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MANAGING THE TECHNICAL RISK OF PERFORMANCE-BASED BUILDING STRUCTURES

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Abstract. During the past decades, the construction industry has been gradually adhering to major conceptual approaches such as those of quality, performance and risk. This paper proposes a management framework that enables the joint application of these conceptual approaches throughout the various phases of building projects – a Risk-Managed Performance-Based Building (RM-PBB) framework. This framework is based on the policies, procedures and practices of initiatives that gather international consensus, including performance-based model codes and standards, internationally recognized management principles and guidelines, standardized requirements for different types of management systems and also agreed principles of conformity assessment and auditing. This paper presents a summary of the strategic and operational components of this RM-PBB management framework. It also shows the practical outreach of the proposed framework by providing an example of application of each component of the management framework to the specific engineering context of building structures. The example of application further shows how technical risks arising from performance-based building structures can be managed, so that an intended level of structural performance can be fulfilled throughout all stages of a building project.

Keywords: risk management, structural performance, performance-based buildings, building structures.

Introduction

Nowadays, many countries are developing and implementing regulatory building environments with the assistance of risk-informed performance-based regulations and standards (IRCC 2010). The performance-based building concept is more concerned with the description of what a building process (e.g. mutual agreement of interested parties), building product (e.g. the output of a design or construction process) and/or building service (e.g. asset in support of business) is required to achieve – the 'end' – than with how these should be achieved – the 'means' (Foliente *et al.* 2005).

Performance-based environments strengthen the decision making capacity of the various stakeholders and participants in the building sector (Lützkendorf, Lorenz 2006). However, serious liability concerns arise from possible failures of a building that is designed according to performance-based principles (CIB 2004). Therefore, there is also the need to strengthen the capacity for responsibility of these actors in face of an ever-increasing global market place (IRCC 2010). In this regard, the quality and the risk conceptual approaches have been recognized as a needed complement to the performance-based building concept (Almeida *et al.* 2010a). For example, performance-based standards providing guidance to describe the performance of houses, such as ISO/PAS 22539 (2007) and ISO 15928, can be complemented with quality and risk management tools for dealing with the possibility of building failures.

This paper deals with the management of technical risks of noncompliance to legal or otherwise stated performance-based engineering requirements for building projects. It offers a management solution that conciliates and integrates the conceptual approaches of quality, performance and risk within the building subsector. This management solution is based on the concept of Risk-Managed Performance-Based Building (RM-PBB). The full outreach of this concept and the way in which it may benefit different stakeholders throughout the various stages of a building project are described in Almeida *et al.* (2014).

A summary of the proposed RM-PBB concept and the general management framework that enables its practical application to the building sector is presented in Section 1. In the same line of other authors (Watermeyer, Pham 2011; Srdic, Selih 2011; Walker *et al.* 2010), the adaptations of this general framework to facilitate its application to the engineering context of building structures are discussed in Section 2. The seven elements of the RM-PBB framework, together with examples of their

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application to manage the engineering risks of performance-based building structures, are detailed in Section 3. The last section presents a final overview and discussion.

1. Framework for Risk-Managed Performance-Based Building (RM-PBB)

The concept of Risk-Managed Performance-Based Building (RM-PBB) is grounded on an engineering perspective and targets at managing the whole range of requirements that relate to the technical performance of buildings. The authors have designed and developed a general management framework enabling the practical application of the RM-PBB concept to the building sector, at transnational, national, regional and/or local levels (Almeida *et al.* 2014). This RM-PBB management framework derives from the policies, procedures and practices of initiatives that gather international consensus, including performance-based model codes and standards (NKB 1978; ASTM 2000; Hattis, Becker 2001; Meacham 2004a; CIB 2004; ISO 22539 (2007); ISO 15928; ISO 11863 (2011)), internationally recognized management principles and guidelines (health and safety – ILO-OSH 2001 (2001), project management – ISO 10006 (2003), risk management – ISO 31000 (2009)), standardized requirements for quality (ISO 9001 (2008)) and environmental (ISO 14001 (2004)) management systems, and also consensual principles of conformity assessment (ISO 17000 (2004)) and auditing (ISO 19011 (2011)).

