RETHINKING DESIGN STANDARDS AS LEARNING FRAMEWORKS

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Who Should Read this White Paper?

This White Paper will be of interest to anyone involved in standardisation processes in the construction industry, particularly to practitioners and standards writers. The accelerating and deepening understanding of how we learn, coupled with rapid information technology innovations, are driving transformation in construction practices and technologies. This White Paper is intended to provoke broad reflection on the fundamental purpose and nature of standards. It argues that current forms of standards are not aligned with these change drivers and are more likely to impede construction transformation than facilitate it.

Key Messages from the White Paper

1. Design standards are fundamental mechanisms in the construction industry to frame common understanding, align and connect practice across the supply network, and to pose necessary performance constraints, for example to provide safety.

   Elaboration: Design standards occupy a key role in the construction industry. Each construction project is inherently unique and there are few opportunities to prototype, so design standards are used to verify the adequacy of designs to meet fundamental requirements for safety, serviceability, durability and robustness.

2. Design standards should foster creativity and innovation, supporting and enhancing the imaginative decision making of designers, rather than overly controlling or inhibiting it.

   Elaboration: It is neither possible nor desirable exhaustively to capture the manifold problems that designers of assets come across. Rather than providing unduly prescriptive provisions, design standards should enable designers better to deploy their imagination as they handle uncertainty, build confidence and take responsible decisions.

3. Design standards should enable continuous improvement and purposeful responses to the rapidly changing and complex demands of society for infrastructure services.

   Elaboration: Standards should accommodate the need for engineers to adapt to the rapid changes in the natural and social environmental drivers and their effects on infrastructure service provision, including: (i) advances in technology; (ii) the emergence of specific technical provisions; (iii) the aim to achieve greater consistency in structural and functional reliability; (iv) the need for efficient asset management; and (v) the promotion of sustainable practices.

4. Design standards in the construction industry should be explicitly reconceptualised, re-evaluated and redeveloped as learning frameworks.

   Elaboration: Technical standards capture best practice and separate them into the successful or unsuccessful. Recognizing the contribution of design standards to learning and knowledge exchange will support critical engagement and close consideration of user needs, improve communication between stakeholders, and facilitate feedback loops and collaborative learning and improvement. The outcome will be greater freedom to innovate safely and thereby create and capture greater value.

Abstract

Standards align practice across the supply network whilst putting in place basic constraints to ensure quality, safety, compatibility, interoperability, and economy. In the construction industry, design standards are used to verify the adequacy of designs to meet fundamental requirements for safety, serviceability, durability and robustness. There are very few opportunities to prototype; thus design in the construction industry is fundamentally code or standard-driven. In the highly diverse built environment, design standards will never cover all possible situations encountered by designers. Hence, standard writers are expected to select, capture and codify technical knowledge, separate best practice from unsuccessful practice, and share the lessons learnt across the professional community. In this context, standards are representations of a community’s mental model about what ‘good’ looks like, and they serve powerfully to reinforce a particular way of doing things. However, in times of rapid change and increasing complexity, these mental models may no longer be fit for purpose. They need to be re-examined and modified in the light of new challenges and demands. The core argument of this White Paper is that design standards in the construction industry need to be explicitly reconceptualised, re-evaluated and redeveloped as learning frameworks, which encourage users’ adaptability and collaborative learning and improvement, as well as foster creativity and innovation. To support this statement, fundamental notions of contemporary learning theory are presented and key challenges in the way design standards are currently developed and used are discussed. The importance of considering standards from a learning perspective is emphasised by looking at mental models underlying the way design standards are developed and used and recognising the learning power of different users explicitly.

Key Words

Standards, Design, Technical, Adaptability, Collaborative Learning, Best Practise, Innovation.

Connections to Other ICIF White Papers

- Learning Journeys & Infrastructure Services: A game changer for effectiveness
- Smart Infrastructure: Benefits and Pitfalls

Where Can I Find Out More?

