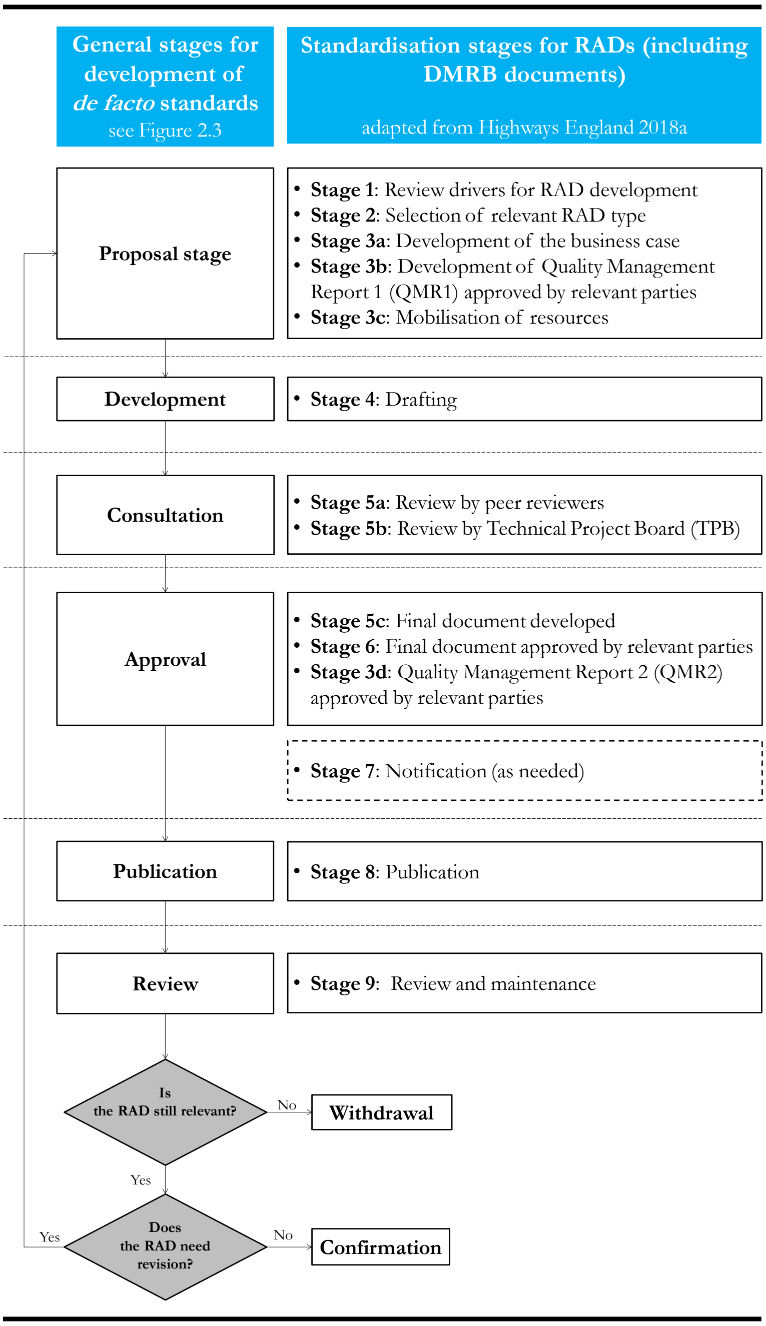


Figure 9.1 Standardisation stages for RADs developed by Highways England

An overview of the stages relevant to RADs is provided below (see Figure 9.2 for the key stakeholders incolved).

Stage 1 is characterised by the review of the drivers for document development and review to ensure the suitability and coverage of the RAD. Key drivers include: changes in strategic approach, needs and objectives of the Overseeing Organisations; changes to or introduction of new formal standards and regulations; changes in operational practice; number and scope of departures (see Chapter 2 for a definition); outcomes from research and development.

Stage 2 is characterised by the identification of the appropriate RAD type based on its scope. It is important to recognise that the DMRB is only one of the sets of documents developed by Highways England, which include *inter alia* the Manual of Contract Documents for Highway Works, the Interim Advice Notes, the Chief Highway Engineer Memoranda.

Stage 3 covers the business management process, which shows that the RAD fulfils business objectives and is supported by a comprehensive business case. The process requires completion of a Quality Management Report at two key stages: before starting the drafting work (QMR1) and once the document has been finalised and approved (QMR2). These reports are developed by the Document Owners (see Figure 9.2), who manage and maintain RADs in their respective practice areas, and are approved by relevant parties.

Stage 4 is characterized by feedback loops between drafting and reviewing to ensure that the document has reached an appropriate stage and that has been subject to suitable governance. Drafting is typically undertaken by document authors, who are identified either internally in Highways England or externally from the supply chain (see Figure 9.2).

Stage 5 is characterized by the initial formal reviews of the final draft by peer reviewers (members of the team of the Document Owner) and potentially technical specialists from other teams. After the initial formal reviews, the draft is submitted for review to a Technical Project Board (TPB). TPB members represent various interested parties from Highways England (e.g. Major Project Directorate, Operations Directorate), the other Overseeing Organisations, other governmental bodies and parts of the highways industry (see Figure 9.2).

Stage 6 is characterized by the approval of the RAD by relevant parties, who confirm that the TPB procedures are complied with (TPB Chair), the document is still required by the business (relevant Divisional Director), appropriate governance has been carried out (TAGG), and the document can be published (the Chief Highways Engineers of the Overseeing Organisations).

Stage 7 is optional and depends on whether the document has to be notified to the European Commission according to the Directive 2015/1535/EU, which aims to prevent new technical barriers to trade being created with the introduction of technical standards and regulations in the European Member States.

Stage 8 covers the publication process, which is under the responsibility of TAGG. Technical changes are not allowed once a document passes the approval of the Chief Highways Engineers or once the document has been notified to the European Commission as relevant.

Stage 9 covers the periodic review process to identify if the document has to be revised, can be retained without modification, or has to be withdrawn.

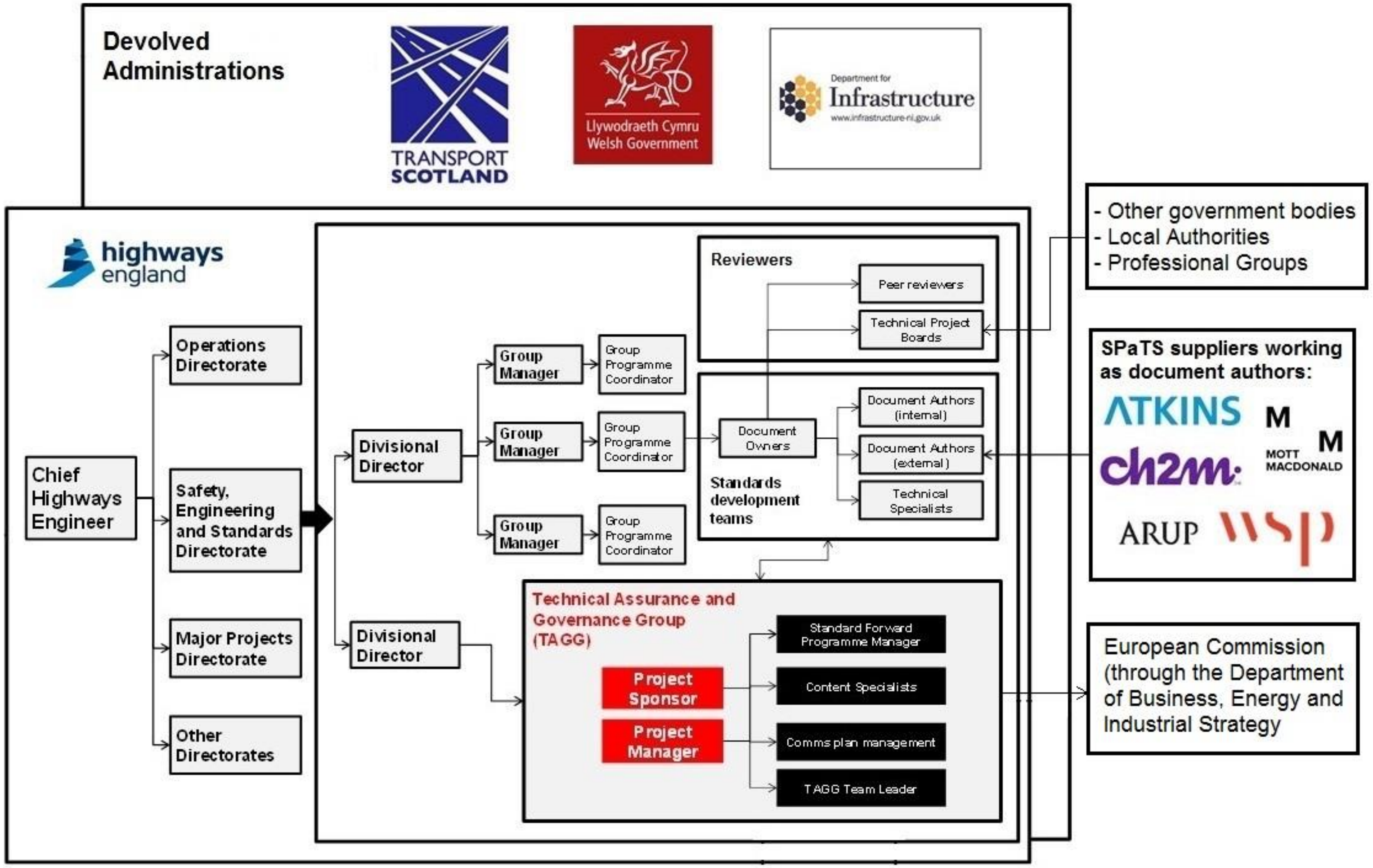


Figure 9.2 Key stakeholders involved in the governance process of DMRB documents

9.2.2 Need for change

Over the years, the DMRB has evolved and expanded and is now in need of an overall update not just to meet the Protocol Agreement (Department for Transport 2015), but also to overcome a few issues in terms of size and quality of the document set. Specifically, from 1980 to 2015 the number of DMRB documents has increased from 60 to more than 300, with the average age increased from 4 to 15 years (see Figure 9.3). Currently, the DMRB contains over 12,000 pages with documents varying considerably in length. For example, 66 documents have fewer than 15 pages and 34 documents have fewer than 10 pages. The page count includes the title, content and amendments pages, meaning that, for documents with less than 15 pages, there are only a handful of pages of technical content. A high proportion of advisory notes (approximately 55% of the DMRB content) with an average age of almost 16 years also raises questions on their abilities to keep pace with the latest developments in best practice as well as their relevance.

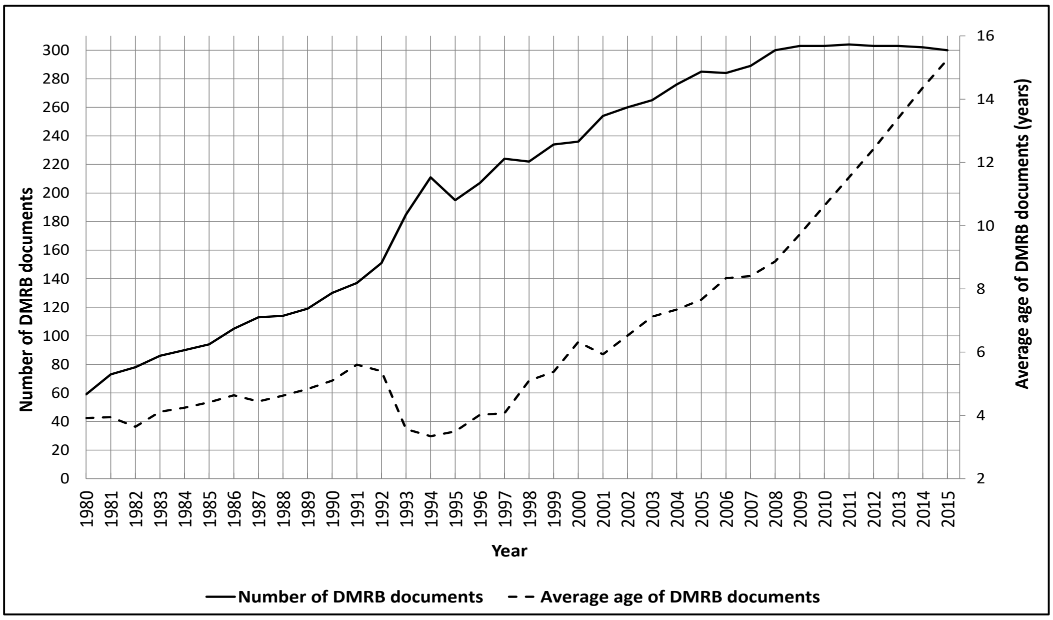
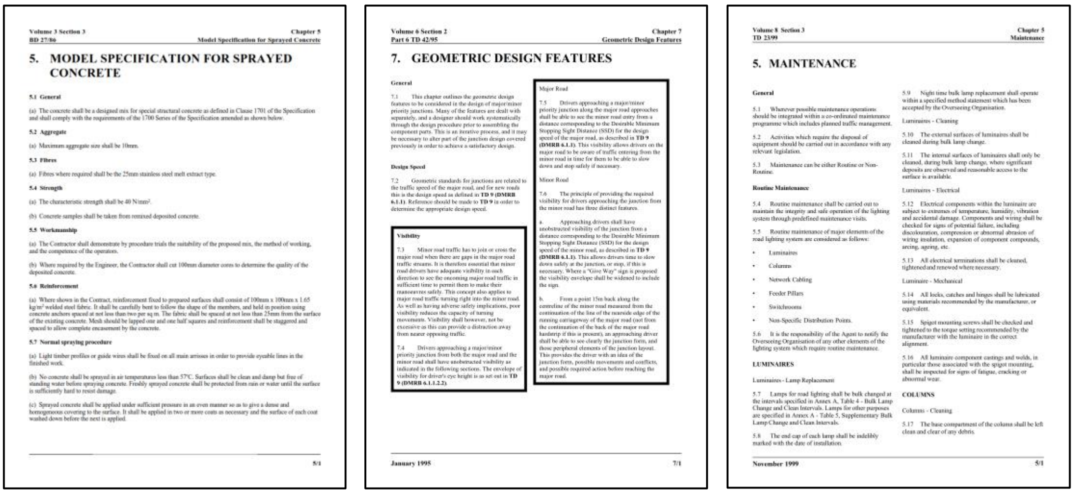


Figure 9.3 Number and average age of DMRB documents (developed by the author and reproduced from WSP Parsons Brinckerhoff 2016a)

Besides, departure applications (see Chapter 2) received by Highways England reveal the need to clarify the distinction between advice and requirements. Over the years different drafting rules have been applied for document development (for example, in some documents black boxes were used to highlight requirements). Yet, these rules have not always been used rigorously, leading to inconsistencies in documents produced and confusion to users. Figure 9.4 compares four DMRB documents developed over the last thirty years: BD, TD and HD represent the document codes, which reflect the document content, i.e. Bridge design, Traffic design, and Highways design; the number after "/" provides the year of publication.



Volume 3 Section 3 — Chapter 5
BD 27/86 — Model Specification for Sprayed Concrete

5. MODEL SPECIFICATION FOR SPRAYED CONCRETE

5.1 General

(a) The concrete shall be a designed mix for special structural concrete as defined in Clause 1701 of the Specification and shall comply with the requirements of the 1700 Series of the Specification amended as shown below.

5.2 Aggregate

(a) Maximum aggregate size shall be 10mm.

5.3 Fibres

(a) Fibres where required shall be the 25mm stainless steel melt extract type.

5.4 Strength

(a) The characteristic strength shall be 40 N/mm².

(b) Concrete samples shall be taken from remixed deposited concrete.

5.5 Workmanship

(a) The Contractor shall demonstrate by procedure trials the suitability of the proposed mix, the method of working, and the competence of the operators.

(b) Where required by the Engineer, the Contractor shall cut 100mm diameter cores to determine the quality of the deposited concrete.

5.6 Reinforcement

(a) Where shown in the Contract, reinforcement fixed to prepared surfaces shall consist of 100mm x 100mm x 1.65 kg/m² welded steel fabric. It shall be carefully bent to follow the shape of the members, and held in position using concrete anchors spaced at not less than two per sq m. The fabric shall be spaced at not less than 25mm from the surface of the existing concrete. Mesh should be lapped one and one half squares and reinforcement shall be staggered and spaced to allow complete encasement by the concrete.

5.7 Normal spraying procedure

(a) Light timber profiles or guide wires shall be fixed on all main arrises in order to provide eyeable lines in the finished work.

(b) No concrete shall be sprayed in air temperatures less than 5°C. Surfaces shall be clean and damp but free of standing water before spraying concrete. Freshly sprayed concrete shall be protected from rain or water until the surface is sufficiently hard to resist damage.

(c) Sprayed concrete shall be applied under sufficient pressure in an even manner so as to give a dense and homogeneous covering to the surface. It shall be applied in two or more coats as necessary and the surface of each coat washed down before the next is applied.

5/1

Volume 6 Section 2 — Chapter 7
Part 6 TD 42/95 — Geometric Design Features

7. GEOMETRIC DESIGN FEATURES

General

7.1 This chapter outlines the geometric design features to be considered in the design of major/minor priority junctions. Many of the features are dealt with separately, and a designer should work systematically through the design procedure prior to assembling the component parts. This is an iterative process, and it may be necessary to alter part of the junction design covered previously in order to achieve a satisfactory design.

Design Speed

7.2 Geometric standards for junctions are related to the traffic speed of the major road, and for new roads this is the design speed as defined in **TD 9 (DMRB 6.1.1)**. Reference should be made to **TD 9** in order to determine the appropriate design speed.

Visibility

7.3 Minor road traffic has to join or cross the major road when there are gaps in the major road traffic streams. It is therefore essential that minor road drivers have adequate visibility in each direction to see the oncoming major road traffic in sufficient time to permit them to make their manoeuvres safely. This concept also applies to major road traffic turning right into the minor road. As well as having adverse safety implications, poor visibility reduces the capacity of turning movements. Visibility shall however, not be excessive as this can provide a distraction away from nearer opposing traffic.

7.4 Drivers approaching a major/minor priority junction from both the major road and the minor road shall have unobstructed visibility as indicated in the following sections. The envelope of visibility for driver's eye height is as set out in **TD 9 (DMRB 6.1.1.2.2)**.

Major Road

7.5 Drivers approaching a major/minor priority junction along the major road approaches shall be able to see the minor road entry from a distance corresponding to the Desirable Minimum Stopping Sight Distance (SSD) for the design speed of the major road, as described in **TD 9 (DMRB 6.1.1)**. This visibility allows drivers on the major road to be aware of traffic entering from the minor road in time for them to be able to slow down and stop safely if necessary.

Minor Road

7.6 The principle of providing the required visibility for drivers approaching the junction from the minor road has three distinct features.

a. Approaching drivers shall have unobstructed visibility of the junction from a distance corresponding to the Desirable Minimum Stopping Sight Distance (SSD) for the design speed of the minor road, as described in **TD 9 (DMRB 6.1.1)**. This allows drivers time to slow down safely at the junction, or stop, if this is necessary. Where a "Give Way" sign is proposed the visibility envelope shall be widened to include the sign.

b. From a point 15m back along the centreline of the minor road measured from the continuation of the line of the nearside edge of the running carriageway of the major road (not from the continuation of the back of the major road hardstrip if this is present), an approaching driver shall be able to see clearly the junction form, and those peripheral elements of the junction layout. This provides the driver with an idea of the junction form, possible movements and conflicts, and possible required action before reaching the major road.

January 1995 — 7/1

Volume 8 Section 3 — Chapter 5
TD 23/99 — Maintenance

5. MAINTENANCE

General

5.1 Wherever possible maintenance operations should be integrated within a co-ordinated maintenance programme which includes planned traffic management.

5.2 Activities which require the disposal of equipment should be carried out in accordance with any relevant legislation.

5.3 Maintenance can be either Routine or Non-Routine.

Routine Maintenance

5.4 Routine maintenance shall be carried out to maintain the integrity and safe operation of the lighting system through predefined maintenance visits.

5.5 Routine maintenance of major elements of the road lighting system are considered as follows:

- Luminaires
- Columns
- Network Cabling
- Feeder Pillars
- Switchrooms
- Non-Specific Distribution Points.

5.6 It is the responsibility of the Agent to notify the Overseeing Organisation of any other elements of the lighting system which require routine maintenance.

LUMINAIRES

Luminaires - Lamp Replacement

5.7 Lamps for road lighting shall be bulk changed at the intervals specified in Annex A, Table 4 - Bulk Lamp Change and Clean Intervals. Lamps for other purposes are specified in Annex A - Table 5, Supplementary Bulk Lamp Change and Clean Intervals.

5.8 The end cap of each lamp shall be indelibly marked with the date of installation.

5.9 Night time bulk lamp replacement shall operate within a specified method statement which has been accepted by the Overseeing Organisation.

Luminaires - Cleaning

5.10 The external surfaces of luminaires shall be cleaned during bulk lamp change.

5.11 The internal surfaces of luminaires shall only be cleaned, during bulk lamp change, where significant deposits are observed and reasonable access to the surface is available.

Luminaires - Electrical

5.12 Electrical components within the luminaire are subject to extremes of temperature, humidity, vibration and accidental damage. Components and wiring shall be checked for signs of potential failure, including discolouration, compression or abnormal abrasion of wiring insulation, expansion of component compounds, arcing, ageing, etc.

5.13 All electrical terminations shall be cleaned, tightened and renewed where necessary.

Luminaire - Mechanical

5.14 All locks, catches and hinges shall be lubricated using materials recommended by the manufacturer, or equivalent.

5.15 Spigot mounting screws shall be checked and tightened to the torque setting recommended by the manufacturer with the luminaire in the correct alignment.

5.16 All luminaire component castings and welds, in particular those associated with the spigot mounting, shall be inspected for signs of fatigue, cracking or abnormal wear.

COLUMNS

Columns - Cleaning

5.17 The base compartment of the column shall be left clean and clear of any debris.

November 1999 — 5/1

Figure 9.4 Examples of DMRB documents developed to different drafting rules

Finally, Highways England was also expected to "reduce the number of prescriptive standards and increase the number of performance standards, in line with industry best practice" (Department for Transport 2015). Future developments of the DMRB thus aimed to purposefully embrace industry best practice and recommendations, such as those contained in the report of the Industry Standards Group (2012).

9.3 Research programme

9.3.1 Overview

As for the Eurocode project, Action Case Research (ACR) has been used by the author as the primary research framework (see Section 4.3.5 for more details on ACR). The author was a member of the WSP team, which worked closely with Highways England to explore the strategies to enhance usability, structure and content of the DMRB.

The objectives of the research programme were to:

(i) appreciate needs and priorities of different categories of stakeholders about the future DMRB and assess potential tensions;
(ii) explore and externalise areas of disagreement between decision makers (i.e. Highways England and, where relevant, the Devolved Administrations) and the key users of the DMRB;
(iii) obtain consensus between decision makers on the recommendations to improve the usability of the DMRB;
(iv) translate the recommendations into practical actions.

The research programme developed for the DMRB project is illustrated in Figure 9.5. It lasted over 39 months (from August 2015 to November 2018) and comprised eight spirals of collaborative work between Highways England and the WSP team. The spirals have been grouped into five stages discussed in detail in the following sub-sections in terms of purpose, data collection, analysis procedures and key outcomes:

- Stage 1: The problem situation unstructured (comprising spiral 1)
- Stage 2: The problem situation expressed (comprising spiral 2)
- Stage 3: Consensus process (comprising spirals 3-5)
- Stage 4: Synthesis (comprising spirals 6-7)
- Stage 5: Implementation (spiral 8)
- Stage 6: Monitoring (spiral 9)

The Future DMRB project is still on-going and will be completed in April 2020 with the update of the entire DMRB.