The proposed framework includes two fundamental components, as shown in Figure 1, one strategic and other operational. The strategic component includes a single element (*element 1: strategic management*) that establishes the base requirements and the organizational structure needed for the implementation of the RM-PBB concept, as well as for the monitoring, review and the continual improvement of such implementation. The operational component comprises six elements (*elements 2 to 7: information modeling, technical programming, technical evaluation, technical control, technical auditing and technical attestation*), which promote the systematic application of the RM-PBB key principles to the technical aspects of the activities related to building construction. The scope of the proposed framework embraces, amongst others, activities associated with:

- *the regulatory environment* – the development and publication of technical regulations;
- *the market environment* – the marketing of building projects, and;
- *the project environment* – the program, design, construction and operation of buildings.

Furthermore, the proposed framework culminates in assisting the commissioning and testing of the constructed facilities and the issuance of decision supportive statements of conformity.

2. Adapting the RM-PBB framework to the context of building structures

The RM-PBB framework is generally capable of addressing the full spectrum of technical requirements of publically or privately promoted building projects, whether the intended use of such buildings is residential or non-residential. However, the elements of this framework must be developed and adapted according to the specific engineering contexts to which they are to be applied. For example, if the proposed framework is to be used for managing the engineering risks arising from performance-based building structures, the peculiarities of this context have to be considered and the elements of the framework must hence be detailed accordingly.

Table 1 lists the inputs that were taken into consideration for detailing the elements of the proposed general framework to the specific context of building structures. These inputs include performance-based regulations and standards, as well as standardized management principles, guidelines and standards. The robustness of the proposed general framework was not affect by taking this inputs into consideration, for neither the framework form

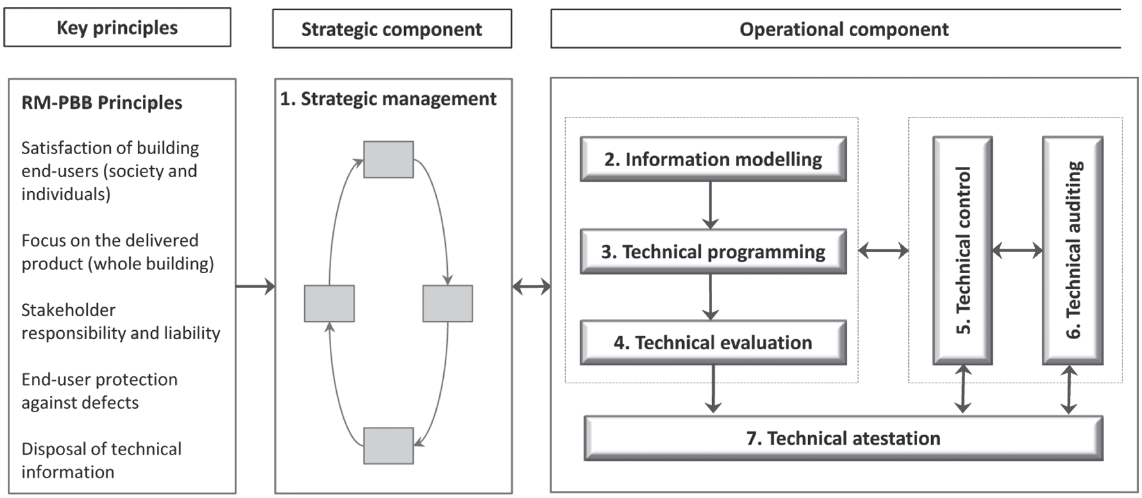

Fig. 1. Risk-Managed Performance-Based Building (RM-PBB) framework (Almeida *et al.* 2014)