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Boundaries of this paper

- The International Organization for Standardization defines a *standard* as a "*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*" (ISO, 2004).
- Standards are not regulations or mandatory documents. However, they can be enforced by authoritative regulations or contracts.
- Technical standards in the construction industry comprise a variety of different documents, including structural standards (i.e. design and assessment standards, product and material standards, test standards, execution standards), quality management standards, environmental standards, health and safety standards, and many more.
- For the purpose of this paper, essentially only structural design and assessment standards will be considered. These are written documents which provide minimum requirements to verify structural adequacy. In this paper the term "design standards" refers to both design and assessment standards. However, many of the arguments raised are equally applicable to other kinds of standards.
- The term "users" adopted in this paper refers to all stakeholders who use design standards, i.e. designers, clients, suppliers, etc.

1 Introduction

Standards codify technical knowledge and expertise through a laborious process of development and implementation (Russell, 2005). Design standards in the construction industry establish a common understanding of design procedures and are used to verify the adequacy of designs to meet fundamental requirements for safety, serviceability, durability and robustness. Therewith they provide an accountability framework for the practising engineer and a benchmark for their professional achievements.

Standards and standardisation in general are also considered a key element for current policy objectives like fostering the resilience of cities (Arup, 2014) or incentivising the development of smart infrastructure (Collins et. al, 2016; Future Cities Catapult, 2016). Although not per se regulatory, "*the development of standards forms part of a trend that sees public authorities* *delegating to private organizations the enactment of rules that, even if they do not have the force of law, are no less binding in nature*." (Borraz, 2007). Thus, standards development not only builds on technical rationale but also constitutes a societal responsibility for standards organisations as well as for the contributing individuals.

If a standard is successfully implemented and adopted by a major part of the industry, it fundamentally shapes the everyday work of the professionals using them. Technical knowledge is commonly not applied before it is included in a standard. Consequently, standards determine the actions and directly influence the mental models of their users. The users in turn can have multiple requirements about what kind of information the standard should provide.

Design standards can never cover all possible situations encountered by designers. Thus, they provide a necessary but not sufficient benchmark for expertise. To apply design standards in a way that optimizes the resulting design, engineering judgement is crucial. In today's rapidly changing and complex demands of society for infrastructure services, confident and imaginative engineering judgement will become more important than ever.

The Royal Academy of Engineering's report *Thinking Like an Engineer* (Lucas, Hanson, and Claxton, 2014) identifies some distinctive ways of thinking and acting by engineers and highlights the importance of better understanding these in order to develop future "engineer-learners". Design standards play a fundamental role in this process. Current design standards do not acknowledge different expertise or learning styles of designers and seem insufficiently to allow for creative and innovative thinking.

This paper proposes explicitly to reconceive standards as frameworks which promote learning and help practitioners at the various stages of their careers to handle uncertainty, build confidence and take responsible decisions. If standards would purposefully engage the learning capabilities of practitioners, the practitioner would learn better and faster, would build a more dependable understanding of the subject matter and choose more effective actions. In this paper, the challenges and opportunities of such an approach are explored explicitly for design standards in the construction industry.

The authors believe that this work will be also beneficial to other areas in the construction industry which face a current need for standardisation, like smart technologies (Collins et. al, 2016). However, additional research will be necessary to understand fully the implications and opportunities of the proposed mind-shift, as well as to explore its transferability to other domains.

2 What is "Standardised" in a Design Standard?

Structures directly influence the safety, health and well-being of the population. "*All portions of a facility's life cycle (design, construction, operation and decommissioning) are circumscribed by codes and regulations*" (Slaughter, 1998). Design standards provide minimum requirements to verify structural adequacy. Specifically, they articulate the provisions - i.e. statements, instructions, recommendations and requirements - for the design of safe, serviceable, robust and durable structures. Design standards are expected to be used in conjunction with material, test and execution standards which provide more 'functional' requirements. This is similar to what happens in the IT sector, where IT 'base' standards establish "*a baseline of a common understanding of what a given system or service should offer*", whereas 'functional' standards "*address implementation and interoperability issues*" (Jakobs, 2000).