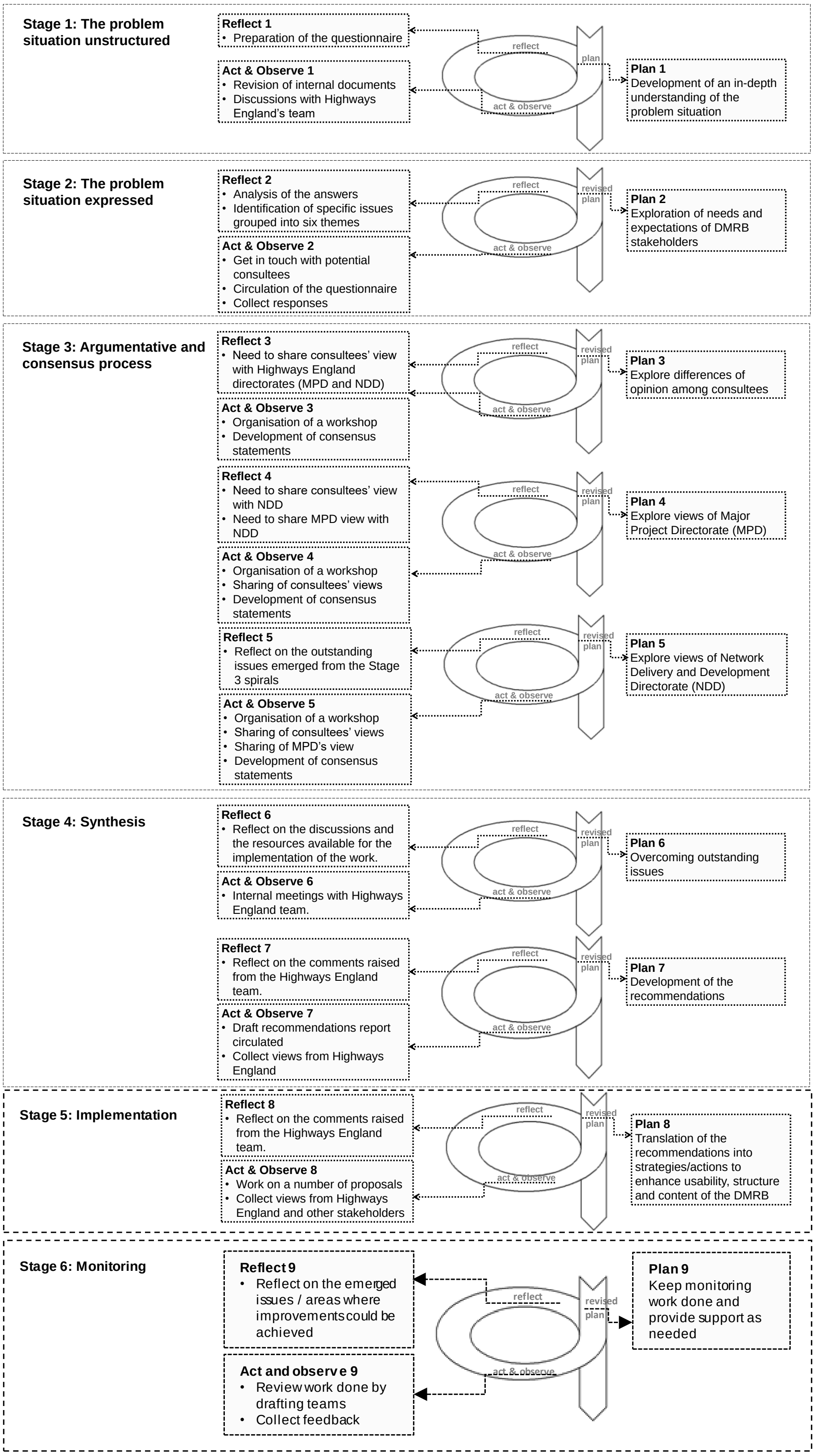


Figure 9.5 Overview of the research programme of the DMRB project

9.3.2 Stage 1: The problem situation unstructured

The purpose of Stage 1 was to develop an in-depth understanding of the problem. Internal documents of the Highways England related to previous studies carried out on technical standards were analysed and open discussions with the Highways England team were held.

Subsequently, a focussed and concise consultation with key stakeholders was carried out as expressly required by the Protocol Agreement (Department for Transport 2015). After intensive discussions with the Highways England team, the categories of stakeholders relevant to the consultation were identified (see 9.3.2) and 95 consultees (mainly companies, associations and institutions) were selected. Participants to the consultation were intended to serve in a personal capacity but, where relevant, expected to have an understanding of and broadly reflect the views of the organisation that nominated them. Technical concerns with specific clauses were not the subject of the consultation.

Table 9.1 Key stakeholders for the DMRB project

Category	Subcategory
Problem owner	- Department for Transport - UK Road Liaison Group, which brings together national and local governments across the UK to consider roads infrastructure engineering and operations matters.
Decision makers	- Highways England Directorates, including: o Safety, Engineering and Standards; o Major Projects; o Operations. - Devolved Administrations of Scotland, Wales and Northern Ireland
Main users	- Designers, including small and medium enterprises (SMEs) - Constructors, including operators and maintenance staff - Suppliers and manufacturers, including SMEs
Other users	- Other transport organisations (e.g. Network Rail) - Local authorities (e.g. ADEPT) - Road Worker Safety Forum (RoWSaF) - Environment Agency - Design Build Finance Operate (DBFO) organisations
Professional Institutions	- CIHT, ICE
Publishers	- BSI, CIRIA, TSO
Technical Software developers	- Autodesk, Bentley, Key Soft Solutions

9.3.3 Stage 2: The problem situation expressed

The purpose of Stage 2 was to develop an understanding of needs and expectations of the DMRB stakeholders. The successful approach adopted for the Eurocodes project (see Chapter 8) was used to explore consultees' view in a structured and transparent manner.

9.3.3.1 Questionnaire

To explore areas of agreement and disagreement among stakeholders, a draft questionnaire was prepared by the author based on the themes emerged from discussion with Highways England and the initial documents review. The questionnaire was reviewed and agreed with the WSP team, and circulated among the consultees via emails. Consultees had one month to reply. The questionnaire comprised three tables.

General information about the consultees and their areas of interest in the DMRB were asked (see Table A in Annex B). This was used to contextualise the answers received.

Thirty-eight statements were prepared (see Table B in Annex B) with a differentiation made between those related to the current DMRB (*as-is* analysis) and the future DMRB (*ought-to-be* analysis). A Likert scale 1-9 was used as for the Eurocodes project, with (1) strongly disagree, (5) neither agree or disagree, (9) strongly agree. A column for comments was also provided. The statements were relating to:

(i) purpose of the current and future DMRB;
(ii) distinction between requirements and advice in the DMRB;
(iii) value of retaining advice in the DMRB;
(iv) performance-based standards;
(v) introduction of more risk-based standards;
(vi) role of the DMRB in the context of innovation;
(vii) role that external organisations (including professional, trade and industry bodies) could play in the management of some DMRB content;
(viii) opportunity to share requirements with other asset owners;
(ix) degree and type of change in the future DMRB.

Eighteen open questions were developed and divided between the current and future DMRB (see Table C to Annex B). The questions were linked to the statements in Table B to check internal consistency in the answers received and to provide consultees with the opportunity to clarify their point of view.

9.3.3.2 Analysis of the responses

64 responses (mainly as corporate responses) were received from the 95 consultees contacted. The distribution of responses is indicated in Table 9.2.

Table 9.2 Summary of the responses received to the DMRB consultation

Consultee	Number of responses
Devolved Administrations	3
Highways England	6(1)
Designers (including SMEs)	25
Constructors	1
Suppliers (including SMEs)	7
Local authorities	6
Other transport organisations	8
Road Worker Safety Forum (RoWSaF)	1
Design Build Finance Operate (DBFO) organisations	1
Professional institutions	1
Publishers	1 (+ 2 general comments)
Technical software developers	1
Environment Agency	0 (only general comments)

(1) Responses from Highways England comprised those from the Major Projects and Operations. Comments of technical specialists from Safety, Engineering and Standards were taken from interviews carried out under a separate task.

A rationalised set was used by the author to calculate the mean value of the responses received for different groups of stakeholders and identify areas where there was agreement or significant disagreement in the point of view of the participants. Constructors and suppliers were grouped into a single category. Moreover, due to the very low number of responses received by the RoWSaF, DBFO, professional institutions, publishers and technical software developers (only one response for each category), their scorings were not considered in the calculation of the mean value of the responses. However, their comments were assessed and considered in the final consultation report presented in Section 9.3.4.3. An example of comparison of responses developed by the author is provided in Figure 9.6.

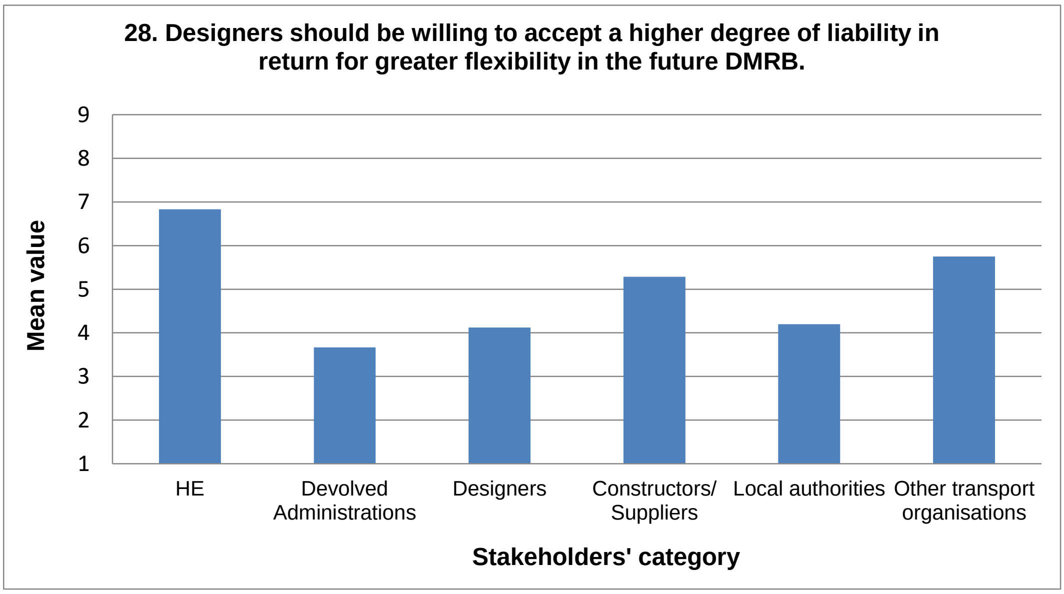


Figure 9.6 Example of comparison of responses (Annex C to WSP Parsons Brinckerhoff 2016a)

9.3.3.3 Findings of the questionnaire

Responses to Table A showed that consultees' expertise covered all technical areas contained in the DMRB and that around 30% of the consultees had expertise in more than one area. Specifically:

- 33 consultees on highways works
- 12 consultees on geotechnics
- 10 consultees on road schemes
- 14 consultees on pavements
- 9 consultees on traffic signs and lighting
- 6 consultees on traffic control and communications
- 7 consultees on environment

Responses to Table B and Table C showed good agreement on the following topics: not reducing the current level of safety in the future DMRB; not duplicating requirements from other standards; eliminating conflicting requirements in the DMRB; enhancing the editorial consistency; reviewing documents at least every 5 years; involving users in the DMRB development.

Responses to Table B and Table C also revealed diverse perspectives on a variety of topics including: the specific type of advice that should be retained in the DMRB; the purposes and scope of application of the DMRB; the target audience of the DMRB; the role of the DMRB in providing a framework for innovation.

Furthermore, responses to Table B and Table C showed limited understanding of the concept of "performance-based requirements" applied to the DMRB, as well as a number of issues connected with risk-based documents, requirements shared with other asset clients, advice externalised to industry, and the strategies to review and implement the future DMRB.

Interestingly, looking at the scorings of the questionnaire contained in Table B without reading comments in detail only gave a partial and sometimes misleading understanding of the stakeholders' view. Comments and responses to the open questions indicated that in some cases disagreement was less than that appeared looking at the average values of the responses. In other cases, whilst the scoring showed a good alignment of stakeholders' views, the comments indicated contrasting points of view.

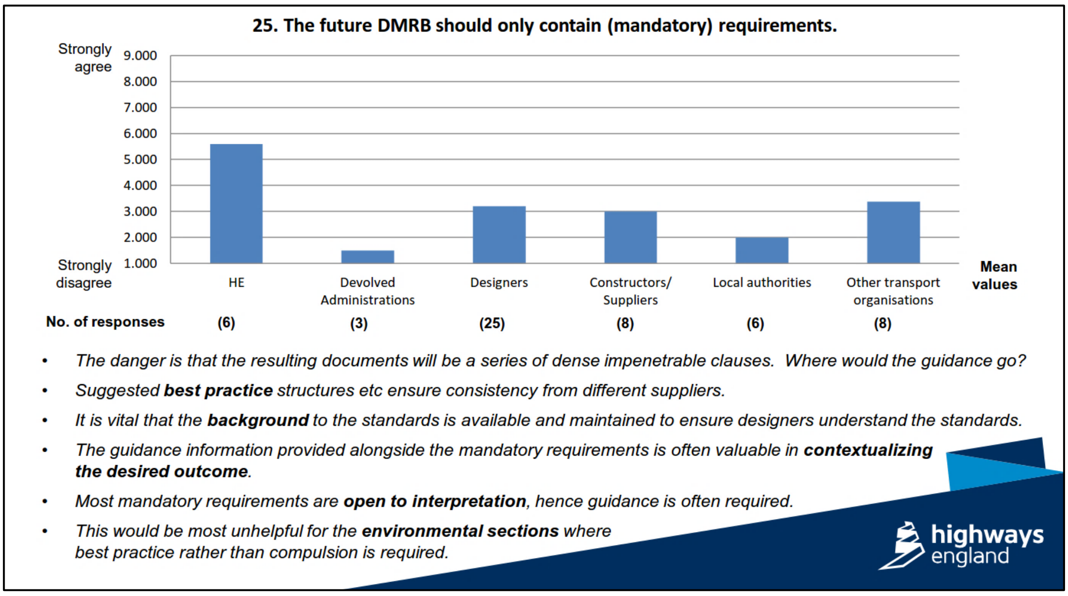
Hence, scorings of the statements contained in Table B were used to develop an initial appreciation of the areas of disagreement. Numerical results were used with caution and combined with the qualitative data emerged from the answers to the open questions in Table C to understand the key expectations of the different categories of stakeholders, inform the development of the work plan for the future DMRB, derive final conclusions and develop the recommendations.

9.3.4 Stage 3: Reaching consensus

The purpose of Stage 3 was to develop a shared understanding among key users on the issues emerged from Stage 2 and to reach the most reliable consensus between decision makers (i.e. Highways England and the Devolved Administrations).

9.3.4.1 Workshops and meetings

A series of workshops was organised to present the main findings of the consultation, explore differences of opinion and externalise areas of disagreement, and seek points of agreement. The author was responsible for the development of summarising sheets (power point slides, see an example in Figure 9.7), which were then used to present the results of the questionnaire in during the workshops.



25. The future DMRB should only contain (mandatory) requirements.

- *The danger is that the resulting documents will be a series of dense impenetrable clauses. Where would the guidance go?*
- *Suggested **best practice** structures etc ensure consistency from different suppliers.*
- *It is vital that the **background** to the standards is available and maintained to ensure designers understand the standards.*
- *The guidance information provided alongside the mandatory requirements is often valuable in **contextualizing the desired outcome**.*
- *Most mandatory requirements are **open to interpretation**, hence guidance is often required.*
- *This would be most unhelpful for the **environmental sections** where best practice rather than compulsion is required.*

Figure 9.7 Example of summarising sheet

The first workshop involved selected consultees from each category: Atkins, Mouchel and AECOM represented designers; Hewson Consulting Engineers Ltd represented the SMEs; ConnectPlus represented the DBFO contracts; the Chartered Institution of Highways and Transportation (CIHT) as the only professional institution which replied to the questionnaire; BSI and TSO to represent publishers. A few other consultees were selected but could not attend. Not all consultees were involved for three reasons: the workshop would have been unmanageable; the selected consultees covered all the different views emerged from the questionnaire; the other consultees were engaged in a later stage to provide feedback on the findings of the workshop (see below).

Subsequent workshops involved representatives from Major Projects and Operations Directorates of Highways England. Separate meetings were also held with the Devolved Administrations to present the findings from the questionnaire and the workshops, and to achieve consensus on the most controversial themes. The WSP team was the facilitator of both workshops and meetings supported by the Highways England's team.

The outcome of workshops and meetings was a set of consensus statements representing the view of the participants on the issues affecting usability, structure and content of the DMRB.

Final feedback on the consensus statements was requested from all consultees (including those who did not take part in the workshop) as part of the 'member checking' strategy to test the credibility of research findings (see Chapter 4).

9.3.4.2 Findings of workshops and meetings

During the workshops and meetings key aspirations of DMRB stakeholders were challenged and/or reinforced, for example on whether the future DMRB should contain both advice and requirements or requirements only, or the role of the DMRB in the context of innovation. The discussion also enabled consultees to appreciate the existence of inherent tensions and unexpected issues. For example, although the development of more shared documents with other asset owners was in principle desirable, the discussion exposed Highways England to the associated issues such as the lack of control on the document produced.

Similarly, whilst expressing design requirements in a performance context was considered a key aspect from early stages of the project (see Section 9.2), the discussion showed a need to investigate further what a performance-based approach actually means in the context of constructed facilities. The issues associated with development and implementation of performance-based requirements that emerged from the consultation also revealed a series of unintended consequences that needed a more in-depth exploration.

Workshops and meetings showed that disagreement among consultees was mainly due to: (i) the expertise of stakeholders and their backgrounds; (ii) the technical area of interest in the DMRB; (iii) a partial understanding of the problem presented in the statements or in the open questions; (iv) a partial consideration of the unintended consequences when supporting one argument instead of another; (v) a misunderstanding of the statement/question itself.

9.3.4.3 Consultation report

The author produced the consultation report (WSP Parsons Brinckerhoff 2016a) containing a detailed analysis of six themes emerged from the consultation:

1) Requirements versus advice
2) Purpose of the DMRB
3) Innovation
4) Performance-based requirements

5) Publication by others
6) Implementation

For each theme the following topics were presented: context; statements and questions in the questionnaire; general issues that emerged from the consultation; points of agreement and consensus; potential options for resolution with their advantages and limitations. The consultation report was circulated among the consultees for information and very positive feedback was received.

9.3.5 Stage 4: Synthesis

The purpose of Stage 4 was to develop the recommendations to enhance usability, structure and content of the future DMRB based on the findings of the consultation. Internal meetings with the Highways England team were organised to discuss the recommendations and investigate resources available for the implementation of the work. As a result of these activities, eleven recommendations were produced by the WSP team (see Table 9.3) and were agreed by the Executive Committee of Highways England.

Table 9.3 Recommendations for the future DMRB (reproduced from WSP Parsons Brinckerhoff 2016b)

1.	The future DMRB will continue to set out the requirements to be used for the UK motorway and all-purpose trunk road network.
2.	The future DMRB will introduce National Application Annexes (NAA) to enable modification/adaptation of DMRB documents by the Overseeing Organisations.
3.	The future DMRB will continue to support the Overseeing Organisations in fulfilling their obligations and controlling their risks.
4.	The future DMRB will clearly define requirements to be fulfilled by supply chain designers.
5.	The future DMRB will place responsibility for design justification with the supply chain designers.
6.	The future DMRB will provide a reduced volume of advice.
7.	The future DMRB will implement more documents developed in partnership with other asset owners and increasingly reference advice published by other reputable bodies.
8.	The future DMRB will be and remain up-to-date.
9.	The future DMRB will have a consistent style and format, and be intuitive to use.
10.	The future DMRB will be produced by Technical Specialists supported by Content Specialists.
11.	The development of the DMRB will be future-proofed for advances in information technology

In practice, these recommendations required, among other things:

- A new structure, style and format for individual DMRB documents.
- A new structure of the overall DMRB document set.
- Creation of the role of Content Specialists to support document development.
- Introduction of National Application Annexes to provide more freedom to develop Overseeing Organisations' specific content and speed up the development process of the standards.
- An online platform to future-proof the future DMRB.

9.3.6 Stage 5: Implementation

The purpose of Stage 5 was to translate the recommendations produced in Stage 4 into practical activities for the document authors involved in drafting the future DMRB.

9.3.6.1 Manual for Development of Documents

A series of proposal papers was developed by the author regarding how to make a distinction between different types of advice, the new structure of the DMRB, the strategies to develop performance-based requirements, and decision trees to support document review and update. These proposal papers were used by the author to develop an updated version of the Highways England's Manual for Development of Documents (MDD).

The MDD was tested into a piloting exercise carried out with five Highways England's suppliers (Arup & AECOM Joint Venture; WSP; CH2M & Atkins Joint Venture; TRL; Pell Frischmann) from January to the end of March 2017. The pilot was also used to explore more effective ways of working and engagement between document authors, technical specialists and content specialists. At the end of the piloting stage, a final MDD (Highways England 2017a, 2017b) was developed by the author and issued to Highways England. The MDD is reviewed and updated every 5 to 6 months, typically to cover enhanced governance processes and clarify the drafting rules as needed.

Training material to support the uptake of the new drafting rules was prepared by the author and confirmed by the WSP team. Training sessions have been delivered by the author and a colleague from WSP to the Highways England staff. Training has also been provided to Highways England's suppliers and the Devolved Administrations.

9.3.6.2 Streamlining document drafting

The programme of work to review around 360 documents (DMRB and associated documents) required significant resources. To support this challenging and ambitious activity, Highways England agreed to explore with the WSP team alternatives into how the document development process could be streamlined. The author was involved in this task to provide a critical view on the proposals made and ensure alignment with the Manual for Development of Documents. This work provided important insights into the strategies to tackle two recurrent issues in the standardisation process, i.e. collaborative authoring and streamlined drafting process. Two tools were explored.

The first was a Collaborative Authoring Review System (CARS). It makes the process of drafting and approval smoother compared to the traditional way of working thanks to an online platform that allows people involved to collaborate virtually. CARS has been developed by a software company employed by Highways England and working under the direction and support of the WSP team. The basic principles of CARS are similar to Google Docs, which supports creation and editing of web-based documents. However, CARS presents additional functionalities including: the development of a background document accompanying the DMRB document developed; the distinction between requirements and advice; the introduction of auto-correctors when the 'vague terms' identified by the authors (see Section 9.5.1.1) are used by the drafting teams.

The second tool made available by Highways England was the 'Agile' approach applied to document development. The main thrust of Agile is assembling a development team with all skills required to complete a task. The team works together full-time for a fixed period and achieves what they can within that period. The Agile approach was tested and enabled the document drafting process to be reduced significantly, from months to few weeks (see Section 9.6.9).

9.3.6.3 Programme visibility and control

The large programme of work (more than 360 documents) required that specific attention was put to the approach for controlling progress and delay. To support better visibility and control, a project management tool called JIRA was adopted. This cloud-based service aimed at (i) providing clarity of the development process of all documents, (ii) enabling better and more proactive resource management, and (iii) ensuring compliance with the Highways

England's quality management reporting (QMR) process while automating it (see 9.2.1 for the development stages of DMRB documents and the QMR system).

9.3.7 Stage 6: Monitoring

From April 2017, all DMRB drafts have been reviewed by the Highways England's content specialists to ensure their compliance with the MDD. The author is working closely with the content specialists and some drafting teams to provide support and guidance as needed.

In April 2018, feedback was collected from those who contributed to the first year of the work programme to update the DMRB. Three best practice workshops involving a selection of document owners and document authors were organised. Of the 42 participants, the majority were Highways England employees (80%). Other attendees were document authors from the supply chain. A questionnaire was also distributed by Highways England. Out of the around 175 number of individuals the questionnaire was distributed to, 24 responses were received (around 15%). Of the responses received, 33% were from Highways England employees; the remaining were from external suppliers.

Three open-ended questions were asked: (1) *What went well?* (2) *What did not go so well?* (3) *What can be improved?* The responses collected were grouped into an overall unified set of themes including document drafting, collaboration, new IT tools, governance processes. Actions and action owners were also identified against relevant items of feedback. The rich feedback collected helped identify key issues and learn lessons to improve the delivery of the work programme in the following years of the work programme.

9.4 Limitations

Five limitations of this work warrant mention. They reflect the view of the author only.

First, a limitation can be argued on the limited number of responses received during the consultation from some categories of stakeholders (professional associations and constructors). As discussed in Chapter 8 for the Eurocodes project, this aspect attains to a larger issue of inadequate participation of stakeholders in the standardisation process. A stakeholders' management plan was carefully established to engage as many stakeholders as possible. It included: emails to contact the stakeholders; a webinar to explain the essence of the consultation and its key steps; reminders of the deadlines; request of substitutes of the consultees where necessary.