Table 1. Inputs for adapting the framework to the context of building structures

Type of inputs	*Selected inputs*	*Direct influence on the elements of the RM-PBB general framework*						
		1: strategic management	*2: information modeling*	*3: technical programming*	*4: technical evaluation*	*5: technical control*	*6: technical audit*	*7: technical attestation*
Performance-based inputs	ISO 15928-1 (2003) (standard for the description of structural safety)		√	√	√			√
	ISO 15928-2 (2005) (standard for the description of structural serviceability)		√	√	√			√
	ISO 15928-3 (2009) (standard for the description of structural durability)		√	√	√			√
	EN 1990 to EN 1999 (Eurocodes)		√	√	√			
Standardized management principles, guidelines and standards	ISO 22111 (2007) (standard describing the general requirements for the design of structures)		√	√	√			
	ISO 13824 (2009) (standard describing the general principles on risk assessment of systems involving structures)		√	√	√	√		
	ISO 2394 (1998) (standard describing the general principles on reliability for structures)		√	√	√			
	ISO 13823 (2008) (standards describing the general principles on the design of structures for durability)		√		√			

nor the original interdependencies of the seven elements had to be altered. Elements 2, 3, 4, 5 and 7 had to be developed and adapted (Table 1), but the original characteristics of the proposed RM-PBB general framework were not affected.

Elements 2 (information modeling), 3 (technical programming), and 4 (technical evaluation) of the RM-PBB framework enable a risk-based evaluation of building structural performance. Element 7 provides guidance for reporting the levels of structural risk and structural performance of buildings. The application of these four elements to the context of building structures must take into consideration parts 1 to 3 of the ISO 15928 standard for the description of performance of houses, for these parts address the building attributes of structural safety, structural serviceability and structural durability, respectively. The first three parts of the ISO 15928 standard provide a harmonized method for describing and evaluating the technical performance of buildings structures. These parts provide a basis supporting international trade and promoting innovation for this particular building subsystem. They enable the development of tools for managing the technical or engineering risks of the building system as a whole. The different parts of ISO 15928 follow the structure and principles laid down by ISO/PAS 22539 (2007) and are, therefore, compatible with other performance-based regulations and standards, such as the Construction Product Regulation or the Eurocodes.

The Eurocodes, namely those that best embody the performance-based building concept (EN 1990, EN 1991, EN 1997 and EN 1998), exert a direct influence on the adaptation of elements 2 (information modeling), 3 (technical programming) and 4 (technical evaluation). For example: 1) the adopted principles for describing the structural performance of a building (element 2: information modeling) are in line with the Eurocodes (and also with international standards such as ISO 15928, ISO 19338 (2007), ISO 22111 (2007), ISO 13823 (2008), ISO 13824 (2009) and ISO 2394 (1998)); 2) the classification of consequences due to structural failures (element 3: technical programming) are also in line the Eurocodes (and with international standards such as ISO 22111 (2007)); and 3) the parameters used for describing and evaluating structural performance (element 4: technical evaluation) are to a great extent included in the Eurocodes (and in several other ISO international standards). This important set of codes for designing buildings and engineering works is compatible both with the ISO 15928 standard and with the Construction Product Regulation.

The international standard ISO 22111 (2007) specifies the general requirements for the structural design of buildings and industrial and civil engineering structures using reliability-based concepts. It exerts a similar influence to that of the Eurocodes over elements 2 (information modeling), 3 (technical programming) and 4 (technical evaluation). This is a relevant standard for adapting the RM-PBB general framework because it aims to: 1) facilitate international practice in structural design; 2) international standardization of the process for setting up rules for structural design, while allowing each economy to specify particular levels of structural performance; 3) provide a means of promoting commonality, interchangeability, consistency and comparability of structural standards developed by different economies; 4) encourage regulatory authorities in each country to describe their mandatory requirements in an internationally agreed format; and 5) facilitate future coordination between the various specialist subcommittees and working groups for ISO structural standards.

The international standard ISO 13824 (2009) specifies general principles for the risk assessment of systems involving structures (including building structures). It aims at facilitating and enhancing decision-making processes with regard to managing risks arising from the design, assessment, maintenance and decommissioning of structures. This standard uses harmonized risk management vocabulary (ISO Guide 73 (2009)) and principles (ISO 31000 (2009)) and is linked to the international standard ISO 2394 (1998). It offers important inputs regarding the adaptation of elements 2 (information modeling), 3 (technical programming), 4 (technical evaluation) and 5 (technical control).

Finally, the international standards ISO 2394 (1998) and ISO 13823 (2008) must also be mentioned regarding the adaptation of elements 2 (information modeling), 3 (technical programming), and 4 (technical evaluation). These standards describe the general principles and rules for designing reliable structures and for verifying the structural safety and serviceability (ISO 2394 (1998)) and the durability throughout the design service life of the structure (ISO 13823 (2008)).