In the highly diverse built environment, design standards will never cover all possible situations encountered by users. Thus, one of the major tasks of standards writers is to select what must be "standardised". Design standards capture and codify technical knowledge, separate best practice from unsuccessful practice and share the lessons learnt across the professional community. Moreover, the appropriate application of design standards requires specific engineering knowledge, which is not just about technical information and data. Vick (2002) argues that "*knowledge is information in context*", which in turn requires synthesis and integration to be meaningful. This leads to the concept of engineering judgment, defined as "*the means by which evidence is recognised, supporting evidence compiled, conflicting evidence reconciled, and evidence of all kinds weighted according to its perceived significance*" (Vick, 2002).

The decision on which and how much knowledge is "standardised" in a design standard is essential as it limits the range of options available to users to fulfil their everyday tasks and, as argued by Shapiro (1997), it shapes the judgment space of users. This decision depends greatly on the skills, capabilities and expectations of users, as well as on the appropriate communication by standards writers. Therefore, if we were able to reconceive design standards explicitly as "learning frameworks" which support learning and purposefully engage and harmonise the learning capabilities and skills of users, users would learn better and faster and would likely form better choices of effective actions. These "learning frameworks" would then become our new design standards specifically targeted to users and how they learn.

This is far from straightforward. A number of challenges need to be overcome in the development and application phase of a design standard to achieve this objective as discussed in the next section.

3. Key Challenges in the Development and Use of Design Standards

The development of design standards inevitably entails tensions concerning content (i.e. *what* is standardised) and process (i.e. *how* those standards are developed and used by stakeholders). Equally, the application of design standards can be challenging for several reasons, potentially leading to inconsistent application in practice. In this section some key challenges for the development and use of design standards are presented more in detail.

3.1 Challenges in standards development – multiple views, politics and future changes

The development of design standards is a multi-stakeholder process facilitated by a standards developing organisation and aimed at defining agreed technical solutions and establishing a common understanding between all those likely to be influenced by them (Yates, 1997; Yates, 1998; Sharif, 2005; Bredillet, 2003; British Standards Institute, 2011; Jakobs, 2000). The aim of standards developing organisations is to develop standards through a transparent, open and consensus-based process. A variety of different stakeholders are involved, including designers, regulators, industry bodies, clients, contractors, professional institutions, research organisations, universities, learned societies, educators, software producers and lawyers. While the process builds on voluntary participation of individuals or organizations, the resulting standards powerfully influence the design practice of a wider audience.

There are inherent complexities and dichotomies in striving to meet the needs of many users. Angelino and Agarwal (2014) list a variety of purposes of design standards as derived from literature, discussions with industry experts and workshops with practitioners. This multiplicity of purposes makes it clear how important is the decision about what is standardised. This issue is not new, but already emerged from debates at the Institution of Civil Engineers and the Institution of Structural Engineers in the early 1980s (Moffatt and Dowling, 1981; Sunley and Taylor, 1982). For example, Sunley and Taylor (1982) report the following comments:

> "*If the structural Codes continue to be drafted as multipurpose documents, they will inevitably become more and more incomprehensible and less and less usable*".

> "*The original purpose of Codes was to provide reliable guidance to an engineer, who is not necessarily an expert in the particular subject covered, […]. I would suggest that the complexity in the latest Codes has arisen because: (1) Their purpose has changed since they have been adopted as an agreed method of compliance with the Building Regulations. Their principal role has become one of control rather than communication* (…)".

Tensions among the stakeholders involved in the standardization process are thus inevitable. Weiss (1991) writes that, while the stated goal of developing a standard may be adopted by most of the committee members, other – secondary – goals may also exist and these may be in conflict with the dominant purpose. Different stakeholders may have competing views and consequently might contribute negatively to the standardisation process (Allen, 1992), thus affecting the usability of standards and their successful application. Takahashi and Tojo (1993) even claim that the standardisation process can become "*a political or economic power game although the topics discussed are mostly of a purely technical nature*".

Moreover, the development of design standards needs to take account of the significant changes affecting the construction industry. Advances in technology are constantly transforming the way structures are designed, built, managed, operated and dismissed. Building information modelling, automation, and new sensor technologies, are some of the most significant changes civil and structural engineers are facing. These changes and challenges have been acknowledged in the vision for the UK construction sector in 2025 (HM Government, 2013) as well as in the "The vision for civil engineering 2025" published by the American Society of Civil Engineers (2006). Future standards need to recognise these changes and enable designers to make better use of the new technologies in a timely manner in order to encourage creative thinking to achieve innovative, cost-efficient, environmentally-sensitive, and sustainable designs.