The second limitation is about the methodology adopted and its effectiveness. As pointed out for the Eurocodes' project, the author does not claim that the methodology adopted in this project was the only and best possible, but rather that it was effective against the objectives set out in Section 9.3.1.

A third limitation can be argued on the findings and their dependency on the methodology adopted. In order to demonstrate the dependability of results, as recommended by Yin (2009) in this thesis details have been provided of the methods adopted, timescale for the project, steps followed and their rationale, data collection and analysis, people involved, key challenges faced and relevant lessons learned. Besides, the credibility of the research findings has been checked by considering some of the strategies suggested by Creswell (2014) such as: (i) a detailed description of the setting, including different perspectives about a theme (see Section 9.3); (ii) the immersion of the author in the project for a prolonged time (20 months) to gain an in-depth understanding of the phenomenon; (iii) the request of feedback from both the consultees and the problem owners (member checking); (iv) self-reflection and critical comments on limitations of the project presented in this section (clarity on researcher's bias).

The fourth limitation refers to the limited implementation of the recommendations presented in Section 9.3.5. The full roll-out of the work programme started on the 1st of April 2017 and is scheduled to be completed by April 2020, thus the evaluation of the results of this work would require additional several years, particularly to gather feedback from users. Yet, the strong contextual understanding that this project brought adds a critical dimension to the discussion on how better design standards can be developed in practice. Moreover, to date (November 2018) over 150 DMRB documents have been processed. Positive feedback has been received by documents authors and document owners on the enhanced quality of the new DMRB documents and the usefulness of the Manual for Development of Documents.

Finally, a limitation is on the transferability of the recommendations, which are context-specific. However, as discussed in Section 4.5.3 what is meant to be transferable are not the specific recommendations, but rather the learning from the methodology adopted and how it was applied in a practical setting, the themes emerged (see Sections 9.5, 9.6 and 9.7), and the general lessons derived from this project (see Section 9.8).

The consultation made it clear that the issues affecting usability, structure and content of the DMRB were intertwined and that a holistic approach was needed to better understand their impact, develop recommendations and propose practical changes for the future DMRB. Enhancing usability of the DMRB thus required considering this as a complex socio-technical problem (see Chapter 6 for a definition). In the following sections the key themes emerged during the project and relevant to this thesis are examined.

9.5 Emerging themes related to the content of design standards

9.5.1 Requirements and advice

9.5.1.1 Distinction between requirements and advice

A lack of a clear distinction between requirements and advice in many DMRB documents emerged from the consultation. This had led to a high number of departures from standards and a negative impact on the day-by-day work of technical specialists due to the limited resources available in Highways England to process them.

To make a clear distinction between mandatory and advisory content, specific verb forms were introduced. These are reproduced in Table 9.4. While they mirror those provided by CEN/CENELEC (2017) and ISO (2016b), they were enforced by a clause numbering system providing a unique level of rigour in making a distinction between requirements and advice. Requirements have been identified with a primary two-level system of numbering, e.g. 5.3, 7.2, etc. On the other hand, advice has been introduced with a secondary three-level system of numbering associated with the related requirement, e.g. 5.3.1, 7.2.1, etc. Advice in the main body of the text was always intended to be associated with a specific requirement.

Comments from some drafting teams also showed the importance of clarifying the source of the requirement or advice – be it an external provision, or a requirement or advice developed by the Overseeing Organisations – and whether or not departures were allowed. These aspects are clarified in Table 9.4.

Table 9.4 Classification of different types of requirements and advice (developed by the author and adapted from Highways England 2017)

Category	Sub-category	Source	Status	Verb form
Requirement	**Legislative requirement** Legislative/statutory requirements set out in regulations at international/ European/national level.	External provision not developed by the Overseeing Organisations.	To be met in all cases – departures not permitted	Must
	Performance-based requirement These should be written as general, high level requirements: e.g. *the design of support shall prevent…*, *the gantry shall be designed such that…*, *the wall shall be constructed such that…*, etc.	Requirement of the Overseeing Organisations.	Subject to departure	Shall
	Method requirement Specific (method) requirement: e.g. *the design of the support shall be undertaken using…*, etc.	Requirement of the Overseeing Organisations.	Subject to departure	Shall
Advice	**Recommendations** One recommended option among several ones without mentioning or excluding others	Developed by the Overseeing Organisations.	Not subject to departures	Should
	Permissible option or approach Useful option(s) to verify the requirement or to meet the recommendation.	Developed by the Overseeing Organisations.	Not subject to departures	May
	Clarification of a concept or statement of fact presented as either a NOTE or commentary in an appendix.	Developed by the Overseeing Organisations.	Not subject to departures	Can / verb expressed in the present tense

An important aspect emerged from this project is that the choice of the verb form is not a simple editorial exercise. Instead, it requires standards' writers to decide what the supplier has to do, what the key technical requirements are, what Highways England needed control over (via departures) and when opportunities to deviate can be given.

In this context specific attention was given to avoiding the use of 'vague' and subjective terms such as 'consideration should be given to', 'care shall be taken to' or 'preference should be given'. The main issue when using these expressions resides in the impossibility to check whether a requirement is actually fulfilled. The author developed a list of 'prohibited expressions' and examples of how they could be rephrased to give clarity of the intended requirement or recommendation. Initial comments from the drafting teams show that rephrasing such ambiguous phrases is a demanding yet crucial task, because it challenges the purpose of the clauses.

9.5.1.2 The value of advice associated to requirements

An issue emerged from the consultation was about the different expectations between users and Highways England as to whether the DMRB should contain requirements only or advice too. Whilst removing all advice from the DMRB meant a shorter suite of standards more easily manageable by Highways England, consultees acknowledged that requirements without advice (both background and methods to fulfil requirements) can be difficult to interpret and would potentially lead to less consistency in terms of design solutions developed. Moreover, it was observed that sometimes advice is important to flag the attention to technical issues that happened in the past and the supply chain could not be aware of.

9.5.1.3 How much advice should be provided

During the training sessions a recurrent query was on the amount of advice to provide. A single answer does not exist to this question as it depends on the specific topic. However, this project showed that two useful techniques are (i) to take account of the level of competence and expertise expected from the target audience, and (ii) to refer to other standards or existing industry guidance documents so that the users can raise the level of their understanding of the subject.

9.5.2 Performance-based requirements (PBRs)

There was limited understanding of what is meant by 'performance-based requirements' in the context of design among consultees as explicitly recognised during a workshop and recorded in some of the consensus statements reproduced below:

> "The interpretation of what is meant by performance standards can be diverse, and can range from service-level requirements through to whole-life contractual obligations".
>
> "Industry best practice for design standards does not include numerous examples of performance standards".

As mentioned in Section 9.2.2, the Protocol Agreement (Department for Transport 2015) also required Highways England “to reduce the number of prescriptive standards and increase the number of performance standards, in line with industry best practice”.

In this section the author delves deeply into this issue. The findings were used by the author to define the directions for the development of performance-based requirements and have been incorporated into the Manual for Development of Document published by Highways England (2017a, 2017b).

9.5.2.1 Meaning

Performance-based design is a design philosophy in which the criteria to design an artefact are expressed in terms of performance objectives. In this context the term ‘artefact’ is used to indicate an engineered entity with varying degrees of complexity, from a manufacturing product (e.g. concrete or steel) to an infrastructure system.

For a performance-based approach, technical provisions should be expressed in a manner that makes the intended outcome and the performance requirements (or design objectives) (i) clear to the designer and (ii) easy to be challenged by the client. Broadly speaking, this demands that the following questions are answered as stated in the Transportation Research Board’s (2014) report[1]:

- What is ‘performance’ and what is the required level of performance?
- How will the compliance against the required performance level be evaluated, measured and monitored?
- What are the consequences of not meeting the required level of performance?

---

[1] Although the American Transportation Research Board’s report is targeted to technical specifications, the general concepts presented can be equally applied to design standards.

9.5.2.2 Performance-based approach for different artefacts

As stated earlier, artefacts may span from simple construction products to complex infrastructure systems. In Chapter 5 a distinction was made between manufacturing products and constructed facilities.

Manufacturing products are generally small and standardised artefacts, which result from a manufacturing process carried out in a highly controlled working environment employing full-scale prototypes and that generally fulfil some very specific performance objectives, easy to define and assess by means of full-scale prototypes. Over recent years, it has become established practice for Product Standards to be wholly performance-based. They are expressly required by the Construction Product Regulation 305/2011 (CPR) and addressed by current product and material standards. They allow more flexibility to select procedures, materials and techniques in order to enhance the performance of the product.

Civil and structural engineering works are instead big, one-of-a-kind, long-lasting and complex structures, which result from a site-specific project-based activity, meaning that building full-scale prototypes is unfeasible. Moreover, they are expected to address multiple, diverse and wide-ranging performance objectives. This becomes even more complicated when dealing with infrastructure systems which are characterised by a strong interaction between engineered, natural and human systems (Aktan et al. 2007).

A key implication of this is that, while the development and application of a performance-based approach to manufacturing products are relatively straightforward, its application to constructed facilities and infrastructure systems requires a different mind-set for the identification of the performance objectives, the expected performance levels, and the criteria and methods for verifying that the final outcomes or outputs meet the agreed performance objectives.

9.5.2.3 Distinction between PBR and MBR

To decide between performance-based requirements (PBRs) and method-based requirements (MBRs), their benefits and limitations need to be assessed. A non-exhaustive list of advantages and disadvantages in using MBRs and PBRs for the design of civil and structural engineering works is provided in Table 9.5. They draw together themes emerged from the DMRB project (WSP Parsons Brinckerhoff 2016a; Highways England 2017b) and relevant content contained in a report published by the Transportation Research Board (2014).

Table 9.5 Advantages and disadvantages of method-based requirements (MBRs) and performance-based requirements (PBRs)

Advantages	Disadvantages
- Well-established and easy to understand and apply to a wide range of subject areas. - The client can have major control over the work. - Generally based on methods that have proved to work in the past: limited risk to introduce less established methods.	- There are few opportunities to deviate from the method required and, provided that the requirements are met, there will be limited responsibilities for performance deficiencies of the design solutions proposed by designers (or contractors). - MBRs may prevent or discourage users from proposing more cost-effective or innovative solutions. - Generally, there are no incentives to provide solutions which may improve final performance in terms of cost, time and quality.
- Better quality of the final constructed facility (since it demands industry experience) and long-term durability. - More flexibility to select procedures and methods in order to enhance the performance of the civil and structural engineering work, for example in terms of quality and/or economy. - Promoting innovative solutions. - Accelerating construction.	- The client may have little control over the work. - Reduced opportunities for small enterprises and local firms. - Challenging to identify all of the parameters affecting performance and establish relevant thresholds. - Difficult to monitor performance (see Section 9.5.2.5). - Increase in cost. - Issues in terms of risk transfer (see Section 9.5.2.5). - Difficult to enforce performance particularly where there are complex interfaces with split liabilities and when dealing with long term assets. - Maintenance issues (see Section 9.5.2.5). - Increased industry costs to control application of performance. - Issues in procurement (see Section 9.5.2.5). - Specific skills needed by the design community (see Section 9.5.2.5).

Overall, MBRs and PBRs are both valid approaches and their choice depends on the outcome sought. The motivation for using MBRs or PBRs generally depends on three factors.

- The type of artefact (see Section 9.5.2.2).
- Number of available methods to verify requirements. If a very limited number of methods exist to verify a requirement, these should be provided as MBRs.
- Novelty of the requirement. For common design situations (i.e. where well-proven technology is required and used) introducing MBRs generally provides faster, less costly and more reliable solutions, whereas employing a performance-based approach can be demanding, with design effort being greater and potentially disproportionate. In contrast, where it is desirable to provide more flexibility to the supply chain to innovate and influence the performance outcomes, PBRs should be provided.

9.5.2.4 Current trends in PBRs

Thinking in performance terms requires considering outputs or outcomes rather than specific inputs, activities or processes (i.e. methods). This represents a key distinction between performance-based requirements (PBRs) and method-based requirements (MBRs). The general trend in standard development is to move from method-based standards to performance-based standards with the aim of giving more flexibility to designers to achieve the specified outcomes in a cost-effective manner (Foliente 2000).

Recently, significant research efforts has been devoted to the development of performance-based design approaches for nuclear power plants, earthquake engineering, blast, fire, tsunami, and wind scenarios, and performance-based building as documented in the special issue on Performance-based engineering published by Engineering Structures in 2014.

The approaches adopted and documented in literature generally focus on the use of reliability models and advanced numerical methods for the evaluation of the structural performance, hazard analysis and handling of uncertainties. Interestingly, what seems to be lacking is the study of the challenges in incorporating performance-based requirements into design standards and implementing them. These aspects are explored in the following paragraphs.

9.5.2.5 Challenges in 'pure' PBRs

The DMRB consultation revealed that there is a tendency in considering performance-based requirements (PBRs) as high-level performance requirements, which are beneficial to drive better quality, encourage innovation and reduce departures from standards. For the purpose of this discussion, these have been called 'pure' PBRs. A number of challenges in development and implementation of pure PBRs emerged from the consultation.

On-going monitoring of performance – There was general agreement between consultees on the fact that the introduction of PBRs could lead to issues regarding monitoring of performance. These include: (i) the definition of a consistent basis as to how this performance is measured; (ii) the definition of clear, measurable and unambiguous benchmarks and the difficulty for asset owners/managers in articulating and quantifying exactly what they want; (iii) regular review of performance to confirm that performance measures are appropriate; (iv) more rigorous site testing and site supervision at a time when this aspect of control on highway works on site is diminishing, thus issues to find resources for monitoring; (v) difficulty in monitoring the proliferation of solutions (see also "Maintenance" below); (vi) cost implications; (vii) check of guarantees; (viii) good records to monitor not only contractual performance, but also long-term performance. These issues can be extremely challenging when there is limited or no control over how the structure is used over a long period of time.

Maintenance – The implementation of fully PBRs could potentially lead to the development of a variety of design solutions which in turn – without an appropriate control/management – may lead to inconsistency on the design solutions developed. Appropriate performance-based maintenance contracts (PBMCs) may thus be needed, which set out clear performance requirements in long term, as well as unambiguous performance criteria to take into account the influence of maintenance on performance.

Procurement implications – Consultees acknowledged that the introduction of pure PBRs would have a strong impact on the procurement process. Arguably, this would require the introduction of performance-based contracts (PBC), which focus on achieving required outcomes rather than supplying a set of prescribed specifications. The procurement method and the period of liability are typically extended under PBC, which bring about questions as to how risks are identified and managed (Gruneberg et al. 2007).

Contractual liability and risk transfer – PBCs also alter the nature and allocation of risks, "shifting increased risks on to the contractor and away from the client" (Gruneberg et al. 2007). Consultees acknowledged that, if full PBRs are introduced, specific consideration should be given to contractual liabilities, particularly in terms of (i) time, (ii) whole-life cost implications of delivering performance based solutions, (iii) monitoring of performance, (iv) durability, and (v) balance of risk between different parties and consequently risk transfer. This issue was also reflected in two consensus statements reproduced below:

> "There are challenges in enforcing performance particularly where there are complex interfaces with split liabilities".
>
> "Successful use of performance standards will require not just a change to the DMRB but will also need a change in procurement particularly for design and build schemes, to increase focus on whole-life operation and maintenance and incentivise achievement of the performance outcomes".

Long-term liabilities could also have the counterproductive effect of leading to a much more conservative design. They could also require contractors to carry public liability insurance for the lifetime of the asset. There can be also issues when defects emerge.

Fit for purpose and insurance issues – A fitness-for-purpose obligation for designers and associated insurance issues are a main concern when dealing with PBCs. Fitness for purpose is not typically covered by professional indemnity policies (Gruneberg et al. 2007). Enforcing means of recourse such as insurances and warranties, particularly some years after the design is completed is thus problematic.

Time and cost implications – When delivering performance-based design solutions, time and cost implications were considered problematic by consultees. Inadequate consideration of these aspects may result in overly conservative designs defeating the purpose itself of introducing PBRs.

Specific competence and skills – Consultees recognised that the application of full PBRs would require a highly skilled, knowledgeable and experienced design community with a very clear view of client outcomes/objectives. This may not be easy due to "the current surge in infrastructure investment spent" and "the shortfall in expertise". Consideration should thus be given to the rate at which this transition can be introduced. This aspect was also recorded in a consensus statement:

> "Implementation of performance standards will need to recognise that different skills needed to write and govern performance standard, have not had this historically, and that interfaces will need to be carefully defined. Competence and capability of people involved will become more important with a shift to performance standards compared with prescriptive standards".

9.5.2.6 'Mixed' PBRs

To overcome the issues associated with pure PBRs, the term 'mixed' PBRs has been introduced by the author in discussion with the WSP team to recognise the need for varying the level of granularity of PBRs.

Standards should be developed to provide clear requirements for competent practitioners. As a result, the performance requirements (or design objectives) should be accompanied, where possible, by methods as a means to meet the requirements, and the methods should be clearly presented as advice, i.e. recommendations or permissible approaches.

The concept of mixed PBR is analogous to the approach taken in the Eurocodes, which have been recognised as "the most comprehensive example of implementing the performance concept in formal design documents" (Becker 2008). The Eurocodes are not pure performance-based standards. They also provide application rules, i.e. alternative specific methods to verify the performance objectives.

In conclusion, the author argues that the implementation of a performance-based approach should vary according to the artefact under consideration. Moreover, the level of granularity of a PBR should not be fixed, but vary from 'pure' to 'mixed' PBRs. Figure 9.8 summarises the key aspects to consider when choosing between PBRs and MBRs for different artefacts.

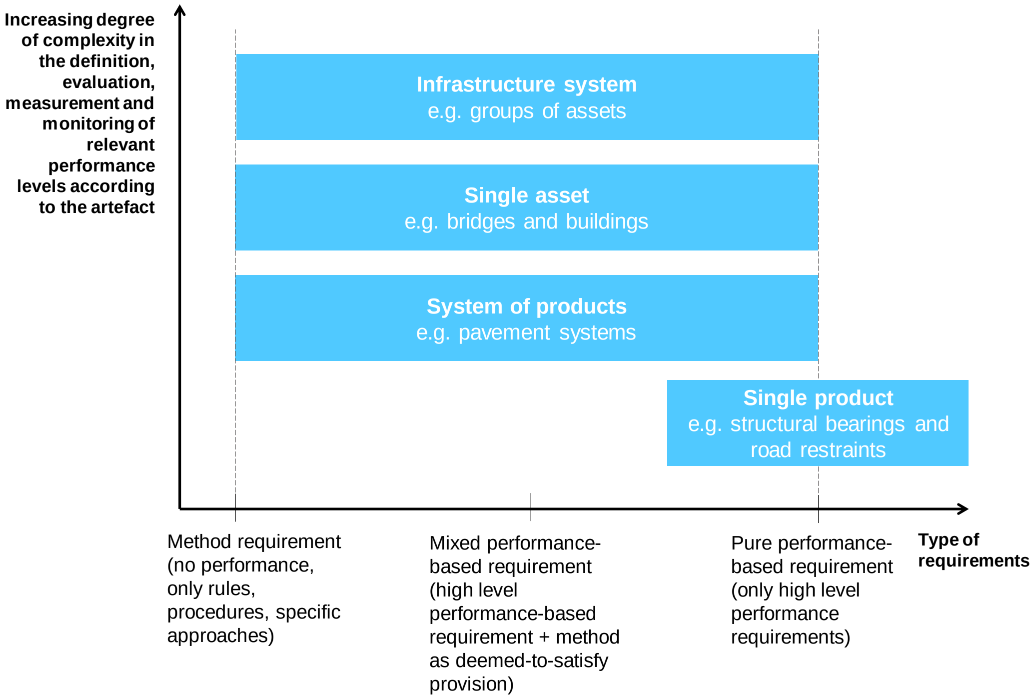


Figure 9.8 **Spectrum of requirements for different types of artefacts (reproduced from Denton and Angelino 2017)**

9.5.2.7 Drafting PBRs

Drawing together the findings of the DMRB project and the themes discussed by the American Transportation Research Board (2014) it emerges that, where the route of 'pure' PBRs is chosen, standards' writers should:

- establish a quantitative measurement strategy for each performance requirement (see Table 9.6 for specific guidance);
- identify potential gaps in the measurement strategy, for example in terms of technology, sampling and testing, and knowledge;
- assess liability/responsibility transfer (see Table 9.7 for some key questions to guide liability/responsibility transfer assessment);
- assess risks (see Table 9.8 for guidance on risk assessment).

The flowchart shown in Figure 9.9 provides the steps derived by the author for drafting new PBRs or updating existing requirements taking a performance-based approach.

Table 9.6 Guidance on the measurement strategy for PBRs (adapted from Transportation Research Board 2014)

Step	Relevant activities
1	Define parameters and performance measures, which must be relevant to users goals, as well as quantifiable and verifiable
2	Specify test or evaluation method through which compliance will be determined including considerations on time to collect data, cost, specialised equipment needed, audit.
3	Establish sampling plan with identification of sample size and location, frequency, and other relevant aspects.
4	Set performance limits/thresholds including consideration of acceptable deviation from the PBR and implications for not meeting the required level of performance.
5	Determine how the results of the test or evaluation method will be used.
6	Determine who will be responsible for the execution of the testing.

Table 9.7 Guidance on liability/responsibility transfer assessment for PBRs

No.	Questions
1	Does the Organisation have authority to transfer the responsibility for the PBR to the supply chain?
2	Does the PBR put unreasonable liability on the supply chain?
3	Does the PBR put unreasonable risks on the Organisation?
4	Is supply chain prepared to assume the responsibility and risk for performance?
5	Is there internal (Organisation) support to the transfer of responsibility?
6	Is there sufficient public support?
7	How can project delivery approach allow the re-allocation of responsibility?

Table 9.8 Guidance on risk assessment for PBRs (adapted from Transportation Research Board 2014)

Step	Relevant activities
1	Identify risks particularly in terms of: - monitoring of the proposed performance, - maintenance implications, - procurement implications, - liability issues (reluctance of the supply chain to assume risk, for example because the required performance level is poorly defined), - fit for purpose and insurance issues, - lack of consistency, - time and cost implications of delivering performance-based solutions.
2	Define attributes of each risk, including risk owner, frequency of its occurrence and how and where it will manifest itself, its impact.
3	Plan for risks, i.e. accept, transfer, mitigate or avoid.