3. Risk management of building structural performance

This section presents the seven inter-related elements of the proposed RM-PBB management framework. It also describes the potential contributes of this framework towards a comprehensive management of the engineering risks of performance-based building structures, throughout the different stages of a building project.

3.1. Strategic management (element 1)

Strategic management provides the organizational basis for executing the principles of the RM-PBB approach within a specific engineering context. It ensures successful operation of the remaining elements of the proposed framework and promotes the performance-based building concept together with the discipline of risk management. Strategic management covers issues such as liability, insurance, accreditation, qualifications, dispute resolution and impact on international trade, education, public policy and infrastructure of support, such as professional registrations and product approval processes (Almeida *et al.* 2010a, b). The degree of sophistication used in dealing with these issues may vary according to the local technical, social and cultural particularities of each country and with the level of involvement of the public and private sectors (van der Heijden 2009a, b).

Taking the engineering context of building structures as an example, strategic management can be used to frame: 1) the development, publication and maintenance of risk-informed performance-based regulations applicable to building structures; 2) the implementation of a mutually recognized procedure for the attestation of the level of performance of building structures; and 3) the creation of an infra-structure that supports the issuance of warranties or insurance policies against natural disasters or against post-construction building defects related with the structural performance of buildings.

This strategic component of the framework is important, as it provides the basis and the organizational dispositions needed for the implementation of the RM-PBB approach. However, authorities supervising the application of this component should promote effective strategies to monitor deviations from the RM-PBB key principles and the intended purpose of this conceptual approach. Excessive technocracy should be avoided, as well as the neglecting of the precautionary principle to adequately deal with unknown risks, which may lead to an unjustified sense of increased security.

3.2. Information modelling (element 2)

The second element of the framework sorts, organizes and classifies the following building-related information: 1) building performance requirements; 2) uncertainties that may have an effect on the objectives set by end-users, authorities, owners, insurance companies, engineering practitioners or other stakeholders throughout the life cycle of a building project, and; 3) building geometrical and physical parts that must fulfill building requirements and stakeholders' objectives. Information modelling is a convenient conceptual representation of a building. It supports the application of the remaining operational elements of the proposed framework (Fig. 1).

Regarding building structures, information modeling helps to establish: 1) the parts of the building structural subsystems that must be properly managed so that performance-based requirements such as structural safety, structural serviceability and structural durability are fulfilled; and 2) the proper management of uncertainties related with the exceeding of ultimate, serviceability and initiation limit states of building structures.

Independently of specific engineering contexts, the effects of uncertainties can be modeled into two major risk categories:

- *inherent technical risk*: technical risks that are more difficult to manage and control because they are typically external to the building project and to human organized systems, and;
- *factors aggravating inherent technical risk*: risk fac-

tors that are easier to manage and control and that may induce an aggravation of *inherent technical risk*, namely due to gross human errors occurring within building project resources and human organized systems.

The first major category of risk is applicable to building structures because there are random uncertainties underlying the estimation of structural actions (e.g. actions originated by natural catastrophes) and in determining the resistance of structural elements (e.g. due to randomness of material properties), as well as epistemic uncertainties in estimating the structural responses of buildings to imposed actions (e.g. resulting from simplifications of the models used).

The second category of risk (factors aggravating inherent technical risk) is also applicable to building structures because there is a finite probability that engineering design faults, construction errors, building subsystems malfunction, or other failures of the kind may occur.

3.3. Technical programming (element 3)

The third element of the proposed framework serves as a communication platform between authorities that need to establish acceptable levels of performance and risk, owners that are interested in amending such levels and engineering practitioners that are required, with a certain degree of reliability, to deliver buildings that fulfil the desired levels of performance and risk (Table 2).

Technical programming bridges engineering practice with risk-informed performance-based building environments promoted by regulations such as the Construction Products Regulation and standards such as the Eurocodes. It establishes a solid link between elements 2 (information modelling) and 4 (technical evaluation) of the operational component of the proposed framework.