Similarly, looking to the much longer term, advances in Artificial Intelligence and machine-based learning, design and manufacturing techniques are likely to progress far beyond their current state. These techniques and tools will automate more design tasks and steps, allowing the designer to explore wider and more complex and imaginative design spaces in search of good solutions.

Intelligent robotic infrastructure manufacture will bring infrastructure more in line with product manufacture. Machine-based design will certainly be closely coupled with machine-based manufacturing and construction. The design process will thus need to embed buildability into the design to avoid a redesign process – which would add significant cost – and to enable machines to actually build the structure. The separation of 'design' standards from 'construction' standards will therefore become less and less relevant, as we will have to move to standards that cover the whole lifespan of infrastructure.

Understanding and characterisation of structural performance (including the performance of the construction process) should co-evolve with the technologies and processes over a longer timescale. Current definitions of performance will probably no longer be valid or will be too simplistic in comparison with how we will perceive them in the far future. Similarly, current performance-based standards do not evolve appropriately, they will not realise the full opportunities that advances in new technologies can offer.

3.2 Challenges in standards application – quantity and usability

Performance-based standards *focus on general principles and desired quality level or performance of the finished work, thus providing more flexibility to select materials, techniques, and procedures.*

The insufficient usability of standards and the resultant necessity to develop more user-orientated design standards has been acknowledged by several institutions. At European level, a major focus of the work on the second generation of Structural Eurocodes will be on improving their usability (CEN/TC 250, 2015). In the US, the purpose of a recent review of the American Concrete Institute Building Code Requirements for Structural Concrete (ACI 318) has been "*to provide a more user-friendly backbone for design*" (Poston and Dolan, 2012). Similarly, Highways England has recently carried out a consultation to explore the view of different stakeholders on how usability, structure and content of the Design Manual for Roads and Bridges (DMRB) could be improved. The reasons for the limited usability of design standards are manifold as discussed below.

Alongside with the development of new technologies and the internationalization of the construction industry, the number of technical standards to comply with for a particular project is increasing. In particular, a growing number of technical requirements is developed at international, regional as well as national levels. Cross-references among standards stemming from different normative sources can cause overlapping and sometimes conflicting requirements or gaps (Angelino et. al., 2014). It is a critical challenge for all stakeholders to respond to the often overwhelming dataflow in a meaningful manner. This requires people who are oriented towards learning and who are capable to select and use data and information in a meaningful way to improve their work.

From a more practical perspective, according to the Industry Standards Group (2012), over-specification and the tendency to use unnecessary standards lead to preventable additional cost to the already high necessary investments for delivering infrastructure.

In addition, practising structural engineers have to apply ever more complicated technical provisions in order to meet customers' demands, achieve greater consistency in structural reliability, and deliver designs perceived as contributing to economic well-being as well as sustainability (Angelino et. al., 2016). In particular, climate change is putting pressure on the built environment and increases the need to address the associated uncertainties in the design of new structures. These uncertainties may also have to do with the relationship between the social and the technical world, and understanding and addressing these goes beyond traditional engineering knowledge.

Moreover, there is a perception among users that design standards are often too prescriptive or solution driven. In this context, a move towards performance-based standards can be beneficial. However, as discussed earlier, this would require s the performance requirements to be clearly understood and characterised. This is far from straightforward for construction projects, where requirements are often complex, multi-layered and interdependent, particularly when dealing with long term assets.

These aspects may lead to the inconsistent application of standards. The UK Industry Standards Group (2012) claims 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*". Likewise, Wilson, Grose and Rawlings (2015) acknowledge that "*inefficient and inconsistent use of codes and standards can hamper effective delivery of infrastructure projects*".

> ***Prescriptive (or method) standards*** *focus on technical details and prescribe specific methods to design. They provide little opportunity to deviate.*

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3.3 Emerging themes and reflections

Several conflicting aims have to be balanced in the development and use of a standard. These include: the aspiration to address all users' needs whilst not making the standard more complex; the need to avoid technical provisions that are overly complex, whilst also not inhibiting experts from applying their knowledge and deploying advanced methods of analysis; the desire to incorporate latest developments whilst providing stability; the aspiration not to inhibit innovation, yet also provide clear provisions for common design situations and also help ensure long term performance and appropriate whole life cost. These tensions mainly stem from the subjective process of codification of standard writers as well as from the existence of many users with different capabilities and skills, who have different expectations of what these documents should provide.