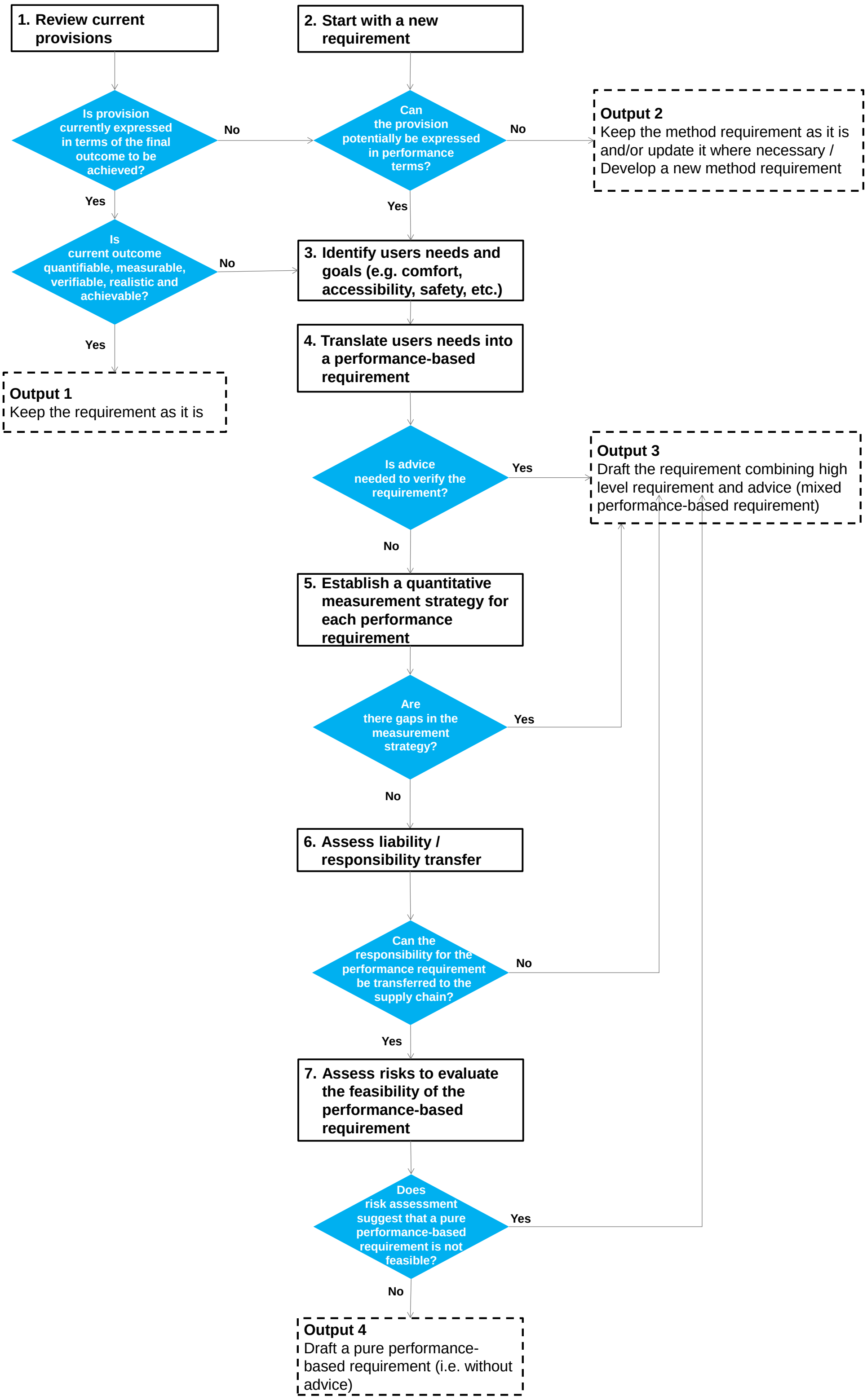


Figure 9.9 Flowchart for drafting performance-based requirements (developed by the author and reproduced from Highways England 2018c)

9.5.3 Risk-based requirements

At the inception of the DMRB project, introducing risk-based approaches was considered as an important incentive to innovation. Interestingly, the consultation showed a lack of agreement among the consultees on the fact that "*the future DMRB should contain a greater proportion of documents where requirements are risk-based*". The general issues associated with risk-based approaches, which emerged from the DMRB project and the report published by the American Transportation Research Board (2014), are outlined below.

Subjective nature of risk – Different people have different perceptions of risk and this would impact the way risk is assessed and managed.

Need to understand parameters affecting risk – Fundamental parameters to carry out the risk assessment should be carefully considered to ensure that they are appropriate and to minimise the risk of unintended consequences.

Project-level vs. programme-level risk assessment – The reliance on risk-based methods carried out at individual project level is likely to result in different answers to the same problem provided by different designers. Instead, programme-level risk assessments (i.e. involving a wider range of similar projects within a programme) would be more effective, although requiring effective liaison between designers and other relevant stakeholders.

Contractual issues – Risk-based approaches are difficult to manage contractually and would need to be tied closely to procurement strategies.

Risk and reward – Risk-based approaches could be steered by more equitable share and reward of risk.

Risk aversion – It can be difficult to change the mind-set of some designers, who can be risk averse due to professional indemnity considerations.

Research funding – Assessment of risk may need research funding and further studies are needed before adopting risk-based approaches.

Document- and case-specific – The introduction of risk-based approach is dependent on the document. Some standards for example require method-based requirements to safeguard against risky or ambitious proposals. Moreover, there may be cases where risk-based approaches do not deliver what is required.

9.5.4 Navigation

The DMRB has evolved over time and its current structure is not consistent, making it difficult to find technical content. Navigation is thus a significant challenge to users and a more intuitive structure was acknowledged to be necessary. Two dimensions exist to restructure the DMRB, which emerged from the analysis of its content. These are (i) asset types / subject area (bridges, environment, etc.), and (ii) life-cycle stage (planning, design, maintenance, etc.). However, the choice of which of these dimensions should be the primary or the secondary was not obvious.

This project showed that defining high-level governing principle(s) helps support decision making. The following principle was formulated: "*The future DMRB structure will be more user-orientated than it is now*." A list of features of the future DMRB was identified by the author (see Figure 9.10). These were classified into 'fundamental' and 'specific' where addressing necessary or desirable needs emerged from the consultation. Four options to restructure the future DMRB were proposed and scored against the features. A final matrix structure was developed by the WSP team set around life-cycle stages (volumes) and asset types/subject areas (parts) and will be used for the future DMRB.

Feature	
Fundamental	1. Relevant content can be easily found.
	2. Content relevant to undertaking any common activity by a user (e.g. designing an asset) is clustered together and follows a logical sequence
	3. Existing documents to fit as much as possible
Specific	4. The variety of documents currently contained in the DMRB and those that will be inserted in the future can be incorporated in a coherent way.
	5. A clear link exists between asset type and life-cycle stage
	6. It enables a good search facility and web browser interfaces to be developed
	7. It supports easy adaptation for future changes / future proofed / machine readable
	8. It provides a rational system of sub-sections
	9. It provides a coherent numbering system

Figure 9.10 Features of the future DMRB structure

9.5.5 Purpose of the DMRB

Consultees' expectations of the purpose of the DMRB differed as summarised below (see WSP Parsons Brinckerhoff 2016a):

> "To enable competent and preferably not risk averse people to design and maintain an effective long-term highways network".
>
> "To provide a safe, consistent, durable and maintainable highway network, which represents value for money".
>
> "To set out requirements and advice for assessing and designing highway schemes and provide a forum alongside the RADs [i.e. requirements and advice documents provided in the DMRB] for users to share best practice and innovation".
>
> "To achieve a buildable, durable fit for purpose and economical safe design and construction maintaining the same standards taking into account of all new innovations and available material latest design techniques".

Achieving consensus on the purpose of the DMRB was crucial for its implications on:

- the target audience of the documents and their scope, i.e. design only or all phases of the life-cycle such as construction, maintenance and operation;
- the type of content provided, i.e. requirements only or advice too;
- the impact of the standards on financial, environmental and buildability aspects;
- the impact of the standards on innovation.

A consensus was achieved on the following purpose statement, which represents the vision for the future DMRB: "*The future DMRB will define clear and unambiguous requirements to ensure that the Overseeing Organisations discharge their obligations*".

9.6 Emerging themes related to the standardisation system

9.6.1 Primary target audience and competence

Consultees were asked to define a primary target audience for the future DMRB. Three categories were proposed: all groups of stakeholders; only designers; only asset owners. Clearly, the choice had practical implications on the coverage of the document set and its level of detail.

The agreed target audience was “Competent practitioners” defined as follows: “typically qualified professionals able to work independently in relevant fields”. Assuming this level of competence and expertise helped avoid complex requirements (which can be understood primarily by experts) while reducing the amount of textbook materials (generally required by less experienced practitioners).

The project also showed the need to investigate how and whether in-depth knowledge of the level of competence and expertise of designers can be used to develop more user-orientated design standards. This aspect is examined in Chapter 10 in a theoretical study.

9.6.2 Users’ needs

In developing the questionnaire, some assumptions were made about users’ preferences. Whilst some of them were confirmed during the consultation (for example the need to differentiate requirements and advice clearly), some others were proved wrong (such as the need to delete all advice or the importance of reducing drastically the number of pages). This corroborates a theme emerged from the Eurocodes project on the importance of consulting users and not prejudging what they want.

9.6.3 Drafting rules

The author was responsible for the development and update of the drafting rules contained in the Manual for Development of Documents (MDD). The DMRB project showed the importance of having in place clear and unambiguous drafting rules targeted to the audience. MDD Part 1 “Governance of document development” was primarily targeted to those involved in governance process such as document owners and group managers. MDD Part 2 “Drafting rules” was targeted to document authors. The training sessions delivered to the Highways England and Devolved Administrations staff and to the supply chain as well as the workshops held and the questionnaire circulated (see Section 9.3.7) were the main conduit to elicit and receive feedback and comments on the MDD and check its appropriateness.

9.6.4 Content Specialists

Whilst technical authors are typically those in charge of the technical aspects of the work, an additional figure may be needed to ensure that the standards are delivered in compliance with the MDD drafting rules. In this context the role of Content Specialist was created for the DMRB project. The value of having experts in technical writing who help develop standards that are appropriate to a particular audience was also recognised in BSI PD 6612.

9.6.5 Sharing requirements

In principle, developing shared documents or requirements (for example between different asset owners) is beneficial to users as it helps reduce the variation in client requirements, increase efficiency for suppliers, enhance leverage of R&D and better enable transfer of solutions from other sectors, as also stated the Industry Standards Group's (2012) report. However, some potential issues may arise when developing shared documents or requirements. These emerged from the DMRB project (Highways England 2018c) and are listed below:

- Need to understand areas where sharing documents may be beneficial
- Limited control on the process
- Difficult to achieve consensus among stakeholders involved
- Difficult to implement due to the huge amount of resources required
- Longer time to develop documents
- Limited control on the document produced
- Need to identify the over-riding owner of the document
- Potential increase in complexity of documents

9.6.6 Transfer to the industry

Transferring advice contained in the DMRB to the industry (which, in this context, includes external publishers, trade/industry bodies and professional bodies) may provide significant benefits, particularly when dealing with content that evolves quickly and requires more efficient route to implementation or adoption. Nevertheless, from this project several potential issues emerged (Highways England 2018c), which are summarised in Table 9.9.

Table 9.9 Issues when transferring advice externally (Highways England 2018c)

External publishers
1. Difficult to control
2. Longer time to find information, which will be scattered across multiple documents
3. Longer time for publication of standards by other standards organisations
4. Inconsistency when splitting off sections from the DMRB
5. Additional costs for subscription to access to users
Trade/industry bodies
6. Limited control over the document
7. Conflict of interest due to the promotion of specific products or solutions
8. Longer time to find information, which will be scattered across multiple documents

9.6.7 Collaborative authoring

In Project 1 "Client technical specifications" presented in Chapter 7 it was noted that working on 'static' documents such as Word templates can be inefficient, particularly when the review and approval processes are characterised by numerous stakeholders and multiple copies and different versions of the same document are circulated, leading to confusion and sometimes re-work. On-line platforms could offer significant benefits for easier access and smart editing.

In the DMRB project an online tool was developed, which is called Collaborative Authoring and Review System (CARS), see also Section 9.3.6.2. CARS was launched in April 2018 and is currently used by all document authors working on DMRB documents. Feedback collected (see Section 9.3.7) demonstrates the value of CARS in supporting collaboration and acceleration of document production. It is worth noting that CARS is not just an authoring tool. It also represents the foundation to future proofing the DMRB as illustrated in the next section.

9.6.8 Technical Standards Enterprise System

One of the recommendations agreed by the Executive Committee of Highways England (see Section 9.3.5) was to future-proof the DMRB for advances in information technology. Early in the project Highways England recognised that an entirely new hosting platform for the documents was needed, which could support rapid development, publication and maintenance of the DMRB in the future. This cloud-based platform called Technical

Standards Enterprise System (TSES) is currently under development by a software company working under the direction of the WSP team.

The TSES will store all requirements, advice, supporting content (tables, equations & figures), background information, comments and feedback received, an archive of superseded documents, etc. which are currently digitalised using CARS, in a structured smart database. This will future proof the DMRB while facilitating future use of its content in alternative formats to the traditional printed/PDF form including XML.

There is scope for other documents sets to be incorporated in the TSES, thus creating a single, consistent repository of knowledge. In addition, work has now started to explore the strategies to integrate the TSES with rapid engineering applications to support human-aided design.

9.6.9 Agile approach to document development

Inefficiencies in the drafting process can be seen in two distinctive situations. First, there can be an ineffective management of stakeholders' expectations and users' needs, particularly when there are many stakeholders involved or frequent changes to requirements. Second, an unproductive interaction can emerge between members of the development team. This reflects on the circulation of multiple copies of the standard draft and the consequent difficulty in tracing comments, which ultimately has a negatively impact on the progress of the drafting work.

To overcome these two issues and streamline document development process, the application of the Agile approach was suggested by Highways England and a preliminary study was undertaken in the DMRB project. Broadly speaking, Agile is a methodology introduced in the software industry to allow frequent changes to goals and needs to be effectively embraced. It encourages engagement and communication within a development team (which comprises key people with relevant skills and knowledge) and between the development team and the client.

A key assumption in the Agile methodology is the unpredictability of the customers' requirements and priorities of the work needed to complete a task. Unpredictability is tackled by introducing adaptability and flexibility in the process and replacing pre-established plans (which can inhibit change) with incremental delivery in short time periods, called "sprints" (usually multiples of two weeks). These activities are supported by regular feedback from the customer, who can easily influence the process and accommodate specific, new needs (Stellman and Greene 2015).

Agile was applied to standards development "for its focus on continuous improvement to optimise collaborative working and making sure that a product (in this case, a document) meets user needs and is of the highest quality" (Highways England 2017c). Based on that, the standardisation process can be assimilated to a software development process (and more in general to a product development process) for two main reasons. First, standardisation requires appropriate collaboration and communication within the drafting team (i.e. the development team) and between the drafting team and external stakeholders. Second, the drafting process typically follows a series of iterations before a final document is produced and there is a need for more flexibility to prioritise the drafting work, respond to change and accommodate new proposals and needs.

A specific Agile methodology was adopted for the development process of some DMRB standards, i.e. Scrum. Scrum focuses on "self-organisation" and "collective commitment" (Stellman and Greene 2015), which are two essential requirements in the drafting process to avoid scope creep and significant rework in subsequent phases. As noted by Stellman and Greene (2015), there are three main roles in the Scrum methodology:

- the "Scrum Master", who ensures that the methodology is followed and that obstacles are removed where needed;
- the "Product Owner", who maintains and prioritises the "product backlog" of requirements and features of the final product. This person can be involved in the development process.
- the "development team", who is responsible for the day-by-day work.

Drawing together lessons learned from the DMRB project, personal involvement in a Scrum activity and the Scrum's activities proposed by Stellman and Greene (2015), the author has derived some general steps to apply Scrum to standards development. They are indicated in Table 9.10.

Table 9.10 General steps to apply Scrum to standards development

1. **Select a standard.**
   In principle, the approach can be applied to both new and existing standards.

	Where the standard to revise is straightforward, does not require significant changes and there are no major time constraints, traditional ways of drafting may be sufficient. In contrast, where standards are particularly complex, require input of multiple stakeholders and must be developed in tight deadlines, these standards could be targeted for the Agile approach.
2.	**Identify the Scrum Master.** This person needs not to be familiar with the technical content of the standard. Rather, he/she must have knowledge of and experience in the application of Scrum to support the development team.
3.	**Identify the Document Owner.** This person must be knowledgeable of the technical content and able to discuss with the development team about technical details. He/she may be involved in the drafting process if for example the document requires prompt inputs and feedback.
4.	**Create the development team with all the skills required to complete the task.** The team may include technical author(s), specific technical experts, peer reviewers and content specialists where available.
5.	**Define the timescale, i.e. the sprint.** Typically, the timescale of a sprint is multiple of two weeks: one week may not be enough to produce a final product; more than two weeks can reduce the focus of the team and cannot be available due to other work commitments. Important to avoid periods where participants have other pressing commitments.
6.	**Define the goal of the sprint.** The team discusses and agree with the Document Owner the final goal of the sprint. This may be the entire document (if small) or specific sections (if large).
7.	**Develop a product backlog, i.e. the list of tasks relevant to the drafting work.** The activities defined in the product backlog generally reflect the sections of the document and some additional activities, such as those related to the initial screening of the entire document and of specific sections, the involvement of specialists or peer reviewers, specific research activities, etc.
8.	**Define what is meant by "work done" for each activity.** The team defines the end of each task. An example of work done is the completion of a section.
9.	**Define time spent each day on the drafting work.** The development team agree the time spent each day on the drafting work. Time must be realistic given the existence of other activities that need to be undertaken in the workplace (for example to attend meetings or review emails received). This is particularly relevant for virtual Scrum (see Table 9.11).
10.	**Work together full-time for a fixed period, i.e. the sprint.** The team works together and achieves what they can within the pre-defined sprint following the principles of "self-organisation" and "collective commitment".
11.	**Have a daily scrum meeting.** Each day the Scrum Master, Document Owner and development team members hold a short discussion (not more than 15 minutes) to update each other on the status of the work against

	the product backlog. This short discussion focuses on: work done, blockers encountered, work to do the day after. If there are items that require more detailed discussions, these should be scheduled separately.
12.	**Hold a review meeting at the end of the sprint.** A sprint review meeting must be organised at the end of the sprint to (i) discuss the work done on completed tasks, (ii) plan future work by updating / modifying the backlog, or potentially (iii) finalise the document. Other stakeholders may be involved. After the first sprint, subsequent sprints may be carried out. Allocating a period of time between them (one month for example) may be beneficial to leave enough time to clear team's mind and refocus on the subsequent sprint. It may also be necessary due to other work commitment of participants.
13.	**Hold a retrospective** After the sprint the development team and the Scrum Master hold a retrospective to discuss emerging issues and figure out lessons learned relevant for future drafting work. The Document Owner may also attend. The retrospective can be carried out after the sprint review meeting too.

The steps in Table 9.10 are relevant to both co-located Scrum (i.e. all participants in the same location) and virtual Scrum (i.e. participants are in different location, but connected on an online platform). These two approaches were tested in two pilot studies in the DMRB project. Merits and demerits emerged are summarised in Table 9.11.

Table 9.11 Merits and demerits of co-located and virtual Scrum

Category of Scrum	Merits	Demerits
Co-located Scrum All participants are in the same location.	• More effective due to the physical presence of people.	• Participants may not be physically available for such a long amount of time. • Venues may not be available. • More expensive due to commuting of participants where working in different locations.
Virtual Scrum Participants are in different location, but connected on an online platform.	• Participants may work from different locations. • Specific venues are not needed.	• An effective online platform to connect participants is needed, but may not be available to all. • Less interaction between participants • More distraction from other activities related to day-by-day work.

Overall, the adoption of Scrum to standards development enabled the document development process to be reduced from many months to only several weeks (e.g. pilot on the DMRB document TD 17). According to the participants, it also provided two main benefits: a more gratifying drafting process and the feeling that the final document was of a higher quality thanks to the prompt feedback provided by relevant participants. Personal experience in drafting standards and observation of the work carried out by standards' writers reveal that introducing incremental delivery in short time periods and regular feedback would be beneficial to focus drafting effort and streamline document production, while elevating the standardisation work to a proper discipline and not as an activity undertaken peripherally to the day-by-day work.

A key limitation of the application of Scrum in the DMRB project resides in its limited adoption (only two pilots). Future work is needed to generalise the conclusions drawn, identify critical areas and provide more guidance in the application of Scrum to standards development.

9.7 Innovation, whole-life costs, construction and maintenance efficiency

The role of design standards in the context of innovation is critical. Standards can create the conditions that stimulate innovation, or they can restrict opportunity for innovation, depending on how content is presented, for example by allowing or inhibiting the use of novel or alternative solutions to meet performance requirements. This is a choice that can be made deliberately by the technical authors during the development process of a standard.

The role that the DMRB currently fulfils in enabling innovation and the features that would enable the future DMRB to achieve this role were explored in the consultation. Whilst most participants recognised that "*the future DMRB should have an important role in eliminating barriers to innovation*", there was no consensus as to how. That was demonstrated by different – and sometimes contrasting – views emerged among consultees. Some participants observed that the current DMRB neither encourage nor inhibit innovation. Indeed, they argued that innovation should be outside its scope as standards, by definition, should support common practice. Other participants argued that innovation should be a matter for guidance better placed outside or alongside the standards themselves. As a result, they suggested that the DMRB should follow, rather than lead, innovation. No comment was made on the role that technical authors have when drafting clauses.

The consultation enables general levers to innovation to be identified. These have been combined with findings from literature review and are presented in Chapter 11 for the framework development.

Consultees also recognised that design standards play a role in the discussion on whole-life costs, even though they do not control costs of construction and maintenance works, rate of return on investment and other variables that affect whole-life costing. It was observed that greater clarity of vision is required on what whole life actually means (e.g. 10 years, 50 years, 100 years, etc.) as the technical solutions developed may be significantly different according to the answer to this question. Consultees noted that delving deeper into this aspect is also relevant in the context of asset management and that opportunity to evaluate accurate whole-life cost should be provided.

It was observed that lessons from schemes such as the Design Build Finance Operate (DBFO) should be considered and that an exploration of the data captured on asset cost and performance should be carried out to support whole-life costing. However, it was noted that an approach more closely aligned with whole-life cost principles could work well with some forms of contract (such as DBFO schemes) and less well for others (such as shorter-term asset maintenance contracts).

Finally, consultees recognised that design standards can play an important role in supporting construction efficiency, quality and safety, as well as maintenance efficiency, even though they are not construction manuals and are not influenced by constraints imposed by contracts. The general findings emerged from the consultation are presented in Chapter 11 as they are relevant to the final framework.

9.8 Lessons learned

General lessons drawn from the DMRB project are listed in Table 9.12. They reflect the views of the author only and do not represent necessarily the perspective of WSP and Highways England.

Table 9.12 Summary of lessons emerged from the DMRB project

Topic	General lessons learned
Value of advice associated to requirements	Providing only general, high level requirements affects negatively on usability (and specifically understandability) of the document produced, as well as consistency of solutions developed. Advice can be important to flag the attention to technical issues happened in the past that the supply chain could not be aware of.
How much advice should be provided	The amount of advice depends on the level of competence and expertise expected from the target audience and the existence of other documents providing relevant guidance material. In the latter case cross-referencing should be preferable.
Distinction between requirements and advice	Making a clear distinction between requirements and advice, and between different types of requirements and advice, can be done by using appropriate verb forms. This requires standards' writers to decide what the key technical requirement is, on which control is needed and when opportunities to deviate can be given.
Performance-based requirement (PBR)	The development of PBRs for assets requires a specific mind-set for the identification of the performance objectives, the expected performance levels, and the criteria and methods for verifying that the final outcomes or outputs meet the agreed performance objectives. Development and implementation of pure (high-level) performance-based provisions require an in-depth understanding of the following issues: procurement implications; contractual liability and risk transfer; fit for purpose and insurance issues; on-going monitoring of performance; maintenance; time and cost implications; specific competence and skills. For technical provisions to be expressed in a manner that makes the intended outcome or the performance requirements clear to the user, a suitable level of detail should be provided. The performance requirements should be accompanied, where possible, by methods as a means to meet the requirements ('mixed' PBRs).
Risk-based requirements	Introducing risk-based requirements is not an easy task and requires considering a number of issues such as the subjective nature of risk, contractual issues and risk aversion.
Purpose	Understanding the purpose of a standard is the first step to focus drafting efforts. This affects the audience of the document, its scope and coverage, and may also influence financial and environmental considerations, as well as buildability and innovation.
Primary target audience and competence	Defining a primary target audience and related level of competence is a fundamental aspect to focus drafting effort.
Users' needs	Do not prejudge what users want and actively consult with them.
Drafting rules	Having in place clear and unambiguous drafting rules is essential.
Content specialists	Technical specialists may require to be supported by experts in editing and content presentation to ensure that the text is coherent, consistent and accurate.
Collaborative authoring	Online collaborative authoring and review systems are essential to

Topic	**General lessons learned**
	accelerate the document drafting process.
Technical Standards Enterprise System	Documents should be future proofed for advances in technology to enable an efficient management throughout their life-cycle and to facilitate future use of their content in alternative formats to the traditional printed/PDF form including XML.
Agile approach	The agile approach, with its focus on continuous improvement to optimise collaborative working and make sure that the standard meets agreed needs and is of the highest quality, is a useful tool to standards drafting. However, its implementation may not be straightforward.
Innovation	Design standards may represent barriers or levers to innovation. A more in-depth exploration of this topic is needed.
Whole-life costs	The concept of whole-life cost in the context of design standards should be better explored.

9.9 Conclusions

The DMRB is an exceptional suite of standards due to the large number of documents and stakeholders involved, and the variety of information that it contains (from design to management of assets on the UK motorway and all-purpose trunk roads).

A rigorous research programme was employed to (i) appreciate the needs and priorities of different categories of stakeholders and assess potential tensions, (ii) develop a shared understanding between key users of the DMRB and explore and externalise areas of disagreement, (iii) obtain consensus between decision makers on the recommendations to improve the usability of the DMRB, and (iv) translate the recommendations into practical actions.