For example, the application of technical programming to building structures allows a clear understanding of what is lower or higher risk, what is lower or

Table 2. Correspondence between levels of structural performance and levels of inherent technical risk

Performance level	Likelihood	Consequences				
A+		Very low importance	…	Important	…	Very high importance
	Extreme event	Inherent risk level 4 (severe)	…	Inherent risk level 3 (high)	…	Inherent risk level 2 (moderate)
	…	…	…	…	…	…
	Significant event	Inherent risk level 3 (high)	…	Inherent risk level 1 (low)	…	Inherent risk level 0 (insignificant)
	…	…	…	…	…	…
	Normal event	Inherent risk level 2 (moderate)	…	Inherent risk level 0 (insignificant)	…	Inherent risk level 0 (insignificant)
A		Very low importance	…	Important	…	Very high importance
	Extreme event	Inherent risk level 5 (very severe)	…	Inherent risk level 3 (high)	…	Inherent risk level 2 (moderate)
	…	…	…	…	…	…
	Significant event	Inherent risk level 4 (severe)	…	Inherent risk level 2 (moderate)	…	Inherent risk level 1 (low)
	…	…	…	…	…	…
	Normal event	Inherent risk level 3 (high)	…	Inherent risk level 1 (low)	…	Inherent risk level 0 (insignificant)
B (legal minimum for new buildings)		Very low importance	…	Important	…	Very high importance
	Extreme event	Inherent risk level 6 (extreme)	…	Inherent risk level 4 (severe)	…	Inherent risk level 3 (high)
	…	…	…	…	…	…
	Significant event	Inherent risk level 5 (very severe)	…	Inherent risk level 3 (high)	…	Inherent risk level 1 (low)
	…	…	…	…	…	…
	Normal event	Inherent risk level 4 (severe)	…	Inherent risk level 2 (moderate)	…	Inherent risk level 0 (insignificant)
...						

higher structural performance, and what levels of performance and risk are tolerable by the society, for different types of buildings and structures. Table 2 shows how inherent technical risk levels may be related with structural performance levels, for buildings pertaining to different classes of importance. Tables of this kind must be developed and calibrated for the cases of structural safety, structural serviceability and structural durability.

3.4. Technical evaluation (element 4)

The forth element of the proposed framework relates directly to engineering practice because it is a technical evaluation system that may be directly incorporated into risk-informed performance-based engineering design procedures. It enables designers to conceive and evaluate concurrent engineering solutions as flexible functional units that fulfil specified levels of performance.

Table 3. Example of metrics for evaluating structural safety

Agent		Parameters for describing structural performance
Actions	Permanent actions (other than self-weight)	Magnitude Locations of the imposed loads Reliability parameters
	Imposed actions	Magnitude of uniformly distributed floor or roof loads Magnitude of concentrated floor or roof loads over a specified area Magnitude of a concentrated wall impact load applied at a specified height above the floor Magnitude of uniformly distributed horizontal line load applied at a specified height above the floor Reliability parameters
	Wind actions	Representative value of the wind velocity derived from the basic wind speed, factored as appropriate to take into account local effects, terrain, shielding, topography, altitude, etc. Probability of occurrence Reliability parameters
	Seismicactions	Representative value of seismic activity (effective peak ground acceleration, ground acceleration response spectrum for the site, or others). Probability of occurrence Reliability parameters
	…	
…		

Table 4. Example of evaluation criteria for structural safety

Agent	Performance level	Performance criteria
Permanent and imposed actions	A+	Building withstands design loads 10% higher than legal minimum values
	A	Building withstands design loads equal to the legal minimum values
	B	
Wind actions	A+	Building withstands wind loads 10% higher than those with a return period higher than the legal minimum (e.g. 2500 years)
	A	Building withstands wind loads equal to those generated with a return period higher than legal minimum (e.g. 2500 years)
	B	Building withstands wind loads equal to those generated with the legal minimum return period (e.g. 1000 years)
Seismic actions	A+	Building withstands seismic loads at least 50% higher than legal minimum values
	A	Building withstands seismic loads at least 25% higher than legal minimum values
	B	Building withstands legal minimum seismic loads
…		…

This evaluation system makes use of metrics (e.g. parameters describing structural loads and structural resistance, amongst others) against which structural performance is to be ranked in accordance with harmonized evaluation criteria (e.g. using an equation that compares these metrics with limiting or acceptable values for applicable engineering parameters). Definitive metrics (see example in Table 3) and definitive evaluation criteria (see example in Table 4) should be established by technical regulations and standards.