The lack of focus on learning is also exacerbated by some inherent features of the construction industry. Dubois and Gadde (2002) noted that the temporary nature of the construction project does not promote learning or intelligent adaptation to better serve the project's purpose. Consequently, the ability to develop stakeholders with the learning power, dispositions, values and attitudes that favour improvement and innovation seems to be severely restricted. In addition, Dubois and Gadde (2002) argued that learning takes place at an individual level rather than an industrial level.

As discussed in section 2, design standards capture and codify technical knowledge, separate best practice from unsuccessful practice and share the lessons learnt across the professional community. For design standards to operate in this way, feedback about whether a standard is being met or not should be captured in two ways:

1. as a benchmark to retrace designers' decisions for accountability purposes, which in education is called "summative assessment";
2. as information that can be used to improve application of the standardized processes and subsequently wider system improvement ("formative assessment").

If design standards are inflexible and only used for summative judgements, they can discourage creative thinking. If, however, design standards are developed to be used formatively and to contribute to a building project as a complex whole, then they are more likely to encourage the designer's adaptability (or learning power), creativity and innovation.

Whilst design standards influence the world view of users and the ways in which they identify and pursue their range of options, the development of design standards does not seem to explicitly recognise the diverse learning processes of users. Design standards should support users' ability to form cognitive structures favouring critical application of technical provisions and learning. Therefore, as mentioned earlier, if we were able to reconceive standards explicitly as "learning frameworks" that purposefully engage and orchestrate the learning capabilities of users, then users would learn better and faster and would choose more effective actions. These aspects are discussed in the next section.

4. Rethinking Design Standards as Learning Frameworks

This section explores the idea of rethinking design standards from a learning perspective and offers preliminary thoughts on how this could be approached.

4.1 Mental models underlying the way design standards are developed and used

Mental models are "*cognitive representations of external reality*" (Jones et al., 2011). Every person builds a personal mental model of a certain theme or domain, which in turn determines the habitual reactions to tasks in this domain. Or, as Johnson-Laird (1983) puts it: "*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.*" A mental model is a short hand for describing the sorts of values (clusters of beliefs), attitudes (emotional orientations) and dispositions (tendencies to behave in a certain way) that frame the ways in which people see the world. As the world is not static, mental models are dynamic and inherently incomplete and inaccurate, because of individual limitations and the impossibility to represent every facet of reality (Jones et al., 2011). Furthermore, mental models often operate 'out of awareness' and function as 'habits of mind' that frame what is possible in any situation.

The Royal Academy of Engineering's report *Thinking Like an Engineer* (Lucas, Hanson, and Claxton, 2014) identifies distinctive ways of thinking and acting of engineers they call 'habits of mind', and highlights the importance of better understanding of these habits in order to develop future "engineer-learners". The identified core habits of mind are illustrated in Figure 1.

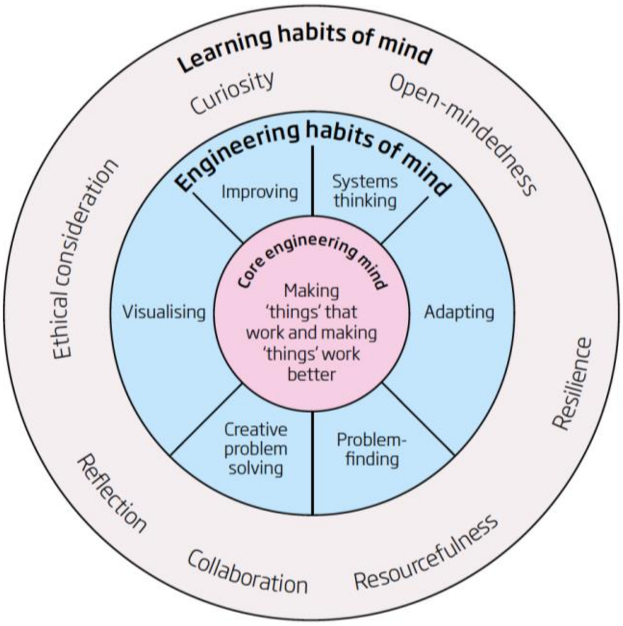

Figure 1 The Centre for Real-World Learning Engineering Habits of Mind (Lucas, Hanson, and Claxton, 2014)