Drawing upon the work done in the Eurocodes project (particularly in terms of the strategies to explore stakeholders' expectations and users' needs), the DMRB project has provided valuable insight into the practical challenges associated with the enhancement of the usability, structure and content of an existing suite of standards with national impact and international adoption.

Lessons have been drawn from the DMRB project to enhance both the content of the standards and the standardisation system, and will be used in Chapter 11 for the framework development.

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Chapter 10

Design standards as learning frameworks

Part of the work presented in this chapter has been published in the white paper Tann et al. (2016) as personal contribution of the author. The study presented in this chapter also builds upon the assignment submitted by the author to the University of Bristol for her independent coursework on Learning Analytics & Engineering Leadership, indicated hereinafter with Angelino 2016.

10.1 Introduction

Design problems are (a) typically[1] ill-defined and ill-structured in terms of goals and actors (Goel and Pirolli 1992), (b) characterised by many interacting components, as well as environmental and social influences (Hastings 2004), (c) often conceived with ambiguous objectives and incomplete information, and (d) generally solved using imperfect models with uncertainty being a key issue (Dym et al. 2005). In this context, the design of civil and structural engineering works is a complex task and designers require specific capabilities to deal with it (Dym et al. 2005).

Different designers have different skills, as seen in Chapter 6, and their approaches to design are a function of their knowledge and experience. This aspect also emerged in the Eurocodes and DMRB projects (Chapters 8 and 9 respectively), where the importance of targeting standards to specific competence levels of designers was acknowledged.

However, there does not seem to be any fundamental study which links the mental processes of learning and designing of different designers due to their skills and capabilities to the way design standards are interpreted. This is surprising as reader's learning is one of the key

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[1] For the sake of completeness, design problems can also be 'well-defined', i.e. those whose solutions are within a certain domain of possibilities (Gero and Maher 1993).

purposes of writers along with accelerating reading speed and efficiency and supporting reader's judgment (Klare 2000). Moreover, the value of focusing on learning has also been recently emphasised by the Royal Academy of Engineering (Lucas et al. 2014), which flagged the importance of developing future "engineer-learners".

A first attempt to explore the value of introducing a "learning" component in standards development has been made by Tann et al. (2016), where the concept of "learning-orientated design standards" was introduced. It was argued that a learning-orientated design standard "would focus on designers and their diverse learning power and knowledge, and would be targeted to accelerate the way designers learn" (Tann et al. 2016). The author has also explored this concept and its relevance to the discussion on the strategies to develop better design standards in more detail in subsequent work (Angelino 2016).

The purpose of this chapter is to review and move forward the arguments presented in Tann at el. (2016) and Angelino (2016) by means of additional literature review and a pilot experiment. In Section 10.2 a flavour of design research is presented with an emphasis on the concept of designing and its link with the learning process. In Section 10.3 the concept of learning-orientated design standards is examined. An overview of the state-of-the-art of the contemporary learning theory is provided to set the context of this research. A methodology to develop and test models of learning-orientated design standards is also proposed. Section 10.4 presents a pilot experiment carried out with practicing engineers to evaluate the feasibility of a future full-scale study exploring this concept more extensively. A discussion on the findings of the pilot experiment and their significance in the context of developing better design standards for the construction industry is also provided.

10.2 Designing as a learning process

10.2.1 Definition

A vast literature exists on design research as evidenced by the papers published in *Design Studies*, a comprehensive and interdisciplinary journal on design research with a focus on the process of designing. Despite the wealth of publications, a single definition of design does not exist. Indeed, Love (2002) argued that "key terms 'design', 'design process', and 'designing' have different meanings in different domains, and are also used in different ways by researchers in the same domain". Evbuomwan et al. (1996) noted that different definitions reflect the various viewpoints of the proponents. In Table 10.1 some key definitions and attributes of designing are presented.

Table 10.1 Definitions and attributes of design in literature

Definitions	Source
"It can refer to a process (the act or practice of designing); or to the result of that process (a design, sketch, plan or model); or to the product manufactured with the aid of a design (designed goods); or to the look or overall pattern of a product ('I like the design of that dress')".	Walker (1989)
"A goal-oriented, constrained, decision making, exploration, and learning activity, that operates within a context that depends on the designer's perception of the context".	Gero (1990)
"A social process requiring the participation of different individuals having different competencies, responsibilities and technical interests. Each participant sees the object of design differently, in accord with the paradigmatic core of their discipline, and their position of responsibility."	Bucciarelli (2003)
"Design refers to a process; this process is goal-orientated; the goal of design is to solve problems, meet needs, improve situations, or create something new or useful".	Friedman (2003)
"A systematic, intelligent process in which designers generate, evaluate, and specify concepts for devices, systems, or processes whose form and function achieve clients' objectives or users' needs while satisfying a specified set of constraints".	Dym et al. (2005)
Attributes	
Imagining, presenting and testing.	Zeisel (1981)
"Needs, requirements, solutions, specifications, creativity, constraints, scientific principles, technical information, functions, transformation, and economics". Evolutionary process; knowledge-based/exploratory task; investigative process; rational process; decision-making process	Evbuomwan et al. (1996)
"Art, not a science; problem solving; decision making; creativity and imagination; heuristic search; learning; evolution; selecting suitable patterns and adjusting; dealing with people; team-building; collecting and processing data; negotiating to achieve a satisfactory solution; optimizing; transferring and transforming knowledge; drawing and calculating; directing, leading, organizing; considering the bottom line of costs and profit; satisfying needs, satisfying the customer; ethical and professional conduct."	Hubka and Eder (2012)

10.2.2 Attributes of designing

In this thesis the word 'designing' is used to emphasise the designer's mental process and the definition provided by Gero (1990) is adopted:

> "A goal-oriented, constrained, decision making, exploration, and learning activity, that operates within a context that depends on the designers perception of the context".

This definition has been chosen as it summarises the key attributes of designing, which are outlined below.

1. **Designing is a multi-stakeholders process**. Designing is a purposeful process led by specific goals. The plural of 'goal' is used to emphasise that designing entails the involvement of individuals having diverse competencies, skills and technical interests, which explains the imperfect closure of the goals stated (Wade 1977).

2. **Designing is a constrained process**. Designing operates within specific boundaries or constraints the design must "satisfice" (Simon 1996). Gero and Maher (1993) suggest that these are generally drawn by the environment, the social actors involved, the "knowledge of the knowledge domain" and personal experience.

3. **Designing is a decision-making process**. The designer is required to make decisions and explore differing and sometimes competing solutions following a rational process to check and test the proposed solutions against specific client's needs and expectations.

4. **Designing is an exploration process which enables different design problems to be addressed**. Despite some variability in terminology[2], there is a general acceptance in literature on the classification of design problems into well-defined and ill-defined according to whether (i) the domain of possibilities to explore is fixed or not and (ii) the solutions are 'routine' or 'non-routine'[3] for the level of novelty embedded in the design process (Gero and Maher 1993; Lawson 2005). Non-routine designs are further classified into innovative and creative designs. Definitions and examples for routine and non-routine designs are provided in Table 10.2.

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[2] Howard et al. (2008) compares the terms used by different authors on design problems/outputs.

[3] Evbuomwan et al. (1996) also mention 'redesign', which involves the modification of an existing design to meet new requirements or enhance its performance under current requirements.

Table 10.2 Classification of design problems (from Gero and Maher 1993)

Category	Sub-category	Definition	Example in the context of civil and structural engineering
Routine designs		Ones that are not fundamentally different from designs developed previously in their category. Routine designs exhibit same properties but with different magnitude.	Design of a reinforced concrete beams subject to specific actions and with a defined span, which generally result in a rectangular cross-section with some reinforcement.
Non-routine designs		Ones that are fundamentally different from designs developed previously in their category.	
	Innovative designs	These use values of the design variables that are outside the common range.	A designer may choose to design a reinforced concrete beam much deeper than usual to emphasise its load bearing function. The resulting beam will present the same design variables as for a typical beam, but unusual values.
	Creative designs	These introduce new design variables, which are novel, useful and valuable.	The introduction of new construction materials, which enable conventional constraints to be overcome and provide new benefits, can be considered a creative design.

5. **Designing is a learning process.** Designing has many similarities with the general area of human problem solving and is both "a mechanism for learning and in itself a learning process" (Dym et al. 2005). The design process is spiral and evolutionary, involving learning about features emerging from the design process and changing action as a result of the learning process.

It is possible to draw some direct links between the first four attributes of designing and design standards. Specifically, one of the roles of design standards is to support a shared understanding between different stakeholders (attribute 1) as discussed in Chapter 5. Moreover, design standards are an example of constraints[4] of the design process (attribute 2) as they bound the range of options available to designers to fulfil their everyday tasks as noted by Goel and Pirolli (1992). In doing so, they also support designers in making

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[4] .

decisions (attribute 3) to design safe structures. For the sake of completeness, design standards are also an enabler of the design process as a key means to reduce uncertainty in design. Indeed, the lack of design standards or standards that are too lax "can introduce errors leading to failure and accidents" (Industry Standards Group 2012) and may lead to over-conservatism in design. In addition, design standards contain a variety of provisions which aim to support designers in tackling different design situations – from routine to non-routine – safely (attribute 4).

However, how and to what extent design standards support the learning process of different categories of designers and their learning capabilities (attribute 5) requires specific conceptualisation. This aspect is examined in the next section.

10.3 Learning-orientated design standards

10.3.1 Learning and mental models

Learning is a complex activity characterising human beings. There is no consensus on what learning is (De Houwer et al. 2013). This issue was explored in Angelino (2016) and the use of the following definition was proposed:

> An increase, through a functional environmental interaction, of problem-solving ability

This definition combines Washburne's (1936) and Lachman's (1997) definitions of learning. It has been adopted in this study for its focus on the value of experience and practice (which represent the functional environmental interaction) and the enhancement of the ability of an actor to solve problems and achieve goals. The components of learning were also investigated in Angelino (2016). The key aspects were taken from Bransford et al. (2000) and are summarised below to set the context for the concept of learning-orientated design standards.

The first component of learning is *understanding*, which entails more than the simple accumulation of knowledge gained through years of experience. It requires: (i) solid factual knowledge; (ii) understanding facts within a wider conceptual structure, which allows using the acquired knowledge in new situations and more rapidly; (iii) organising acquired knowledge in such a way that can be easily retrieved and used. The second component of learning is *knowing* (i.e. possessing knowledge), which represents the ability of remembering, reasoning, solving problems and acquiring new knowledge based on prior knowledge, skills and beliefs. The third component is *active learning*, which refers to people's abilities to take control of their own understanding by monitoring their level of mastery (e.g. using self-assessment and personal reflections on areas that were successful and those which were not and would require improvement) and recognising when they need more information.

The importance of understanding how engineers learn is at the heart of some recent debates, particularly in professional organisations. In its vision for the future of American structural engineers, the Structural Engineering Institute (2013) has acknowledged the importance of transforming the US engineering colleges taking on board the vast knowledge and research on how people learn. Equally, in the UK the Royal Academy of Engineering (Lucas et al. 2014) has recognised the importance of focusing engineering education on learning and, specifically, on the distinctive ways of thinking, acting and learning by engineers, called "engineering habits of mind".

The concept of habit of mind is similar to the concept of "mental model", which is an individual's mental representation of the world and of the relationships between its parts (Forrester 1971; Jones et al. 2011). Johnson-Laird (1983) argued:

> "Our view of the world is causally dependent both on the way the world is and on the way we are. [Thus] all our knowledge of the world depends on our ability to construct models of it".

Mental models are often called "worldviews". However, a key difference exists between them. Worldviews are in general socially and culturally embedded in the norms and structures of a particular society, whereas mental models are specific to an individual, thus they refer to his or her personal sphere.

10.3.2 Characterisation of learning-orientated design standards

Broadly speaking, current design standards support a "learning-as-script" approach in Deakin Crick's (2014) terms, where knowledge is prescribed and transmitted from experts to the engineering community (Angelino 2016). Different standards writers have different mental models of what a design standard should provide. For example, there are those who provide detailed information versus those who believe that only high-level principles should be given. Whichever approach standards writers take, ultimately design standards influence the worldview of the engineering community as a whole and the mental models of civil and structural engineers as individuals.

In principle, a learning-as-script approach supports the achievement of necessary levels of safety, thus cannot be considered wrong. However, this approach can lead to unduly prescriptive design standards. In complex and dynamic situations such as designing civil and structural engineering works, the learning-as-script approach would require a degree of adaptation. To overcome this issue, in the last two decades the research community has devoted particular attention to the development of performance-based design approaches (see also Chapter 9). They provide more flexibility to design appropriate technical solutions insofar as they focus on final outcomes rather than prescribed inputs.

Set against this context, to allow for more flexibility a further step would be to understand and characterise the learning capabilities of different categories of designers and develop design standards that explicitly engage with the processes of understanding, knowing and active learning (Tann et al. 2016; Angelino 2016). Arguably, such design standards would provide the right level of information to different audiences. Designers would potentially perceive less mental constraints as the standard produced would match their capabilities, thus they would be able to better manage risk and uncertainty and perhaps access and explore a wider and more innovative and creative design space. Such standards have been called "learning-orientated" design standards (Tann et al. 2016).

10.3.3 Impact of the learning power on designers' learning

Developing learning-orientated design standards is far from straightforward. A key issue is that every individual is characterised by a personal power to learn, called "learning power". It enables data and information to be identified, selected and operated (Crick et al. 2016) and the flow of information to be controlled over time (Siegel 2012; Deakin Crick et al. 2015). Deakin Crick et al. (2015) identify three elements of learning power: (1) "mindful agency" and its four active dimensions; (2) a "relational component"; (3) an "orientation towards learning". They are outlined below and adapted in the context of designers.

Mindful agency refers to the core ability of designers to be agent of their own learning (Deakin Crick et al. 2015). This can be seen in the ability to manage the learning process and personal feelings when dealing with specific challenges, as well as to be proactive towards learning.

The four active dimensions associated with the mindful agency are (Deakin Crick et al. 2015): (i) *creativity*; (ii) *sense-making*; (iii) *curiosity*; (iv) *hope and optimism*. In the context of designers these dimensions reflect on their imagination and intuition, their attitude towards risk-taking, their ability to make connections between themes, the perception of limited understanding, and the perception of having the ability to achieve a specific objective successfully by following a chosen path.

The "relational component" (Deakin Crick et al. 2015) refers to the relation between the designer and other people. Broadly speaking, it can be seen in their dependence on or collaboration with other designers in solving problems, and in a sense of belonging to a team. Finally, the "orientation towards learning" (Deakin Crick et al. 2015) refers to the openness of designers to learning, which in turn reflects on their attitudes towards risk and uncertainty.

10.3.4 Proposed methodology

In order to develop and test models of learning-orientated design standards addressing the learning power of different categories of designers, a six-step methodology was proposed in Angelino (2016). It has been refined based on more recent reflections carried out by the author. An eight-step methodology is proposed in this chapter as outlined below:

Step 1: Identification of specific categories of designers.

Step 2: Development of different versions of a design standard characterised by different levels of information (new step).

Step 3: Preliminary exploration of the correlation between category of designers and different versions of the standard (new step).

Step 4: Characterisation of the design process as a function of the design standard being used.

Step 5: Characterisation of the learning power of different categories of designers in relation to the design standard being used.

Step 6: Based on the learning capabilities of different categories of designers, identification of the following key aspects: (i) points in the design process where key information should be provided for all categories of designers to meet the core purposes of design standards (see Chapter 5); (ii) points where flexibility should be provided to support innovative and creative solutions (see Table 10.2), especially for more experienced designers; and (iii) points where more guidance is needed (more detailed step compared to Angelino 2016).

Step 7: Translation of this work into practical steps, which can be used by standards writers to draft and structure design standards that reinforce and accelerate the learning power of specific categories of designers.

Step 8: Exploration of relevant implementation strategies, for example smarter content management system (see Chapter 9) which can enable filtering systems and metadata associated with clauses to be included (new step).

10.4 Pilot experiment

A pilot experiment has been carried out to start exploring Steps 1 to 3. This represents a novel contribution of the author to the discussion on learning-orientated design standards.

10.4.1 Hypotheses formulation

A vast literature exists in contemporary learning theory and engineering education research on the study of the design process, the characterisation of the real-world engineering design expertise and the results of successful learning (e.g. Lawson 2005; Mehalik and Schunn 2007; Cross 2006; Sanders 2006; Atman et al. 2007). Specifically, this literature explores the differences between experts and novices on their approach to learning and designing. Table 10.3 illustrates some distinguishing features of the experts' approach as derived by Bransford et al. (2000), which make experts more inclined to use what they have learned to manage and solve problems.

Table 10.3 Experts' features (from Bransford et al. 2000)

1. Experts see relationships or discrepancies between parts and develop "sensitivity to patterns of meaningful information that are not available to novices".
2. Experts' understanding allows them to notice, interpret and extract an in-depth meaning from data and information, whilst organising and representing this information meaningfully.
3. Knowledge retrieval is relatively "effortless".
4. Experts' knowledge is typically organised around concepts or "big ideas", which support their decision-making process in specific contexts (Chi et al. 1981). Novices tend to focus on formulas or seek for specific answers to be used in specific problems, rather than thinking in terms of major principles and laws (Larkin 1983).
5. Experts' knowledge is generally "conditionalised", i.e. well-connected to the domain in which it is relevant (Simon 1980). This is important insofar as knowledge that is not conditionalised is not activated.

6.	Experts' deep understanding transforms factual information or general data into "usable knowledge".

Being these intrinsic features of experts, the author argues that they can be used to start exploring the differences between experienced engineers and novices in their approaches to design and, ultimately, in their use of design standards. Based on Table 10.3, six hypotheses have been formulated which have been tested in the pilot (see Table 10.4).

Table 10.4 Hypotheses for the pilot experiment

H1	Novices prefer detailed and step-by-step information.
H2	Experienced engineers refer to major principles and laws much more than novices.
H3	Experienced engineers prefer design standards that provide only high level principles.
H4	Experienced engineers prefer flexible tools to apply.
H5	Experienced engineers have a clearer idea of what a design standard should provide to fill knowledge gaps than novices have.
H6	Novices find it hard to retrieve relevant knowledge to carry out the design task without the support of a detailed design standard.

10.4.2 Phases

The pilot was a study of practitioners who individually were asked to solve a design problem, i.e. the verification of a concrete beam for bending and shear (see Annex C). Three different versions of a design standard were developed, which were characterised by an increasing level of details and information. Version 1 was developed by the author by providing one high-level design principle: "*The design of a beam shall be such that it is safe, serviceable, durable and robust*". Version 2 was the English translation of a chapter of the Italian Technical Norms for Constructions (NTC 2008), which are based on EN 1992-1-1 but provide much less details. Version 3 was the old British standards BS 5400-4 for concrete design, which are more detailed than the other two.

The pilot study consisted of five phases as reproduced in Annex C. In Phase 0 participants were asked to reflect and write down the key steps necessary to carry out the calculations, the fundamental principles or key aspects to consider in the design of a concrete beam, and their expectations on what the design standard should provide as a minimum to enable the design to be carried out. Participants were not allowed to read the versions of the standard provided by the author. Once the questions were answered, they were asked to comment on their feelings (frustration, satisfaction, etc.) on this preliminary activity. Subsequently, they were invited to move on to Phase 1, but they were forbidden to go back to the previous phase once moved to the next stages.

In Phase 1 participants were allowed to open Version 1 of the standard and answer five questions. Once completed, they were allowed to move to Phase 2 where Version 2 of the standard was open and five questions were provided. In Phase 3 participants were asked to review Version 3 of the standard and answer one question. In the final stage, Phase 4, participants were asked to reflect on the entire session and answer three questions. Annex C provides the questions for each phase. Participants had one hour to complete the task and were asked to provide as many details as possible at each phase.

10.4.3 Data collection

To contextualise the findings participants to the pilot were asked to provide the following information: age; nationality; degree and country where it was awarded; current role in the company; years of working experience; details of the past working experience. Participants were classified into two categories according to the years of working experience and design practice: (1) novices with less than 5 years of design experience; (2) experienced engineers with more than 5 years of design experience.

Participants were selected from a large UK consultancy company with over 35,000 employees. They were 10 civil engineers distributed as follows: 7 novices, from 1 to 3.5 years of design experience; 3 experienced engineers, one with 7 years of design experience and the remaining two with more than 15 years of design experience. Of the novices group, five had a Master's Degree, one had a BEng and one had PhD. Of the experienced engineers, two had a PhD and one was doing an EngD. Nine participants had gained their degree in the UK, one in another European country. Nine participants were men and one was a female.

10.4.4 Analysis and results

Due to the small and non-representative sample size, statistical analyses have not been carried out. Data were analysed by reviewing responses to the questionnaire and identifying patterns against the six hypotheses presented earlier. Findings from the pilot are presented in Table 10.5.

Table 10.5 Findings from the pilot experiment

Hypothesis		Confirmed?	Comment
H1	Novices prefer detailed and step-by-step information.	Yes	Novices tended to prefer detailed and step-by-step information. They found background information to requirements very important, as well as formulae.
H2	Experienced engineers refer to major principles and laws much more than novices.	Yes	This was demonstrated by the extensive treatment of major principles and laws in the answers of experienced engineers.
H3	Experienced engineers prefer design standards that provide only high-level principles.	No	Providing only high-level principles was not appropriate for any of the participants. The reasons for that were: (i) requirements set out as high-level principles can be hard to follow without additional guidance material, which provides "*the benefits of the wisdom of the engineering community*" (comment from one of the participants); (ii) a lack of consistency in the design solutions proposed can emerge; (iii) there is a need for strong reliance on designers' skills; (iv) it can be difficult to achieve an independent consensus by checkers (e.g. for complex structures belonging to category 3 checking); (v) there is a risk of designing unsafe and more costly structures.
H4	Experienced engineers prefer flexible tools to apply.	Yes	This emerged from the comments made on Version 3 of the standard, which was considered to be unduly detailed and prescriptive.
H5	Experienced engineers have a clearer idea of what a design standard should provide to fill knowledge gaps than novices have.	Yes	This was demonstrated by the answers to the first set of questions, which clearly stated the kind of information and data needed to carry out the design task.
H6	Novices find it hard to retrieve relevant knowledge to carry out the design task without the support of a detailed design standard.	No	This statement was not always true. With same design experience, their ability to retrieve relevant knowledge depended on their education path (see further insights below).

Further insights also emerged from the pilot experiment. Most of participants relied on design standards much more heavily than they actually envisaged. Design process appeared to be closely interlinked with the design standard. Some comments provided by participants are reproduced hereinafter:

> Tricky to separate thoughts on fundamental principles from knowledge of design codes.
>
> [When thinking about design process it is] hard not to be influenced by the real standards.
>
> Expectations are skewed by familiarity with existing standards.

Most of the participants also recognised that the design task required a lot of effort without a design standard as a guidance document. Moreover, several participants suggested including more pictures and tables to guide designers, not only for clarity and better navigation, but also for equality and diversity reasons (difficulty in reading and following long sections without visual aids).

The pilot experiment also revealed that selecting and providing specific content can be misleading to users where not appropriately balanced. It was observed that sometimes "*no information is better than incomplete information, which can be badly applied* [particularly] *by inexperienced users who might rely on what is given without thinking about limitations*". Furthermore, the pilot experiment showed that clear boundaries should be introduced between what goes in a design standard and what instead should be provided into other publications, such as designers' guides or textbooks.

While recognising the importance of defining a target audience for the overall document, some participants also observed that in reality different design tasks may have different audiences, for example the design of a beam is typically carried out by graduates rather than experts, conversely complex design solutions are typically designed by experts. Therefore, it was noted that it would be relevant to consider not just the audience of the overall standard, but also of the specific design being carried out.

Finally, the pilot experiment revealed that classifying designers only on the basis of the number of years of working experience can be misleading. The level of education is another important factor to consider. Indeed, although novices had similar number of years of working experience, those with higher degree (MEng) were generally more reflective in their approach to design and use of the standard.

10.4.5 Limitations and future work

A key limitation of this pilot was the small number of designers involved. To infer generalisable conclusions a representative sample of practitioners must be involved. Yet, the aim of the pilot was not to derive final results, rather to carry out an initial exploration of the first three steps of the methodology and delve deeply into the concept of learning-orientated design standards.