It is relevant to note that this evaluation system is applicable to the abstract functional unit that represents the building subsystem (e.g. the structure of the building) and that it is not restricted to a unique context-specific engineering solution into which this abstract functional unit may be materialized (e.g. concrete structure, steel structures, wood structure, etc.). This system evaluates the basis for engineering design, but it does not evaluate the entire process in which designers and builders transform that abstract functional unit into a tangible engineering output.

3.5. Technical control (element 5)

The fifth element of the proposed framework (element 5 in Fig. 1) covers the finite probability of building non-performance or "failure" to meat specified levels of performance (e.g. levels of structural safety, structural serviceability and structural durability). This element comprises a comprehensive risk management process in accordance with the ISO 31000 (2009) standard, including the establishment of the context, risk assessment (risk identification, risk analysis and risk evaluation) and risk treatment, which is applicable to the successive phases of a building project.

For example, the technical control of a building structure is a process for managing the 'inherent technical risk' and also the 'factors aggravating inherent technical risk' throughout the design, construction and use of a building structural subsystem. On the one hand, controlling the 'inherent technical risk' of building structures involves the confirmation that engineering calculation hypothesis and design bases are in accordance with the programmed levels of structural performance (Table 2). On the other hand, controlling the 'factors aggravating inherent technical risk' involves the assessment (identification, analysis and evaluation) and, if necessary, the treatment of risks due to uncertainties and "gross human errors" that may induce an unacceptable aggravation of 'inherent technical risk'. This control includes, among other aspects, the verification of geotechnical design and analysis, the inspection of ground conditions and movements, the review of the structural design and also the inspection of construction works.

3.6. Technical auditing (element 6)

The sixth element of the framework comprises a reproducible guidance and methodology that helps defining the amount of effort, time and resources that should be allocated in routine technical audits, especially when these are used for supporting independent demonstration of results. This guidance includes the principles of technical auditing, namely those for managing technical audit programs, conducting technical audit activities and defining the competence of technical auditors.

Technical audits are a disciplined approach which makes use of the engineering perspective for collecting technical evidences necessary for the verification of compliance against predetermined technical audit criteria and for generating conclusions regarding the technical status of building subsystems (e.g. of a building structure). This disciplined approach ensures that different technical auditors, in similar circumstances, do not generate contradictory conclusions.

Technical audits may be used for different purposes and may be conducted by various parties (first, second or third parties). For instance, they can be used as a complement to technical control activities in order to ensure the efficiency and efficacy of those activities and, above all, to learn with the successes and failures of those activities (internal audits to technical control activities). They can also be used for the accreditation of technical control bodies or for validating or confirming the reliability of the conclusions of technical controllers (external audits to technical control activities).

3.7. Technical attestation (element 7)

The seventh element of the proposed framework facilitates the planning and the definition of the formal strategies for attesting the status of technical attributes of a building and its parts, namely to those stakeholders in need of trustworthy and readily available decision support information. Technical attestation is the most visible output of the proposed framework. It not only strengthens decision making capacity of the various stakeholders and participants in the building sector, but it also improves the capacity for making each of these actors accountable in face of an ever-increasing global market place.

Technical attestation is also a means of communicating the levels of technical performance and technical risk of a building project. The attestation of technical performance delivers highly aggregated and easy to understand information in the format of performance declarations, issued by building designers, and performance certificates, issued by third-party independent technical controllers. The attestation of technical risk involves the issuance of risk reports by third-party independent technical controllers, which can be used by banks in lending decisions and by insurance companies in calculating insurance premiums.