Deep learning takes place when individuals and teams are agile and reflexive enough to (i) challenge their own assumptions and beliefs, (ii) identify, select and apply new information to their task and (iii) arrive at novel solutions to the problems they are solving. From the learning perspective we know that peoples' approach to learning and change can be one which understands knowledge as static and pre-scribed (a fixed mind-set) or one which understands knowledge as fluid and adaptable in the context of problem solving (a growth mind-set) (Dweck, 2006; Dweck, 2000; Goldspink, 2015).

Design standards are representations of a community's 'mental model' about what 'good' looks like and they serve to powerfully reinforce a particular way of doing things. The way professional knowledge is codified into standards reflects the mental models of standards writers consolidated through the consensus process, and influences the mental models of users, specifically designers. In times of rapid change and increasing complexity these 'mental models' may no longer be fit for purpose. They need to be decoded and modified in the light of new challenges and demands. Knowledge is rapidly created, communicated and recreated, hence a balance has to be achieved between the need for continuous change and adaptation, which in turn enables innovation, and the need for stability and fixation, which simplifies alignment of practice across the supply chain and provides a necessary bottom-line.

One could presume that a designer who struggles to use a standard cannot readily translate the requirements and explanations provided by the standard into their own mental model of the design situation they are dealing with. Reasons for that could be:

1. Designers lack the facility (i.e. competency and/or prior knowledge) to do so. This aspect sheds light on education needs and the importance, when writing standards, of being aware of the target audiences.
2. The mental model of designers departs from what a standard should provide ('*provide me with step-by-step information*' vs '*here is a flexible toolkit to apply*'). This aspect concerns different professional expectations.
3. The standard is written for a different context than the one it is applied in. This aspect needs to be acknowledged considering the internationalization of the construction industry.
4. The standard is not written and/or structured in a way that is accessible for designers by virtue of their learning styles. This aspect should be investigated and inform how standards are structured and written.

The last point is the most relevant to our discussion. Purposeful harmonisation of the mental models of standard makers and designers would enable collaborative learning and improvement. Reconceptualising, re-evaluating and redeveloping design standards as learning frameworks would enable users to learn better and faster and to choose more effective actions.

4.2 Characterizing the learning power of different designers

The 'mental models' and the related 'habits of mind' of engineers both as individuals, teams and organisations, can be understood through an analogy with cooking. If standards were cookery books, we could make a distinction between:

1. Designers who use, and keep using, the standard like a 'recipe book', which provides step-by-step information on how to cook even the simplest things, and

2. Designers who learn about ingredients, the alchemy of food and the art of cooking in general, master measures and ingredients to create their own dishes, and are able to manage the cooking process with competence, taking the right actions in the right moment, and doing them correctly.

Designers in the first category are generally those who are content with a prescriptive standard, which tells you all you need to know to design something. However, this type of standard can be overly restrictive when new ideas are to be implemented or unprecedented situations appear, and taking independent decisions is prevented as far as possible. Moreover, with growing number of 'recipes' or situations covered, as well as with the increasing accuracy of description of these situations, the documents can become more difficult to follow and use, especially if a situation does not fit any of the 'recipes' provided, or the purpose of the meal has changed.

Designers in the second category are generally competent practitioners who want a standard that provides a 'safety net' or bottom-line as well as an accountability framework to take responsible and independent decisions, since giving absolute freedom and unrestricted liability may lead to over-conservatism in design. Generally, this kind of standard does not inhibit innovation; rather it provides appropriate freedom to develop innovative solutions.

Lay people, students and many engineers at the beginning of their career tend to have a very concrete understanding of the situations or 'problems' encountered and can be ascribed to the first category of designers. With experience, their understanding or 'mental models' become more abstract (Jones et al., 2011) and they can thus be ascribed to the second category of designers. In other words, through learning the worldview of designers changes.