The findings from the pilot could be used as a starting point for future experiments. These should be extended to a larger set of participants, with an appropriate distribution of practitioners. It is suggested to consider three categories: (1) novices with less than 5 years of design experience; (2) senior engineers with 5 to 10 years of design experience; (3) experts with more than 10 years of design experience. Designers should be selected across multiple companies and consideration of different educational paths should also be given to contextualise the findings.

10.5 Conclusions

The process of design can be described as a learning process, which is affected by a number of factors including knowledge, skills and experience of designers. Civil and structural engineers have specific mental models and learning power, which influence the way they use design standards.

Gaining a better understanding of designers' learning capabilities (i.e. "learning power") and their impact in the way they use design standards would be beneficial to both enhance these documents and develop more "learning-orientated" design standards. Such standards have been defined as user-orientated design standards, which consider explicitly how designers with differing levels of experience and expertise think, learn and design.

Bringing standards development into harmony with the new discoveries about how the human brain learns is a challenging task and would require specific work. A preliminary pilot has been carried out to start this exploration and learn some initial lessons. Future work in this area will include a full-scale experiment with a large number of designers. This would enable such a novel area to be further explored as well as feedback lessons to the engineering and standardisation communities.

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Part 3 Findings and conclusions

Chapter 11

A framework for better design standards

11.1 Introduction

This thesis has taken an interpretative perspective (see the methodology in Chapter 4) to explore what good design standards are and how better design standards can be developed. Theoretical explorations (Chapters 6 and 10) and practical work on live projects (Chapters 7, 8 and 9) revealed that the development of design standards is a complex socio-technical problem due to the existence of a variety of intertwined factors. Having a clear understanding of these factors and their relationships is crucial to managing their complexity and producing better design standards.

In Chapter 6 some preliminary features of better design standards were proposed. They reflect learning from literature and a qualitative study carried out with key users and stakeholders. These features have then been tested against the themes emerged from the live projects (Chapters 7, 8 and 9) and the theoretical work examined in Chapter 10. It is worth noting that, while the subjects of the live projects have been diverse, general lessons and common themes emerged and have provided valuable practical insights into the research questions addressed in this study.

This chapter consolidates learning and evidence from the previous chapters to provide a definition of good design standard and to produce a practical framework, which can help standards' writers in developing better design standards for the construction industry. This chapter also synthetises the role of design standards in the context of innovation and touches upon their role in supporting efficiency of solutions developed as emerged from Chapters 8 and 9.

11.2 Definition of good design standards

The findings of this research suggest that developing a single definition of good design standards is not only difficult, but also inappropriate for four main reasons.

First, different stakeholders have diverse perceptions of what good design standards are. Hence, in principle, different and sometimes conflicting definitions of good design standards might be possible to suit different actors. This aspect emerged primarily in the Eurocodes project (see Chapter 8) and led to the development of statements of intent for different categories of stakeholders (see Figure 8.9). This would align with Tayi and Ballou's (1998) claim that data quality can be difficult to determine when multiple users with differing quality data requirements are involved.

Second, design standards fulfil several roles as examined in Chapter 5 (see Table 5.4). Each of them could be rephrased into a perfectly valid definition of good design standard.

Third, the exploration presented in Part 2 of this thesis shows that a variety of aspects are involved when seeking to develop good design standards or, similarly, when trying to avoid the production of 'bad' design standards. They span from the quality of the document to the quality of the standardisation system.

Fourth, the exploration presented in Part 2 reveals the existence of numerous tensions in the development of design standards, including:

- the need to balance safety and economy in civil and structural engineering works, thus not compromising long-term performance and appropriate whole-life cost;
- the desire of having simple and not unduly complex technical provisions, whilst not making them too conservative (thus compromising cost effectiveness and competitiveness of the technical solutions developed);
- the aspiration to make technical provisions flexible enough to address the needs of users with different expertise, whilst not making the standards more complex;
- the aspiration to provide clear provisions for common design situations, whilst not inhibiting experts from applying their knowledge and deploying advanced methods of analysis;
- the desire of providing current good practice, whilst not inhibiting technological developments and the introduction of new approaches;

- the attractiveness of updating design standards frequently versus the users' desire for stability;
- the desire of streamlining the standard development process, whilst not compromising accuracy and ensuring adequate peer review of the document produced;
- the importance of balancing mandatory and advisory provisions, as well as performance-based and method-based requirements;
- the need to achieve a compromise between conciseness and comprehensiveness in technical provisions.

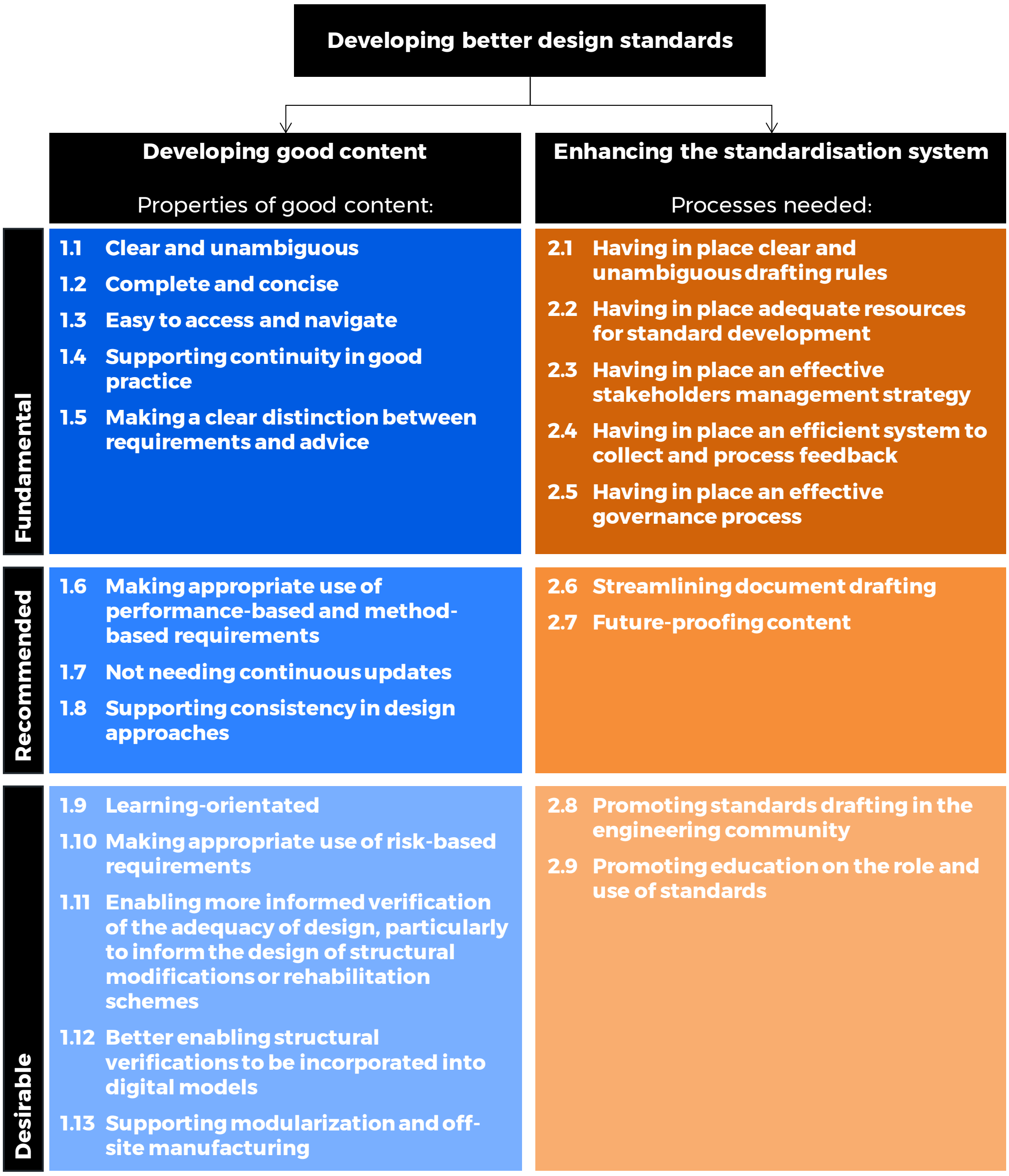
A definition of good design standards should cater for these tensions and, to be meaningful, should also help manage those. Therefore, one definition of good design standards would be either too narrow (when focusing only on one aspect) or too complicated (when trying to cover multiple aspects).

These considerations would align with Reeves and Bednar's (1994) acknowledgment of the difficulty in establishing a single definition of quality and the value of developing multiple definitions or introducing "multiple attributes or dimensions accounting for different aspects", as stated by Tayi & Ballou (1998) for the quality of information.

Following this line of thinking the author has not developed a single definition of good design standards. Instead, it is argued that the quality of design standards is best described by introducing a holistic framework which (i) incorporates the attributes of good and easy to use design standards emerged from Part 2 of this thesis and (ii) enables challenges to be managed, while helping navigate and overcome identified tensions by means of specific strategies.

11.3 Framework

The framework for enhancing the quality of design standards proposed in this thesis is made up of two components as shown in Figure 11.1. The first focusses on the content of design standards and its properties. The second deals with the standardisation system and the processes needed to support the development of better design standards. These two components have been disaggregated into "fundamental", "recommended" and "desirable" sub-components according to whether they are necessary, highly recommended and potentially appropriate to develop better design standards.



Developing better design standards

	Developing good content Properties of good content:	**Enhancing the standardisation system** Processes needed:
Fundamental	**1.1 Clear and unambiguous** **1.2 Complete and concise** **1.3 Easy to access and navigate** **1.4 Supporting continuity in good practice** **1.5 Making a clear distinction between requirements and advice**	**2.1 Having in place clear and unambiguous drafting rules** **2.2 Having in place adequate resources for standard development** **2.3 Having in place an effective stakeholders management strategy** **2.4 Having in place an efficient system to collect and process feedback** **2.5 Having in place an effective governance process**
Recommended	**1.6 Making appropriate use of performance-based and method-based requirements** **1.7 Not needing continuous updates** **1.8 Supporting consistency in design approaches**	**2.6 Streamlining document drafting** **2.7 Future-proofing content**
Desirable	**1.9 Learning-orientated** **1.10 Making appropriate use of risk-based requirements** **1.11 Enabling more informed verification of the adequacy of design, particularly to inform the design of structural modifications or rehabilitation schemes** **1.12 Better enabling structural verifications to be incorporated into digital models** **1.13 Supporting modularization and off-site manufacturing**	**2.8 Promoting standards drafting in the engineering community** **2.9 Promoting education on the role and use of standards**

Figure 11.1 A framework for developing better design standards

The following criteria have been used to place properties and processes into the “fundamental”, “recommended” or “desirable” category:

- the fundamental properties and processes are necessary to develop better design standards as emerged from the contextual information provided in Chapter 2, the theoretical work presented in Chapter 6 and all live projects examined in Chapters 7, 8 and 9;

- the recommended properties and processes have been suggested for their positive impact on the quality of the standard and the efficiency of the standardisation as emerged from some of the live projects examined in Chapters 7, 8 and 9;

- the desirable sub-processes reflect potential future directions in design standards development to be further explored; these emerged from the theoretical work presented in Chapter 6 and some of the live projects, as well as from personal reflections of the author based on discussion with practitioners, clients and standards' writers.

For each property and process, summary tables have been produced and are presented in the following sections. They contain: the strategies for their management and related sources (i.e. whether they were derived from theoretical or practical work); observations on potential challenges to fulfilling the strategies; potential solutions to overcome or minimise them. To emphasise the rigor and depth of the empirical ground of the framework, the source of the strategies is indicated using the following notations:

- T - theoretical work presented in Chapter 6 and Chapter 10;
- P - practical work:
  - P1 for the client technical specifications project (Chapter 7);
  - P2 for interim advice on structural bearings design (Chapter 7);
  - P3 for the PAS 8812 on temporary works design (Chapter 7);
  - P4 for the Eurocodes project (Chapter 8);
  - P5 for the DMRB project (Chapter 9).

11.3.1 Properties of good design standards

There are five fundamental properties of good design standards as shown in Figure 11.1. They are "fundamental" insofar as:

- clear (**1.1**), complete (**1.2**) and easy to navigate (**1.3**) requirements have a direct impact on the quality and usability of the document;
- supporting continuity in good practice (**1.4**) is a core purpose of design standards since knowledge acquired and promulgated through a standard over years of successful applications must not be abandoned without careful consideration;

- having design standards which make a clear distinction between requirements and advice (**1.5**) has a direct impact on understanding as well as innovation (see Section 11.4).

Summary tables are provided below (see Tables 11.1 to 11.5).

Table 11.1 Clear and unambiguous (1.1)

No.	Strategy	Source	Observations on potential challenges to fulfilling the strategies	Possible solution
1.1.1	Define purpose of the standard to focus drafting effort.	T&P	Achieve an agreement on the purpose of the document and agree at the outset what would be a better outcome and how that better outcome will be achieved through the approach to be defined during the standards development process.	Set clear expectations among stakeholders and support transparency in decisions.
1.1.2	Define clear scope of the standard and limitations in the application of requirements to focus drafting effort.	T&P		
1.1.3	Define primary target audience of the standard and the expected competence level, and write requirements understandable by them and in general by those who may have not participated in their preparation. *Linked to "Enhancing standardisation system" component process*	T&P	Achieve an agreement on the primary target audience.	Discuss the definition of the primary target audience as a priority item in initial stakeholders' meetings. Knowing the level of competence expected by the users helps understand the level of detail to be provided in the document. Note that professional expectations on the significance of competence are affected by a variety of factors, including educational traditions and specific working environments.
1.1.4	Adjust content to suit learning capabilities of the primary target	T&P	Define learning capabilities of users due to lack of research.	Chapter 10 provides a preliminary exploration of this issue.

No.	Strategy	Source	Observations on potential challenges to fulfilling the strategies	Possible solution
	audience.			
1.1.5	Avoid vague terms that may cause uncertainty (e.g. qualitative and subjective terms such as 'adequate', 'as appropriate', etc.).	P5		
1.1.6	Ensure consistency in terminology within the standard and among other related standards. *Linked to "Enhancing standardisation system" component process*	P2	Effective liaison with other standardisation organisations.	
1.1.7	Clarify new terms, particularly when historically they have been used differently.	P3		
1.1.8	Provide supporting advice to clarify how the requirement can be verified – providing only high-level requirements can affect negatively on understandability as well as on consistency of solutions developed.	T&P	Balance advisory provisions: too much and counterproductive advice is provided.	Take account of the level of competence and expertise expected from the primary target audience. Raise the level of understanding by making reference to other available publications. Provide advice to avoid technical problems previously experienced.
1.1.9	Develop background information to clarify the context of requirements and the rationale behind them, and identify the appropriate location for it (in the main text, in informative annexes, separate publications, or kept internally). *Linked to "Enhancing standardisation system" component*	T&P	Not always appropriate to make background information available externally, particularly where requiring additional time and resources to be developed.	Most of the time background information could be usefully retained by the standards organisation for audit trail and made available externally only where requested. It however should be kept up-to-date.

No.	Strategy	Source	Observations on potential challenges to fulfilling the strategies	Possible solution
1.1.10	Peer review by standards makers not involved in the drafting process. *Linked to "Enhancing standardisation system" component*	P4	Lack of availability of peer reviewers.	Have in place an efficient system to manage workload of peer reviewers.
1.1.11	Understand reasons for lack of clarity, e.g. wrong content, not clearly written, unclear scope of application, unclear type of content (advice or requirement), and make necessary modifications.	T&P		
1.1.12	Measure understandability of requirements.	P4	Not easy to do.	Potential measures include: multiple-choice tests or questionnaires for target users on the clarity and understandability of provisions; time to understand; time to complete a task (design) correctly; number of errors made by users; rating of mental effort by target users.

Table 11.2 Complete and concise (1.2)

No.	Strategy	Source	Observations on potential challenges to fulfilling the strategies	Possible solution
1.2.1	Make effective use of cross-referencing to other relevant publications.	T&P		
1.2.2	Answer the questions 'what' (requirement), 'how' (method) and 'why' (background).	T&P	If the answers are not clear or ambiguous, this may be an indication of the incompleteness of the information provided.	
1.2.3	Avoid repetitions within a standard or between	P1, P5	Repeating information is sometimes considered	

No.	Strategy	Source	Observations on potential challenges to fulfilling the strategies	Possible solution
	related standards.		necessary. However, standards' writers need to be aware of the unintended consequences of repeating content, key one being the potential inconsistencies when one standard is updated and the related one, which has duplicated information, is not.	
1.2.4	Make sentences concise and to the point, but note that sometimes longer text is beneficial for clarity.	T&P		
1.2.5	Develop clear document layout, system of indexing and cross-referencing.	T&P		
1.2.6	Define the purpose of the standard to focus drafting effort.	T&P	Achieve an agreement on the purpose of the document. This in turn can lead to scope creep.	Set clear expectations among stakeholders and support transparency in decisions.
1.2.7	Define clear scope of the standard and limitations in the application of requirements to focus drafting effort.	T&P		
1.2.7	Define primary target audience of the standard and the expected competence level to focus drafting effort. *Linked to "Enhancing standardisation system" component*	T&P	Achieve an agreement on the primary target audience.	Discuss the definition of the primary target audience as a priority item in initial stakeholders' meetings.
1.2.8	Balancing simplified and rigorous approaches and presenting them consistently.	T, P4	Define criteria for the introduction of simplified and rigorous approaches in the standard and decide where simplified or rigorous approaches should be allocated in the main part of the	It may be useful to establish pre-emptive principles on when simplified methods can be introduced, for example when they are of general application, address commonly encountered topics, are technically justified, and

No.	**Strategy**	**Source**	**Observations on potential challenges to fulfilling the strategies**	**Possible solution**
			document or in annexes.	give more conservative results than the rigorous methods they are intended to simplify.

Table 11.3 Easy to access and navigate (1.3)

No.	**Strategy**	**Source**	**Observations on potential challenges to fulfilling the strategies**	**Possible solution**
1.3.1	Organise information into functional groupings (i.e. groups of related topics). Cluster analysis could be a valuable tool (see Chapter 8).	P4		
1.3.2	Rationalising content by eliminating unnecessary duplication and conflict, and supporting collaboration and engagement between different teams responsible for standards development.	T&P		
1.3.3	Make appropriate use of new content editing and publishing tools based on XML. These provide the platform for a more dynamic user's experience from the information provided in the standard, and better accessibility of the content.	T&P		

Table 11.4 Supporting continuity in good practice (1.4)

No.	**Strategy**	**Source**	**Observations on potential challenges to fulfilling the strategies**	**Possible solution**
1.4.1	Avoid introducing unsafe methods or approaches by preserving technical knowledge gained in	P3		

No.	Strategy	Source	Observations on potential challenges to fulfilling the strategies	Possible solution
	years of research and practical work.			
1.4.2	Develop standards which are up-to-date and make reference to current best/good practice, and clearly present it as advice.	P5	If best/good practice is presented as requirements, when superseded by more up-to-date practice it becomes obsolete and may inhibit innovation.	Present current best/good practice as advice and not as a requirement.

Table 11.5 Making a clear distinction between requirements and advice (1.5)

No.	Strategy	Source	Observations on potential challenges to fulfilling the strategies	Possible solution
1.5.1	Understand what aspects need control and translate these into requirements. Aspects that are not fundamental requirements should be provided as supporting advice. *Linked to "Enhancing standardisation system" component*	T&P	Require significant intellectual effort to identify the fundamental requirements.	Training of standards' writers and practice by standards' writers.
1.5.2	Use appropriate verb forms for requirements.	P5	Statutory, legislative requirements should be clearly distinguished from the requirements of the design standard under consideration. Where regulations refer to standards in an "exclusive" way (see Section 2.4), it can be difficult to understand their legal status and how they should be referred to.	Use appropriate verb forms and clarify their meaning (see Chapter 9).
1.5.3	Use appropriate verb forms for advice.		Recommendations, methods and options to verify requirements, commentary / statements of fact, should be clearly distinguished.	Use appropriate verb forms and clarify their meaning. This requires an in-depth understanding of the intended meaning of the advice provided.

No.	Strategy	Source	Observations on potential challenges to fulfilling the strategies	Possible solution
				Background information should not always be provided in the standard, but may be kept internally as a technical audit trail to decisions taken in the standardisation process.

There are three recommended properties of good design standards as shown in Figure 11.1. They are "recommended" insofar as:

- making appropriate use of performance-based requirements and method-based requirements (**1.6**) is one of the key drivers to innovation (see Section 11.4);
- reducing need for continuous updates (**1.7**) makes the standardisation system more efficient;
- consistency in design approaches (**1.8**) reduces potential conflicts in the design process, which may arise when different types of structures interact (for example structural and geotechnical design).

Summary tables are provided below (see Tables 11.6 to 11.8).

Table 11.6 Making appropriate use of performance-based and method-based requirements (1.6)

No.	Strategy	Source	Observations on potential challenges to fulfilling the strategies	Possible solution
1.6.1	Understand advantages and disadvantages of performance-based requirements (both "pure" and "mixed") and method-based requirements.	P5	Appreciate the complexity in developing performance-based requirements (PBRs) for civil and structural engineering works	See Chapter 9 for the sources of complexity when developing PBRs.
1.6.2	When choosing 'pure' performance-based requirements: • appreciate key issues in their development and implementation; • have in place an appropriate	P5		See Chapter 9 for an extensive treatment on issues in development and implementation of pure PBRs.

No.	Strategy	Source	Observations on potential challenges to fulfilling the strategies	Possible solution
	measurement strategy; • assess liability/ responsibility transfer; • assess relevant risks.			

Table 11.7 Not needing continuous updates (1.7)

No.	Strategy	Source	Observations on potential challenges to fulfilling the strategies	Possible solution
1.7.1	Make appropriate cross-referencing to other relevant publications.	P5		Avoid reference to specific clauses unless imperative, and minimise reference to documents that might be subject to change over time. Make use of DOIs in combination with XLM as providing unbreakable links.
1.7.2	Make requirements contract- or function-neutral as far as possible.	P5		
1.7.3	Have in place an efficient mechanism for reviewing and, where needed, updating documents. *Linked to "Enhancing standardisation system" component*	T&P	There may not be enough resources (human and technological) in place.	Make content future proofed by using smart database.

Table 11.8 Supporting consistency in design approaches (1.8)

No.	Strategy	Source	Observations on potential challenges to fulfilling the strategies	Possible solution
1.8.1	Provide requirements which support consistency in design between different civil and structural engineering works	T&P4		

No.	Strategy	Source	Observations on potential challenges to fulfilling the strategies	Possible solution
	where possible.			

There are five desirable properties of good content for design standards as indicated in Figure 11.1, which reflect potential future directions in design standards development requiring further exploration.

Developing learning-orientated design standards (**1.9**) would help consider explicitly how designers with differing levels of experience and expertise think, learn and design, while reinforcing and accelerating their learning power. Supporting users' capabilities and skills requires taking a learning perspective (see Chapter 10) and recognises the importance of encouraging critical application of design standards and learning.

Making appropriate use of risk-based requirements for the design of civil and structural engineering works (**1.10**) has been explored in the DMRB project (see Chapter 9). The properties "enabling more informed verification of the adequacy of design" (**1.11**), "better enabling structural verifications to be incorporated into digital models" (**1.12**), "supporting modularisation and off-site manufacturing" (**1.13**) have been introduced as discussed in Chapter 5.

11.3.2 Processes needed in the standardisation system

There are four fundamental processes for enhancing the standardisation system as shown in Figure 11.1. They are "fundamental" insofar as:

- clear and unambiguous drafting rules (**2.1**) have a direct impact on the quality of the document produced;
- adequate resources (**2.2**) are an essential component of the drafting work;
- managing stakeholders effectively (**2.3**) enables clear expectations to be set, communicated and met;
- collecting and processing feedback effectively (**2.4**) is essential to improve an existing standard or as a trigger for the development of a new one;
- having in place effective governance processes (**2.5**) is an essential part of the development of both formal and *de facto* standards.

Summary tables for individual processes are provided below (see Tables 11.9 to 11.12). A more extensive treatment of specific topics is presented separately in the annexes.

Table 11.9 Having in place clear and unambiguous drafting rules (2.1)

No.	Strategy	Source	Observations on potential challenges to fulfilling the strategies	Possible solution
2.1.1	Refer to well-established drafting rules (e.g. ISO, BSI, CEN standards drafting rules).	T&P		
2.1.2	Develop specific rules where needed, for example to cover style and formatting of particular types of standards.	P5	The rules produced are not effective.	Test the rules in pilot exercise(s). Collect and address feedback during usage. Monitor use of the rules to ensure that they are applied consistently. This can be managed by appointed content editors, see (2.2).