The attestation of the structural performance of a building shall include a structural performance declara-

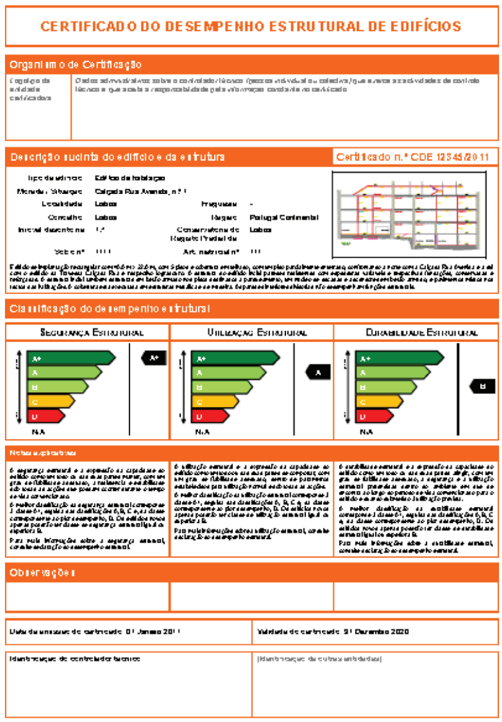

Fig. 2. Example of a structural performance certificate

tion, issued by the structural designer (first-party attestation), and a structural performance certificate, issued by an accredited technical control body (third-party attestation).

Structural performance certificates are the output of technical control activities (element 5 of the proposed framework) and communicate the definitive rating of the building (e.g. "A+", "A" or "B") regarding structural safety, structural serviceability and structural durability. Figure 2 depicts an example of a one page building structural performance certificate. This certificate results from an exercise of application of the proposed framework to a building project in Lisbon. The contents of the certificate include the identification of the technical control body and of the individual that performs the technical control activities, the certificate identification number, a summarized description of the building structural system, the final rating of the building structural performance in terms of three indicators (structural safety, structural serviceability and structural durability), explanatory notes about the meaning of each structural performance indicator, a field for comments and information about the validity period of the certificate.

Structural performance declarations are the output of technical evaluation activities (element 4 of the proposed framework), which are still subject to control and certification procedures. These declarations provide the technical evidence for confirming that the information provided in the certificate is correct. The attestation of the technical risk of a building structural subsystem is a set of risk reports which provide the information needed by those interested in the status of the risk and its management with a view of sharing this risk by means of insurance or other solutions.

Conclusions

Because building information has become so complex, statements of technical conformity are becoming increasingly valuable, above all within performance-based building environments. Moreover, stakeholders such as authorities and official bodies, owners, banks and insurance companies, conformity assessment bodies, designers, builders and suppliers, and also end-users (both society and individuals), are more and more dependent on clear and accessible information regarding performance and risk to support decision making processes in the building sector.

This paper presents a RM-PBB management framework that offers explicit information about the risk and the performance of delivered building projects. This general framework comprises seven elements. They are: strategic management (element 1), information modelling (element 2), technical programming (element 3), technical evaluation (element 4), technical control (element 5), technical auditing (element 6) and technical attestation (element 7).

One of the most important features of this framework is that it enables the demonstration that technical risks are being properly managed and also that specified performance-based requirements are fulfilled throughout all stages of the building project (e.g. engineering requirements relating to the building structural safety, structural serviceability, structural durability, fire safety, energy efficiency, etc.).

The formal strategies for issuing such demonstrations of conformity are covered in the seventh element of the framework (technical attestation). These demonstrations of conformity include engineering performance certificates, which attest the results of technical evaluation activities covered in the fourth element of the framework, and also technical risk reports, which attest the results of technical control activities covered in the fifth element of the framework. Both types of demonstrations are particularly valuable to inform decisions related with contractual or other legal guarantees against building nonconformities.

The certification of building structural performance not only provides unprecedented information to building end-users, but also to authorities, insurance companies and banks. The type of information that must be made explicitly available to these stakeholders is established in the second element of the proposed framework (information modeling). For example, insurance companies may be more willing to accept, for a given premium, the risks of a certified "A+" building structure (with lower level of technical inherent risk) than those of a certified "B" building structure (with normal level of technical inherent risk) or of a non-certified building structures (with unknown level of technical inherent risk), particularly in countries where catastrophic losses or building defects during warranty periods are an issue. The same reasoning may be applied to banks and lending decisions. Also, end-users will be able to use this information in cost-benefit analysis.