An analysis of 15 years of data covering how people describe themselves as learners (Deakin Crick, Huang et al., 2015) suggests that the "learning power" of a person consists of three distinct structures (see also Crick et al., 2016):

1. a set of 'active' dimensions which include 'mindful agency' as a core factor that is predictive of creativity, curiosity, sense-making and hope;
2. a relational component – a sense of belonging to a team or a social network and the capacity to collaborate with others in solving problems;
3. an orientation towards risk and uncertainty, in which one is open and ready to engage, evaluate and adapt, rather than being either dependent and fragile on the one hand or rigidly persistent on the other.

Characterizing the learning power of individual designers taking into account their experiences and habits, as well as concerns, will enable identification of feasible modifications of standards if they shall support each designer at different phases of their personal and professional journey.

4.3 Learning-oriented standards - aligning contents and context

Current standards do not have learning as an explicit purpose. The existence of different mental models underlying the development and use of design standards and of different categories of users with different learning power is not explicitly recognised. Not surprisingly, complaints can be heard in meetings and workshops with practising structural engineers about the fact that, for some, standards are to prescriptive while for others they are too open or difficult to interpret.

Exploring the mental models underlying the development and use of design standards, and characterizing learning power of different designers, will provide meaningful insights into how design standards can be reconceptualised, revaluated and redeveloped to encourage learning and better align the content of design standards to the context in which they are used.

This leads to the idea of *learning-orientated design standards*, which would form a sub-category of the more general framework of *users-orientated design standards* as proposed by Angelino (2016)**.** They would focus on designers and their diverse learning power and knowledge, and would be targeted to accelerate the way designers learn. *Learning-orientated design standards* recognizing the contribution of design standards to learning and knowledge exchange will:

(1) support users' ability to critically engage with the application of design standards and thus contribute to professional improvement;

(2) enable consideration of the needs and expectations of the users of design standards more explicitly, thus providing more flexibility for users with differing levels of expertise;

(3) improve communication between stakeholders and enable them to better articulate, characterize and implement common purpose; and

(4) facilitate feedback loops, and thus collaborative learning and improvement in standardization processes.

Understanding skills and capabilities designers need to best respond to future challenges in the engineering practice both as individuals and in team, will be an important part of this task. Recent advances in neuroscience and contemporary learning theories will provide the tools to enable this investigation.

Models of *learning-orientated standards* addressing the learning power of different designers should be developed and tested in terms of usability and effectiveness taking into account different phases of personal and professional journey.

5. Conclusions

The construction industry is at a critical point where many new enabling technologies are mature enough to provide real benefits for infrastructure provision. In addition, there is a need to transition infrastructure provision from a conventional business-as-usual approach to one that stimulates the kinds of disruptive transformations that are necessary to address global grand challenges such as climate change. The current mindset will be a barrier to the development and adoption of new transformative approaches.

New forms of standards are needed to enable this transition. These standards have to be appropriately and effectively framed such that designers can realise the potential, and need to arise from and reflect new industry mindsets that are orientated towards the opportunistic future rather than the risk averse past.

Both the mindset shifts and the new standards depend on us improving our understanding of the fundamental role of learning in all aspects of the infrastructure provision process and on us folding this understanding into the formation of new standards. These will facilitate capture and reuse of experience in discovering better solutions, whilst actively managing risk and assuring safety. As a consequence, engineers will be able to access and explore a wider, richer and more creative design and provision space.

This paper has presented the key challenges in this process of transition towards new standards. It has pointed to the pathway that *learning-orientated standards* offers for reframing and dramatically improving the design process of infrastructure.

Delivery of these new forms of standards will require secure theoretical and methodological framing, neither of which currently exist. However, as Hesser has stated, standards and standardization yet have to "*reach the status of an academic discipline in their own right, while on the other hand they cannot be classified under one of the accepted academic disciplines such as engineering or social science*" (Hesser, cited in de Vries, 2011). We therefore need to elevate the importance of academic study of standards and set this within a holistic context, if

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we are to underpin the successful co-production of the much needed new generation of standards for future infrastructure.

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