Table 11.10 Having in place adequate resources (2.2)

No.	Strategy	Source	Observations on potential challenges to fulfilling the strategies	Possible solution
2.2.1	Select experienced and skilled technical authors.	P5	Not all technical specialists are capable of drafting standards. Open discussion with different client organisations and practitioners showed that drafting requires appropriate skills, knowledge and experience.	Train technical specialists.
2.2.2	Involve content editors to support authors where possible.	P5		
2.2.3	Allocate appropriate time for drafting the standard.	P		
2.2.4	Allocate appropriate time for reviewing the standard.	P		Consider the involvement of peer reviewers.

Table 11.11 Having in place an effective stakeholders-management strategy (2.3)

No.	Strategy	Source	Observations on potential challenges to fulfilling the strategies	Possible solution
2.3.1	Identify key stakeholders, involve them in the process, explore carefully their expectations, assess their needs and ask for feedback.	T&P	Easy to prejudge what stakeholders want and jump to conclusions. This however may have a negative impact on the standard produced, which does not meet relevant needs.	Actively consult with stakeholders.
2.3.2	Define which (key) needs are going to be addressed for different categories of stakeholders.	P4	Disagreement among stakeholders.	Do not attempt to do everything for all categories of stakeholders. Structure argumentative processes among decision makers carefully. Identify statements of intent for different categories of stakeholders.
2.3.3	Identify situations where other standards organisations should be actively consulted as having shared interest.	P4, P5	The definition of the boundaries of responsibilities between standardisation organisations or groups may be challenging and need careful attention and management.	Enhance liaison between organisations to eliminate incompatibilities and ambiguities, and develop consistent standards. Following relevant strategies to build international consensus as needed (see Chapter 8).
2.3.4	Identify situations where requirements could be shared with other organisations (relevant in the context of client technical specifications).	P5	See Chapter 9 for a list of key issues.	
2.3.5	Have in place an appropriate publication strategy	T&P5	The engineering community may be hostile to the introduction of new or revised standards, particularly users of the standards who are not engaged in the standardisation process.	Create a climate of anticipation clarifying – before the introduction of the standard – why it is needed and how the content provided will be easier to use and quicker to implement. Explain how the new

No.	Strategy	Source	Observations on potential challenges to fulfilling the strategies	Possible solution
				standard should be used. Show how problem areas and users' concerns have been addressed. Have in place an appropriate education strategy to support usage and more in general to educate users on the role of standards.

Table 11.12 Having in place an efficient system to collect and process feedback

No.	Strategy	Source	Observations on potential challenges to fulfilling the strategies	Possible solution
2.4.1	Have in place an efficient mechanism to collect, analyse and process feedback from external inputs (see Figure 2.3).	T		
2.4.2	Have in place an efficient mechanism to collect, analyse and process feedback from the built environment (see Figure 2.3).	T		
2.4.3	Have in place an efficient mechanism to collect, analyse and process feedback from users (see Figure 2.3).	T&P	Time consuming process.	Prepare background information (this helps streamline process of reply to future queries).
2.4.4	Have in place an efficient mechanism to manage derogations where relevant (see Figure 2.3).	T&P5	See Industry Standards Group's (2012) report.	See Industry Standards Group's (2012) report.

There are two recommended processes for enhancing the standardisation system as shown in Figure 11.1. They are "recommended" insofar as:

- having a streamlined standardisation system (**2.6**) enables documents to be updated more quickly, thus reducing resources needed for the drafting work and ensuring timely delivery to the market;
- future-proofing content (**2.7**) supports easier management of technical provisions (including meta-data attached to clauses) in future.

Table 11.13 Streamlining document drafting (2.6)

No.	Strategy	Source	Observations on potential challenges to fulfilling the strategies	Possible solution
2.5.1	Apply online authoring tools for collaborative document drafting.	P1, P5	Have in place user-friendly tools which can support multiple individuals and organisations to access the same content and contribute to the standardisation work. Ensure that such tools are reliable and can be used for audit trail of the decisions taken.	A pilot project is currently undertaken by CEN/CENELEC on online standards development as part of the Digital Transformation Initiative. CARS has been developed for the DMRB project (see Chapter 9). It has delivered significant benefits to users and to the client organisation.
2.5.2	Introduce more efficient ways of working, for example Agile approach to document drafting.	P5	Its implementation may not be straightforward (particularly due to the potential difficulty to get team members together with the necessary availability), with the consequent temptation to adapt it to the specific situation, thus losing the benefits of its structure approach.	Guidance to apply the Agile approach to document drafting is provided in Chapter 9.

Table 11.14 Future-proofing content (2.7)

No.	Strategy	Source	Observations on potential challenges to fulfilling the strategies	Possible solution
2.6.1	Making use of advances in information technology to develop smarter database and manage standards throughout their life-cycle.	T&P		

There are two desirable processes for enhancing the standardisation system as indicated in Figure 11.1.

The first is promoting standards drafting in the engineering community (**2.8**). Standards drafting has a significant impact on the wider engineering community. However, it is still a niche sector and a small number of practitioners are typically involved in this activity. This is demonstrated by the limited number of engineers in standardisation committees, as well as the limited number of publications in the field of standards development in the construction industry. Identifying thought leaders to present this issue to different audiences (including professional institutions) would be helpful to discuss this issue more widely, involve more designers and promote standards drafting as an important activity for the engineering profession.

The second desirable process is promoting education on the role and use of standards (**2.9**). Awareness, education and understanding of the European Standardisation System are the three pillars of the strategy implemented by CEN/CENELEC and associated NSBs to increase the use of standards and participation in the standardisation process at all levels. However, standardisation could be made more attractive if digital technologies were exploited more extensively not just to draft standards, but also to use them. Current trends toward digitalization of standards (see CEN-CENELEC Digital Transformation strategy and the work done on the DMRB presented in Chapter 9) are offering unique opportunities to make them machine-readable and able to provide the foundations for a more effective human-aided design.

11.4 Innovation and construction and maintenance efficiency

Knowing the properties of good design standards and processes for developing better design standards which also have an impact on innovation can help standards' writers in making more informed decisions and develop design standards which have innovation as a key driver. From the exploratory study presented in Chapter 6, the need for more flexibility in design standards emerged as a recurrent theme, particularly in the Industry Standard Group's (2012) report. Whilst it is not rare to hear that design standards may inhibit or enable innovation, how and to what extent this actually happens is still vaguely defined.

The Eurocodes and DMRB projects, coupled with literature review (Moffatt and Dowling 1981; Sunley and Taylor 1982; Gann et al. 1998; Blayse and Manley 2004; Reichstein et al. 2008; Industry Standard Group 2012; Altuwaijri and Khorsheed 2012; Ozorhon et al. 2016), helped shed light into this issue. The themes emerged from this review show that design standards should not be regarded as a tool to 'enable' innovation because 'enabling' is typically in the procurement or in other processes outside the control of the design standard. These documents can have an active, explicit role in providing a framework for developing innovative solutions.

Key to that is the approach taken by the technical committees / authors. If they approach the drafting of a standard as a way of encouraging designers to be innovative, then that is what will happen. Technical authors need to focus on levers to innovation while eliminating potential barriers. Levers to innovation related to the development of better content, the enhancement of the standardisation system and other factors external to the system of interest (see also Figure 6.5 for its boundaries) are provided in Figure 11.2. The existence of significant external factors affecting innovation (key one being mitigation of risk aversion by clients and designers) indicates that a joint approach to innovation should be taken.

Providing a framework for the development of innovative solutions

1. Levers in relation to the properties of good content

1.1 Clear first principles are set.
Clarity and simplicity in provisions should be provided to enable the up-take of good practice and encourage innovation.

1.2 Opportunities for innovation are clearly indicated
Making a clear indication in the standard where there is scope for greater flexibility and opportunity/lever/space for innovation.

1.3 Sophisticated and simplified methods are effectively balanced
Attention should be paid to clarify the scope of application of simplified methods and to avoid that the use of simplified methods can stifle the application of advances in technology.

1.4 Existing technology is codified to create 'demand pull' for new practices and technologies.
This can be done by incorporating innovative solutions when satisfying specific tests, such as when the innovation solution does not compromise safety, it is proven to result in a better outcome, or it is not restricted due to patent or copyright restrictions (the IP issue is generally managed effectively in formal standards, but may not be in proprietary standards). However, attention needs to be paid when introducing specific innovative solutions as requirements. This could lead to over-prescription.

1.5 Requirements that force the industry to develop new solutions to comply with them are imposed.
An example is BIM.

1.6 Method-based requirements and performance-based requirements are effectively balanced.

1.7 The content of the standards is learning-orientated.

2. Levers in relation to the standardisation process

2.1 Have in place an efficient system to collect and process feedback
In case of de facto / proprietary standards, this requires the development and implementation of an efficient system to manage derogations, as well as the development of clear guidance on how to apply for departures related to innovative solutions to avoid reluctance to submit departure applications. This also needs to minimise subjectivity in the review process of applications – consider peer review to approve and to advise on the need to change the standards

2.2 Provide a specific framework for submission of innovative solutions
This may require development/ implementation of leaner processes to consider the innovation proposed and arrive at a decision.

2.3 Streamline document drafting
This has a positive impact on the speed of publication and quick availability of latest information to users.

3. Levers in relation to additional factors external to the standardisation system

3.1 Mitigating risk aversion of clients

3.2 Mitigating risk aversion of designers.
This may be an education issue and requires the following:
- Avoid rigid interpretation and application of the standard, which can result in missed opportunities
- Minimise subjectivity in the review process of applications (see 2.1)
- Recognise and promote innovative solutions by means of a rewarding schemes
- Invest in the adoption of new knowledge and organizational practices
- Support R&D on the use of new technologies/materials/construction processes
- Consider partnership in high risk innovative contracts

3.3 Selecting appropriate procurement routes.
Avoid procurement routes that inhibit the adoption of non-traditional methods.

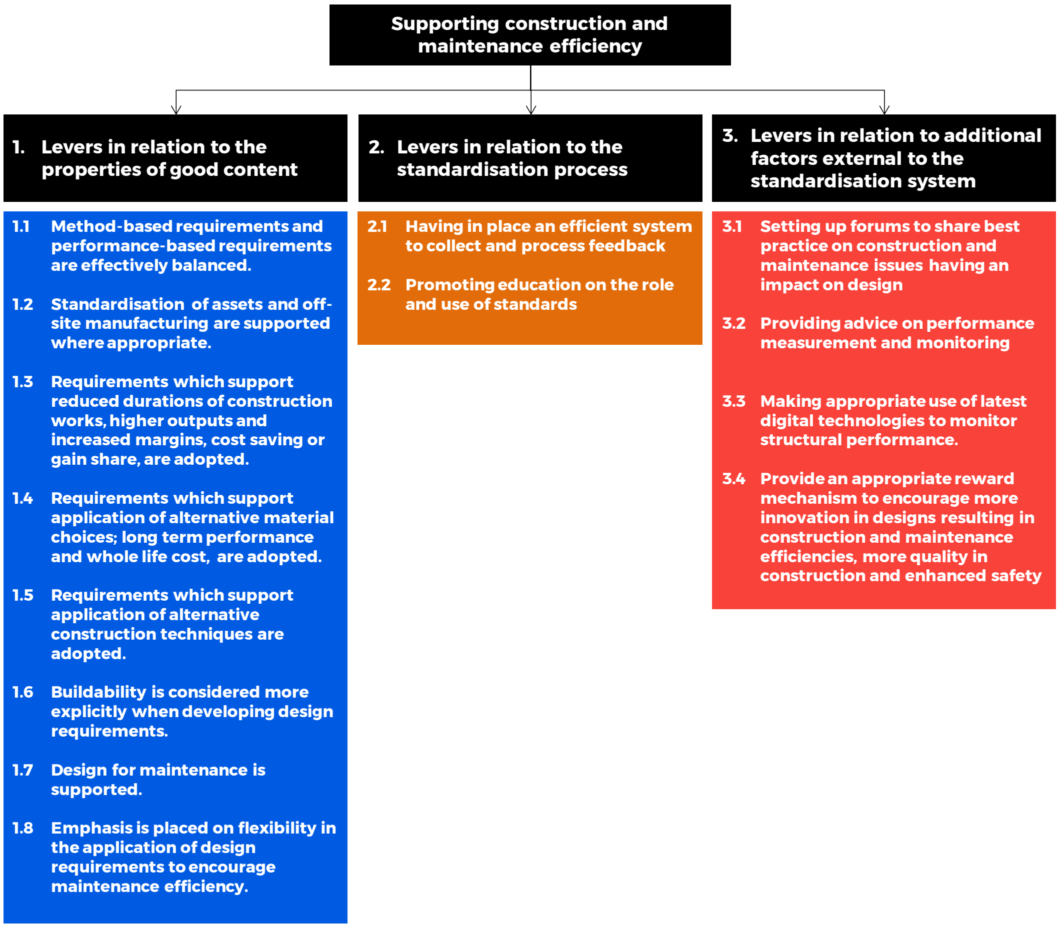
3.4 Supporting cooperation among stakeholders
This can be done:
- putting in place mechanisms that nurture knowledge sharing, both internally in the standardisation body and externally in the supply chain;
- sharing successful innovations through the design community by using appropriate channels;
- limit situations where the client owns the research that backs up the technical specification.

3.5 Engaging and communicating with suppliers more effectively
Topics for discussion may include:
- opportunities to secure R&D funding;
- communication of new technologies;
- identifying commercial viability of new technologies.

3.6 Supporting trends in the construction industry

Figure 11.2 Levers to innovation

Knowing the properties of good design standards and processes for developing better design standards which have a direct impact on the technical solutions developed, can also help standards' writers in making more informed decisions and develop design standards which have the efficiency of the technical solutions developed as a key driver. The DMRB project provided some initial findings to help shed some light into the role of design standards in supporting construction and maintenance efficiency as synthesised in Figure 11.3. Figure 11.3 also provides levers to construction and maintenance efficiency represented by other external factors. A joint approach to the whole-life process should thus be taken. Being the identified new sub-processes only emerged from the DMRB project, they have been categorised as "desirable" insofar as they would require further work to be tested and classified either fundamental or highly recommended as relevant.



Supporting construction and maintenance efficiency

1. Levers in relation to the properties of good content

1.1 Method-based requirements and performance-based requirements are effectively balanced.

1.2 Standardisation of assets and off-site manufacturing are supported where appropriate.

1.3 Requirements which support reduced durations of construction works, higher outputs and increased margins, cost saving or gain share, are adopted.

1.4 Requirements which support application of alternative material choices; long term performance and whole life cost, are adopted.

1.5 Requirements which support application of alternative construction techniques are adopted.

1.6 Buildability is considered more explicitly when developing design requirements.

1.7 Design for maintenance is supported.

1.8 Emphasis is placed on flexibility in the application of design requirements to encourage maintenance efficiency.

2. Levers in relation to the standardisation process

2.1 Having in place an efficient system to collect and process feedback

2.2 Promoting education on the role and use of standards

3. Levers in relation to additional factors external to the standardisation system

3.1 Setting up forums to share best practice on construction and maintenance issues having an impact on design

3.2 Providing advice on performance measurement and monitoring

3.3 Making appropriate use of latest digital technologies to monitor structural performance.

3.4 Provide an appropriate reward mechanism to encourage more innovation in designs resulting in construction and maintenance efficiencies, more quality in construction and enhanced safety

Figure 11.3 Levers for construction and maintenance efficiency

11.5 Discussion

11.5.1 Link between framework components

The strategies to enhance the content of design standards and the standardisation system presented in the previous sections have been developed to be as independent as possible for ease of use.

There are however some interdependences. Some strategies are common to multiple properties, e.g. the importance of clearly identifying purpose, scope and target audience of the standard. Equally, some strategies affect both the content and the standardisation system, for example: defining the primary target audience of the standard is essential to develop better requirements ("content") and requires discussion and agreement in initial stakeholders meetings ("standardisation system"); to develop clearer requirements ("content") involving peer reviewers is crucial ("standardisation system").

This re-emphasises that the development of better design standards is a complex problem and taking a systems view is necessary to appreciate the existence of interrelated factors. Figure 11.4 links schematically the framework components and the additional external influences, which must be considered when innovation and construction and maintenance efficiency are the drivers in the development of a design standard.

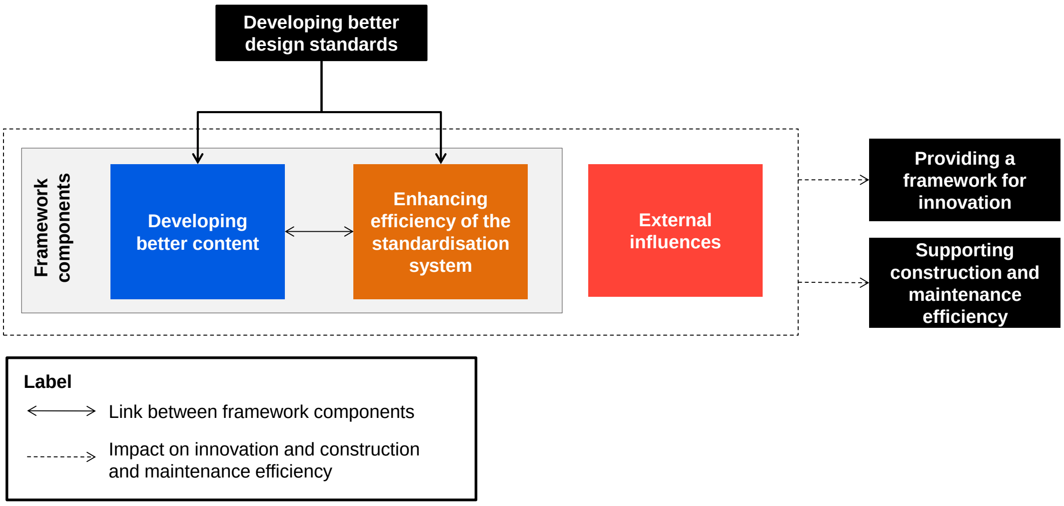


Figure 11.4 Link between framework components

11.5.2 Framework quality

The case studies have contributed to the cumulative development of knowledge. While it is not possible to generalise from one case to another due to the different contexts, working on multiple case studies provided a stronger base for building the framework (Yin 2009), which is more robust, better grounded and more accurate than it would be using a single case study. Moreover, when dealing with situations where there are significant human affairs as in this research, as acknowledged by Flyvbjerg (2006) "concrete, context-dependent knowledge is more valuable than the vain search for predictive theories and universals". The projects presented in this thesis were purposefully selected. Working on standards developed at different levels enabled the challenges identified in Chapter 6 to be clarified and extended while showing different perspectives on the issue of the quality and usability of design standards.

In line with Eisenhardt and Graebner's (2007) recommendations for robust theory building, only the themes that confirmed the theoretical exploration presented in Chapters 5 and 6, that were replicated across most or all of the case studies, or which were general enough to be retained, have been used for the "fundamental" and "recommended" sub-processes of the framework shown in Figure 11.1. The "desirable" sub-processes have been retained to flag attention for future work. It can be argued that the emerging framework is parsimonious; yet, it is also dependable, credible and transferable (see assessment criteria for research quality in Section 4.5).

11.5.3 Framework testing

The methods adopted in the projects proceeded iteratively and were refined to pursue themes emerged from previous cases. A key implication of iteratively applying and refining research approaches has been that, while the objective of case study research is generally theoretical development and not testing/validation (Eisenhardt and Graebner 2007), the iterative approach taken has enabled the framework to be tested.

Moreover, industry buy-in/client acceptance of the approach developed and the recommendations proposed presented in Chapters 7, 8 and 9 demonstrate their fitness for purpose. In line with Rittel and Webber (1973), this represents a key criterion in wicked problems to identify the end of the process and evaluate whether proposals are "good enough" to those concerned.

11.5.4 Framework applicability

11.5.4.1 New and existing design standards

The framework provides standards' writers with a tool to improve the development of design standards in a systematic way. In principle, it is valid for both new and existing design standards. However, specific attention is needed when dealing with an existing standard. In such a case, the amount of work required to review and enhance it is influenced by the following factors:

- its length,
- its style and quality,
- the extent and nature of any technical updates needed, including any analysis or development required to incorporate research and innovation,
- the relationships between the standard and other external standards, regulations and guidance,
- whether part or all of the standard is no longer needed or useful.

11.5.4.2 Single standards and set of standards

The sub-processes in the framework can be applied to both a single standard and a collection of standards. However, specific attention is needed when reviewing large suites of standards as emerged in the Eurocodes and DMRB projects (Chapters 8 and 9). In such a case, targeting the documents to review is a necessary step and may be governed by the interests of specific categories of stakeholders. Broadly speaking, criteria for targeting standards in large sets may include:

- standards that most affect safety
- standards that are critical to cost (e.g. maximise long-term benefit to economy)
- oldest and out-of-date standards, which may refer to obsolete practices
- most used standards
- most referenced standards
- highest risk standards
- parts of the standard which have been most affected by rapid changes in industry practice, improvements in technology, new research etc.

Finally, it is worth noting that, while a single standard could be fit for purpose, in the context of other linked standards it can become unworkable. This is a typical property of complex interrelated documents and procedures.

11.5.4.3 Managing tensions

The strategies to tackle specific issues presented in the previous tables provide a means to manage the tensions identified in Section 11.2.

11.5.5 Framework limitations

Three limitations of the framework warrant mention.

First, the framework is not intended to be a comprehensive tool for decision making, but a practical guide to identify key processes, relevant management strategies, observations on potential challenges to fulfilling the strategies, and potential solutions. The tables can indeed be easily converted into practical checklists and additional processes may be potentially added as relevant.

The second limitation attains to the validation of the outputs of the framework, i.e. the standard / suite of standards produced using it. While iteratively applying and refining research approaches in the case studies coupled with industry buy-in of the recommendations produced helped validate the framework (see Section 11.5.3), the validation of its outputs would require further work. This aspect was also mentioned in the limitations of the work carried out for the Eurocodes (Chapter 8) on the limited discourse around the implementation of the guidelines and recommendations produced. Validation of the outputs can be done by comparing the standards produced against the checklist of issues identified in the earlier sections. It is worth noting that, in the context of the DMRB, feedback collected so far from document authors has demonstrated that following the new drafting rules provides clearer, shorter and higher-quality standards. Feedback from users of new DMRB documents need to be collected to support these encouraging preliminary findings.

The third limitation can be seen in the sub-processes related to construction and maintenance efficiency (see Figure 11.3). These emerged only from one case study (the DMRB project). Although it involved a consultation with more than 60 organisations in the UK construction industry, further work is needed to explore this issue in more detail and draw more definitive conclusions.

11.6 Conclusions

The various roles of design standards and the variety of intertwined hard and soft aspects emerged from this research suggest that providing a single definition of "good design standards" is not only difficult, but also inappropriate. Indeed, the resulting definition would be either too narrow, when focusing only on one aspect, or too complicated, when trying to cover multiple aspects.

To enhance design standards in the construction industry, both content of the standard and standardisation system need to be improved. A practical framework has been proposed, which provides the properties of good content and the processes to enhance the standardisation system. Properties and processes have been further separated into "fundamental", "recommended" and "desirable". This distinction also reflects their generalisability as emerged from the case studies and the theoretical work presented in Part 2 of this thesis.

The framework developed in this chapter is aimed at supporting standards' writers to easily identify key processes, strategies for their management, observations on potential challenges to fulfilling the strategies, and potential solutions. The framework is applicable to both new and existing design standards, and to single standards and sets of standards. It is further augmented by additional sub-processes, which show how design standards can provide a framework for innovation and potentially for construction and maintenance efficiency.

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Chapter 12
Conclusions

12.1 Research questions addressed

This thesis has explored the theoretical foundations of good design standards in the construction industry as well as real challenges and practical solutions in the development of better design standards. This thesis has gained from the systems thinking arena to explore and tackle this complex problem. It has adopted a pragmatic approach to investigation, using qualitative and quantitative methods to guide and shape the research programme. To answer the main research question "*How can better design standards be developed?*" four research sub-questions have been addressed, as summarised below.

12.1.1 Current and future roles of design standards

Design standards play and will continue to play a fundamental part in the construction industry particularly given the fundamental changes that the construction industry is experiencing. The impossibility of building full-scale prototypes due to the one-of-a-kind nature of constructed facilities coupled with their complexity, size and long life, means that design of civil and structural engineering works will continue to be primarily standards-driven.