Regarding insurance companies, the authors suggest that the calculation of premiums of insurance policies covering building structural nonconformities may be based on transformation functions that depend on (see dashed lines in Fig. 3):

- the level of *inherent technical risk,* which is directly related with the levels of structural performance certified by technical controllers (levels of structural safety, structural serviceability and structural durability) – the correspondence between levels of structural performance and levels of inherent technical risk is covered by the third element of the proposed framework (technical programming);
- the level of *aggravation of inherent technical risk* that may be induced by "gross human errors" occurring during the design, construction or use phases of the building structural subsystem, and;
- *the particular risk attitude* of the insurance company or risk taker.

Performance-based building environments, generated by performance-based codes and standards, have

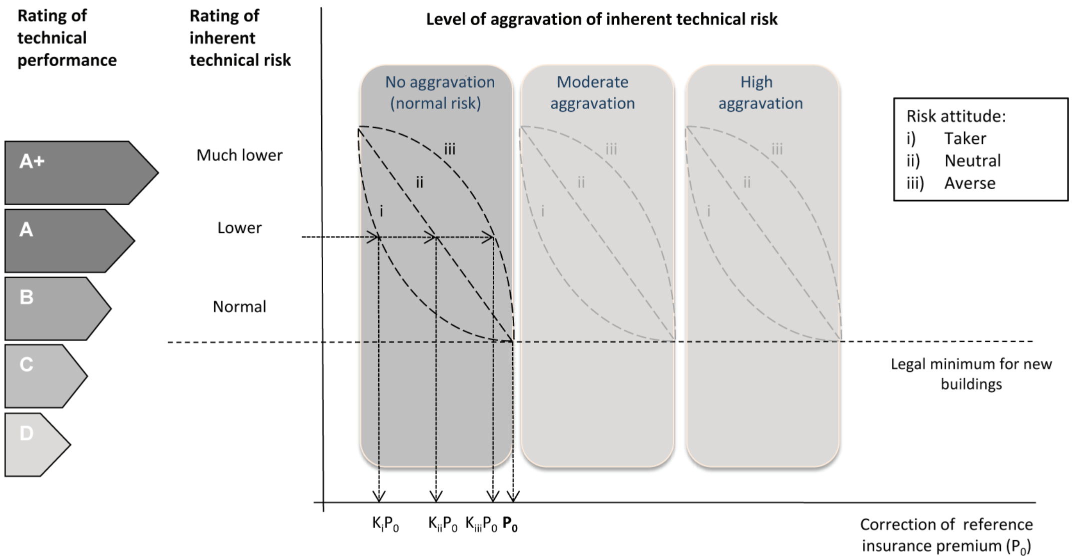

Fig. 3. Transformation functions for correcting reference insurance premiums

been developed to such an extent that it is now possible to implement the proposed framework at a transnational level, namely for those building performance requirements mentioned in the international standard ISO/PAS 22539 (2007) and for those attributes covered by the parts of the ISO 15928 standard that have already been published – ISO 15928-1 (2003), ISO 15928-2 (2005) 15928-3 (2009), 15928-4 (2011) and ISO 15928-5 (2013). There are also other standards worth mentioning, namely those supporting the risk management of building structures, such as the ISO 13824 (2009), the ISO 22111 (2007), the ISO 2394 (1998) and the risk-informed performance-based Eurocodes.

Together, these standards establish the foundations for independent third-party certification schemes of building structural performance, including all underlying engineering risk management practices. Such demonstrations of results are intimately related with the application of reproducible methodologies. These methodologies are covered in the seventh element of the framework (technical auditing).

The proposed framework deals not only with operational aspects, but also with strategic ones. The first element (strategic management) covers issues such as liability, insurance, accreditation, qualifications, dispute resolution and impact on international trade, education, public policy and infrastructure of support, such as professional registrations and product approval processes.

The proposed framework promotes the formal management of the technical risks inherent to building projects, providing an explicit insight of the uncertainties that neither the performance-based, the safety-base or the older prescriptive-based approches do. However, as Greenspan (2008) states: "The essential problem is that our models, ..., as complex as they have become, are still too simple to capture the full array of governing variables that drive global economic reality. A model, of necessity, is an abstraction from the full detail of the real world." Models dealing with uncertainty may be affected by errors due to bias, extrapolations or overconfidence. This strengthens the relevance of a strategic component in risk-based management frameworks to ensure that risk is being correctly managed (Sousa *et al.* 2012). The strategic component of the proposed framework is paramount for the continual improvement of its operational elements.

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