To explore the role of design standards, a critical review has been carried out looking at: (i) the historical evolution of design standards with design practice over the centuries; (ii) the different artefacts (i.e. engineered entities) developed in construction, manufacturing and aerospace industries; (iii) the emerging vision of the future construction industry; and (iv) a qualitative study with practitioners, standards writers, researchers and clients.

This research has revealed that design standards fulfil sixteen distinctive roles. Some of them represent fundamental accomplishments and successes of design standards that need to be preserved and reinforced:

1. Control built environment.
2. Support competitiveness.
3. Frame common understanding among stakeholders.
4. Provide common basis for research and development
5. Manage risk and uncertainty.
6. Codify technical knowledge in a user-orientated fashion.
7. Enable adequacy of design to be verified, including for the design of structural modifications or rehabilitation schemes.
8. Ensure consistency in design approaches.
9. Provide a framework to develop innovative civil and structural engineering works.
10. Support the design of safe, serviceable and durable civil and structural engineering works.
11. Support the design of cost-effective civil and structural engineering works.
12. Support the design of common design solutions.

Some others represent new roles that need to be introduced or better understood to drive and support the profound changes in the construction industry:

1. Enable structural verifications to be incorporated into digital models.
2. Support modularisation and off-site manufacturing.
3. Support the design of sustainable civil and structural engineering works.
4. Support a whole-life view.

These roles are pertinent to three distinct areas. Some of them are about high-level objectives of standardisation for design standards (e.g. control built environment and frame common understanding among stakeholders). Some are strictly connected with the content of the document (e.g. codify technical knowledge in a user-orientated fashion and enable adequacy of design to be verified). Some others refer to the design of civil and structural engineering works (e.g. support the design of safe and cost-effective civil and structural engineering works).

12.1.2 Issues that affect design standards at different life-cycle stages

The life-cycle of a design standard is a complex socio-technical system affected by hard, soft and macro-environmental challenges. They have been explored by means of literature review and a qualitative study, and subsequently confirmed by practical experience in live projects. Hard challenges involve physical elements, such as the quantity of technical provisions and their cross-references, and the way provisions are presented in terms of performance-based requirements or method. Soft challenges concern human and social aspects, such as competing needs and expectations of stakeholders and users and the skills of standards writers. Macro-environmental challenges pertain to political, social and procedural considerations among others.

The challenges of design standards are intertwined and their impact (either positive or negative) can be seen not just on the documents themselves, but also on the flexibility to design and the safety, cost-effectiveness and sustainability of the technical solutions developed. Taking a systems view is essential to appreciate these aspects and the existence of potential unintended consequences when seeking to solve one aspect in isolation without appreciating the big picture. An important conclusion drawn from this research is that managing the identified challenges helps reduce complexity and aid the development of better design standards.

12.1.3 Definition and features of good design standards

The various roles of design standards and the variety of intertwined hard and soft aspects emerged from this research suggest that providing a single definition of “good design standards” is not only difficult, but also inappropriate. Indeed, the resulting definition would be either too narrow, when focusing only on one aspect, or too complicated, when trying to cover multiple aspects.

A framework has been introduced to describe a good design standard. It draws together the properties of good and easy to use design standards (see 1.1 to 1.13 below) with the processes for enhancing the standardisation system (see 2.1 to 2.9), shows how to manage hard and soft challenges, and helps navigate and overcome identified tensions.

1.1 Clear and unambiguous
1.2 Complete and concise
1.3 Easy to access and navigate
1.4 Supporting continuity in good practice
1.5 Making a clear distinction between requirements and advice
1.6 Making appropriate use of performance-based and method-based requirements
1.7 Not needing continuous updates
1.8 Supporting consistency in design approaches
1.9 Learning-orientated

1.10 Making appropriate use of risk-based requirements
1.11 Enabling more informed verification of the adequacy of design, particularly to inform the design of structural modifications or rehabilitation schemes
1.12 Better enabling structural verifications to be incorporated into digital models
1.13 Supporting modularization and off-site manufacturing

2.1 Having in place clear and unambiguous drafting rules
2.2 Having in place adequate resources for standard development
2.3 Having in place an effective stakeholders management strategy
2.4 Having in place an efficient system to collect and process feedback
2.5 Having in place an effective governance process
2.6 Streamlining document drafting
2.7 Future-proofing content
2.8 Promoting standards drafting in the engineering community
2.9 Promoting education on the role and use of standards

12.1.4 Practical steps for standards writers to develop better design standards

To develop better design standards in the construction industry, standards writers need to improve both the content of the standard and the standardisation system. These represent the two components of the practical framework for better design standards proposed in this thesis.

The properties of good content and processes for enhancing the standardisation system listed in Section 12.1.3 have been classified into fundamental, recommended and desirable . Management strategies, observations on potential challenges to fulfilling the strategies, and potential solutions have been proposed for each property and process. Key interdependences between them have also been identified.

The framework has been further augmented by additional elements, which show how focusing on specific properties or processes can provide a framework for innovation and potentially support construction and maintenance efficiency. The proposed framework is valid to both new and existing design standards, and to single standards and sets of standards. It is not intended to be a comprehensive tool, but a practical guide to support the process of development of better design standards, particularly from a user-perspective.

12.2 Impact of this research

From an academic point of view, exploring the quality of design standards represents a new field of research having a positive impact on the engineering design community, the systems community and the standardisation community. Developing better design standards in the construction industry can significantly enhance the design practice of thousands of designers. This work also responds to a call for practical examples of the application of systems principles to solve real problems (Howick and Ackermann 2011; Kotiadis and Mingers 2006). As far as the author is aware, the combination of methods applied in this thesis represents a novel approach for policy making embedded into the standardisation field. Moreover, this research represents a first attempt to explore and manage the quality of standards in a systematic way and support decision making of standards writers. It can thus help shape future practice in standards development. From the author's host organisation perspective, developing an approach to enhance design standards gives a specific expertise to the company and help support clients' requirements. From a wider industrial perspective, improving the quality of design standards could reduce the time required to develop a technical solution, improve the technical solution itself, or both.

12.3 Future work

This research has found that exploring the issue of the quality of design standards requires taking a holistic perspective while investigating a variety of topics. Each of them may be a research area of its own and might require a specific treatment and an extensive discussion. This could be a limitation of this study. Nevertheless, this thesis represents a first attempt to link all these topics together to understand the research challenges in developing better design standards. Therefore, the author would like to consider this potential limitation as an opportunity to provoke interest among the research community to further explore this under-researched field. The following represent lines of investigation that have not been covered in this thesis or have only been touched upon, and may be addressed in future work.

The first suggested area for research could look in more detail into the future roles of design standards in the construction industry, particularly in relation to the current processes of digitalisation. In Chapter 5 the value of incorporating structural verifications into digital models and supporting modularisation and off-site manufacturing has been touched upon to show the potential need for bringing in some extra factors to the development of future design standards. These themes require a more extensive exploration.

The second area for research could investigate cluster analysis to enhance text navigation and accessibility of information. In Chapter 8 cluster analysis was adopted to analyse the pattern of EN 1990 and improve its structure. More work should be done to define global and local measures of the index of navigation of standards in order to optimise the network of information.

A third avenue of research could focus on the Agile approach applied to document development. In Chapter 9 Agile has been introduced as a novel approach to streamline standards drafting. While some preliminary benefits of this approach have been identified in the DMRB project, more work is needed to draw more general conclusions on its applicability and identify its limitations.

The fourth suggested area of future work attains to the concept of design standards as learning frameworks. In Chapter 10 some initial speculations have been made on the value of bringing standards development into harmony with recent advances in contemporary learning theories. This initial exploration requires a more systematic exploration.

A fifth area for future research is represented by the validation of the outputs of the framework proposed in Chapter 11 (i.e. the design standards produced). This will require collection of feedback from standards writers and users.

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Annexes

Annex A

Questionnaire for the Eurocodes project

This Annex reproduces Tables A and B circulated to collect the view of the CAP on ease of use and reduction of nationally determined parameters (NDPs) of the Eurocodes.

Introduction

In order to collect view of the membership of the CAP on ease of use and the reduction of NDPs, please can you complete the following questionnaire. The results will be analysed and used as a basis for discussion. There are two tables to complete.

Table A: Strategy for improving the ease of use

Please rate your level of agreement with each of the statements listed in the table on a scale of 1-9, with *(1) strongly disagree*, *(5) neither agree or disagree*, *(9) strongly agree*. You can also enter your comments relating to your answer in the right hand column of the table.

Table B: Key performance indicators / attributes of user-friendly design standards

Please rank the attributes listed in the table in order of their importance to the user friendliness of the Eurocodes, assign (1) to the most important, then number sequentially (2, 3, 4 etc) to the least important.

Responses are requested by 17 January 2014 and should be sent to Mariapia Angelino (mariapia.angelino@pbworld.com)

Table A Strategy for improving the ease of use

		Strongly disagree				Neither agree or disagree				Strongly agree	
No.	**Statement**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**Comment**
	GENERAL										
01	Designers are the most important users of the Eurocodes										
02	The Eurocodes need to be suitable for adoption by the Regulators / in regulation / in national regulation										
03	The Eurocodes need to be suitable for teaching at university / for use in education, therefore should use consistent principles irrespective of application										
04	The Eurocodes must clearly define the responsibility of Clients										
05	The Eurocodes should incorporate/include all design requirements for products for which CEN standards exist										
06	The Eurocodes should contain rules for execution										
07	The Eurocodes should contain rules for product performance										

		Strongly disagree				Neither agree or disagree				Strongly agree	
No.	**Statement**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**Comment**
STRATEGY FOR PROMOTING EASE OF USE											
08	The work on the development of the next generation of the Eurocodes should be an evolution avoiding fundamental changes to the approach to design and to the structure of the Eurocodes										
09	The number of pages will be a key factor affecting the ease of use of the Eurocodes after 2020										
10	Electronic hyperlinked versions of standards will be the predominant way that standards will be used after 2020										
11	Providing simple/simplified methods for design is important to promote ease of use										
12	It is essential that the underlying structural / geotechnical mechanics are clear for the users of the Eurocodes										
13	It should be clear to users why the Eurocodes include the requirements they do										

		Strongly disagree				Neither agree or disagree				Strongly agree	
No.	**Statement**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**Comment**
14	The Eurocodes should clearly state what a designer must achieve										
15	The Eurocodes should provide designers with tools setting out how to achieve requirements										
16	Clear statements of principles underpinning important elements of the Eurocodes should be provided										
17	The Eurocodes should include detailed design methods for specific applications										
18	The Eurocodes should not contain material that can be found in standard textbooks										
19	Simplified formulae should be provided to avoid the need for computer analysis										
20	Where simplified methods are provided, the boundary of their application must be clearly stated										
21	The background to design requirements and methods should be provided within the Eurocodes themselves										

		Strongly disagree				Neither agree or disagree				Strongly agree	
No.	**Statement**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**Comment**
22	Alternative design methods for satisfying the same requirements / for fulfilling a particular requirement should always be avoided										
23	The Eurocodes should not cover special cases that are very rarely encountered by designers										
24	The Eurocodes should not inhibit the freedom of expert practitioners to work from first principles										
25	The Eurocodes should provide adequate freedom for innovation										
26	Alternative safety concepts that those in EN 1990 should be adopted to improve the ease of use of the Eurocodes										
27	The content of the Eurocodes should contain state-of-the-art material the use of which has been validated through research and sufficient practical experience										
28	Model codes prepared by Non-Standardization Bodies should become a source for new design approaches and new concept										
29	The Eurocodes should include greater emphasis on what can practically be achieved during construction										

		Strongly disagree				Neither agree or disagree				Strongly agree	
No.	**Statement**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**Comment**
30	Improving the clarity of the Eurocodes should be the highest priority in the improvement of ease of use of the Eurocodes										
31	Simplifying routes through the Eurocodes (i.e. simplifying navigation within and between different parts) is the highest priority for improving ease of use										
32	Limiting the inclusion of alternative application rules is the highest priority thing for improving ease of use										
33	Inclusion of additional and/or empirical rules for particular structure or structural-element types should be avoided										
34	Any simplified rules must be consistent with the principles of the Eurocodes and have sound technical justification										
35	Potential for misinterpretation must be minimize in the development of the next generation of the Eurocodes										
36	The Eurocodes should be developed to make them easier to apply by new users										
37	The use of informative annexes should be minimized										

		Strongly disagree				Neither agree or disagree				Strongly agree	
No.	**Statement**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**Comment**
38	Care must be taken in the evolution of the Eurocodes not to lose the thinking behind the current versions										
39	We should try to define some measures of what constitutes a 'good' standard that we can use to assess improvement in the Eurocodes										
	PRESENT EUROCODES										
40	There is significant opportunity to improve the clarity of the existing Eurocodes										
41	There is significant opportunity to reduce the number of pages in the Eurocodes										
42	There is significant opportunity to present complicated requirements in a simpler fashion without important methods and insight being lost										

		Strongly disagree				Neither agree or disagree				Strongly agree	
No.	**Statement**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**Comment**
	REDUCTION OF NDPS										
43	The variation on NDPs / the number of NDPs significantly impacts on the ease of use of the Eurocodes										
44	The rules of the inclusion of NDPs should be strictly adhered to in the development of the next generation of the Eurocodes										

Table B Key performance indicators / attributes of user-friendly design standards

No	KPI	Ranking 1-18	Comment
01	Have clear scope.		
02	Readily understandable, i.e. using effective and simple language understood by all the expected standard users.		
03	Concise		
04	Clearly defined limitations on application of design methods		
05	Users can readily identify the information they require		
06	Provide flexibility for expert designers		
07	Unambiguous, with a minimized potential for misinterpretation and misapplication of the contents		
08	Easy to navigate with a clear, coherent and logical structure		
09	Number of cross references is minimized		
10	Consistent in language and structure		
11	Enable cost-effective design		
12	Provide simplified calculations for the most common design cases		
13	Provide clear routes through the standards for the most common design cases		
14	Design methods are technically consistent irrespective of type of structure being designed		
15	The number of alternative methods is minimized		
16	Comprehensive for all common design cases		
17	Provide design basis for special cases		
18	Content should be at the state of the art, validated through research and sufficient practical experience		

Annex B

Questionnaire for the DMRB project

This Annex reproduces Tables A, B and C circulated to collect the view of selected stakeholders on the usability, structure and content of the DMRB. A preliminary draft of the tables was developed by the author and finalised with the WSP team.

Introduction

In order to collect view of selected stakeholders on the usability, structure and content of the "Design Manual of Road Bridges" (DMRB), please can you complete the following questionnaire. For specific information on the project please read the Briefing Paper attached. The results will be analysed and used as a basis for discussion.

There are three tables to complete:

Table A: General information

Please complete the table by providing the general information required.

Table B: Statements

Please rate your level of agreement with each of the statements listed in the table on a scale of 1-9, with *(1) strongly disagree*, *(5) neither agree or disagree*, *(9) strongly agree*. You can also enter your comments relating to your answer in the right hand column of the table.

Table C: Open questions

Please provide answer to the open questions listed in the table.

Responses are requested by 16 October 2015 and should be sent to Mariapia Angelino (mariapia.angelino@pbworld.com).

Table A: General information

Name:	
Organisation:	
Role in the organisation:	
Key areas of interest in DMRB Please specify	

Table B Statements

		Strongly disagree				Neither agree or disagree				Strongly agree	
No.	**Statement**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**Comment**
						CURRENT DMRB					
1.	The DMRB is a user friendly suite of documents.										
2.	Relevant information can easily be found in the DMRB.										
3.	The purpose of the DMRB is to provide (mandatory) requirements.										
4.	It is helpful for the DMRB to provide advice.										
5.	A high level of editorial consistency exists in the DMRB.										
6.	The distinction between (mandatory) requirements and guidance (advice) is clear.										
7.	The current DMRB provisions lead to an unduly conservative design.										
8.	The current DMRB inhibits innovation.										
9.	The DMRB has an important role in enabling efficiency in construction.										
10.	The DMRB has an important role in eliminating barriers to innovation by providing requirements and/or guidance for the application of innovative techniques or products (e.g. new materials).										
11.	The DMRB helps enable innovative methods to become widespread industry practice										

		Strongly disagree				Neither agree or disagree				Strongly agree	
No.	**Statement**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**Comment**
	FUTURE DMRB										
12.	The future DMRB should have fewer pages.										
13.	The future DMRB should contain fewer documents.										
14.	Short documents (say less than 10 pages) should be incorporated into other documents or deleted where possible.										
15.	The future DMRB should not duplicate requirements in other Standards.										
16.	Future DMRB documents should be updated at least every 5 years.										
17.	It should be straightforward for future DMRB documents to be updated regularly.										
18.	Conflicting requirements in the DMRB should be eliminated.										
19.	Other publishers (e.g. CIRIA, BSI) should be encouraged to publish advice and/or guidance currently contained in DMRB, so that it can be removed from the DMRB in future.										
20.	Professional, trade and industry bodies should be encouraged to maintain and publish advice and/or guidance currently contained in DMRB, so that it can be removed from the DMRB in future.										

		Strongly disagree				Neither agree or disagree				Strongly agree	
No.	**Statement**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**Comment**
21.	Highways England and the devolved Administrations should endeavor to produce more shared documents with other asset owners (e.g. Network Rail; Environment Agency).										
22.	The future DMRB needs to be suitable for working electronically.										
23.	The structure of the future DMRB should enable new information or requirements to be added without disrupting its use.										
24.	A higher level of editorial consistency would be helpful for users.										
25.	The future DMRB should only contain (mandatory) requirements.										
26.	The future DMRB should be more flexible.										
27.	The level of safety in the future DMRB should not be reduced.										
28.	Designers should be willing to accept a higher degree of liability in return for greater flexibility in the future DMRB.										
29.	The future DMRB should contain a greater proportion of performance standards (i.e. documents where requirements are performance based).										
30.	The use of performance standards requires effective ongoing monitoring of compliance with required performance levels										

		Strongly disagree				Neither agree or disagree				Strongly agree	
No.	**Statement**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**Comment**
31.	Performance standards can lead to a diversity of solutions on the network resulting in challenges for ongoing management.										
32.	Contractual liabilities will need to change / be extended to enable performance standards to be used more widely.										
33.	The future DMRB should enable best whole life cost design being produced.										
34.	The future DMRB should contain a greater proportion of documents where the requirements are risk based (i.e. the action required is dependent upon an assessed level of risk).										
35.	The future DMRB should have an important role in eliminating barriers to innovation by providing requirements and/or guidance for the application of innovative techniques or products (e.g. new materials).										
36.	The DMRB should help enable innovative methods to become widespread industry practice										
37.	DMRB documents should be updated as soon as possible once a threshold number of departures to a particular requirement have been received (e.g. say, 10 departures triggers an automatic review)										
38.	The users of the DMRB should be more involved in its development										

Table C Open questions

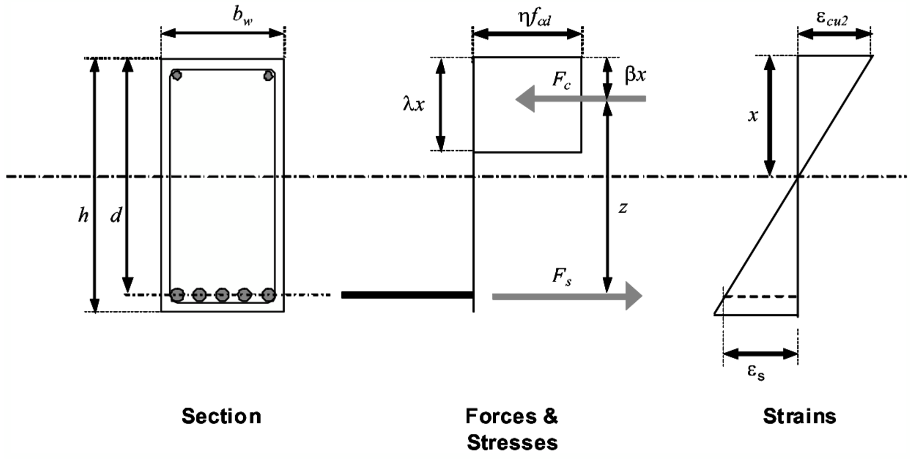
CURRENT DMRB		**Comment**
1.	What is the overall purpose of the DMRB?	
2.	What are the current limitations of the DMRB?	
3.	Which features of the current DMRB are particularly important and do you not want to lose in the future DMRB and why? Please provide the three most important to you.	
4.	Are there gaps in the current DMRB that need to be filled?	
5.	Should the current structure of the DMRB be changed? If so, how should this be done?	
6.	Should the current DMRB be changed to enable greater innovation? If yes, how could this be done and could there be any adverse (unintended) consequences?	
7.	Which parts of the DMRB should be targeted for change first (e.g. most used, least used, oldest, highest risk, most rapidly changing field of application)? Why?	
8.	Does the current DMRB inhibit innovation? If yes, please provide example of how it does and specific illustrations.	
9.	Does the current DMRB encourage innovation? If so, how? Could this be improved?	
10.	Any other comments?	
FUTURE DMRB		**Comment**
11.	What should the overall purpose of the DMRB be?	
12.	The DMRB is used by different groups (i.e. designers, asset owners, contractors, suppliers). Which group should be the primary target audience? Why?	
13.	Should the DMRB contain advice and/or guidance? If yes, what kind of advice and/or guidance do you think should be included in the future DMRB and where?	
14.	Do you have any concerns about the more widespread use of performance based requirements in the future DMRB?	
15.	How could the DMRB be improved to enhance the efficiency, quality and safety of construction?	
16.	How could the DMRB be improved to enhance the efficiency of network operations and maintenance?	
17.	Should the future DMRB be modified to enable to work electronically more effectively? If yes, what changes would you like to see?	
18.	Any other comments?	

Annex C

Instructions for the pilot experiment

ULS design of a concrete beam

Please calculate bending and shear resistance of the following concrete beam section.



Maximum ULS bending moment	M_{ed} = 800 kNm
Maximum ULS shear force	V_{ed} = 650 kN
Zero axial force	

Material properties

Characteristic cylinder strength	f_{ck} = 35MPa
Characteristic tension reinforcement yield strength	f_{yk} = 500 MPa
Characteristic shear reinforcement yield strength	f_{ywk} = 500 MPa

Coefficient for long term effects and other unfavourable effects (for bending) α_{cc} = 0.85

Section Details

Width of section	b_w = 500 mm
Height of section	h = 1000 mm
Tension reinforcement diameter:	Φ_t = 25 mm
No. of tension bars:	n = 5
Nominal cover	c_{nom} = 40 mm
Link diameter	Φ_v = 12 mm
Area of tension reinforcement	A_s = 2453 mm^2
Effective depth	d = 935.5 mm

Phase 0 (20 minutes)

Please start reflecting and write down providing as many details as possible:

1. the key steps necessary to carry out the calculation,
2. the fundamental principles/aspects to consider in the design of a concrete beam,
3. your expectations on what the design standard should provide as a minimum to enable the design to be carried out.

Once you have answered these questions, please provide any comments on how this activity was to you (straightforward, frustrating, etc.) and the reasons for that.
You can then move on to Phase 1.
Please do not come back to this stage once you have moved to the next stages.

Phase 1 (10 minutes)

Open Version 1 and answer the following questions. Please provide as much detail as possible.

1. Were your expectations from Phase 0 on the content of the standard met?
2. If no, why is that?
3. Can you carry out the design by using Version 1?
4. If the answer is no, why is that? What are the issues?
5. What should the design standard provide for you to complete the exercise?

Phase 2 (10 minutes)

Open Version 2 and answer the following questions. Please provide as much detail as possible.

1. Does Version 2 meet your expectations on what the design standard should provide? If so, why? If not why?
2. What can you say about the level of detail provided by Version 2?
3. Can you carry out the design by using Version 2?
4. If no, why?
5. Please reflect on what the design standard should provide for you to complete the exercise and provide details.

Phase 3 (10 minutes)

Open Version 3 and answer the following questions:

1. What can you say about the level of detail provided by Version 3, particularly compared to Version 2?

Phase 4 (10 minutes)

Please reflect on what you have done.

1. Which version best suits your capabilities in tackling this design task? Why?
2. How have different versions of the design standards contributed to the design task?
3. What have you learned about your expectations on what a design standard should provide as a minimum to carry out this task?