

ENGINEERING RISK MANAGEMENT IN PERFORMANCE-BASED BUILDING ENVIRONMENTS

Nuno Marques ALMEIDA, Vitor SOUSA, Luís Alves DIAS, Fernando BRANCO

*Department of Civil Engineering, Architecture and GeoResources Technical University of Lisbon – IST,
Av. Rovisco Pais 1049-001 Lisbon, Portugal*

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Abstract. Nowadays, a wide range of stakeholders seek explicit performance and risk information on construction projects. These stakeholders include end-users, authorities, insurance companies and financial institutions, among others. They look for proof that engineering risks are being properly managed and that specified performance-based requirements are fulfilled throughout all stages of the project (e.g. technical requirements related to the building such as structural safety, structural serviceability, structural durability, fire safety, energy efficiency, or others). Such demonstration can be conveyed through statements of technical conformity, such as technical risk reports or engineering performance certificates. Statements of conformity are particularly valuable to make informed decisions associated with contractual or other legal warranties against building nonconformities. This paper describes the conceptual background and the methodologies undertaken to design and develop a management framework that enables recognition of the conformity assessment results of building projects. It also presents the outreach of this management framework throughout the planning, programming, design, construction and use phases of building projects. This paper also summarizes the wide range of practical implications and benefits of this management framework for authorities and official bodies, owners and their representatives, banks and insurance companies, conformity assessment bodies, designers, builders, suppliers and end-users.

Keywords: risk management, construction management, civil engineering, performance-based buildings, quality management, conformity assessment.

Introduction

Following the end of the Second World War, the construction sector, and the building subsector in particular, have been interpreting and adhering to three influent and interrelated conceptual approaches: 1) quality; 2) performance; and 3) risk. These conceptual approaches are the basis for several project management theories and practices, which are being used to support the complex task of consistently addressing the wide range of objectives that must be achieved throughout all activities and phases of construction projects in general, and building projects in particular, including the communication amongst stakeholders (ISO 10006).

The authors propose a solution to integrate the conceptual approaches of quality, performance and risk within the building subsector. The fundamental issues and complexities involved in such integration have been previously solved by the authors (Almeida *et al.* 2010a), together with a 1960–2010 review and discussion of the progresses of performance-based model codes and standards, standardized management principles, guidelines and systems, along with conformity

assessment and auditing standards (Table 1). This discussion and literature review established the conceptual background for a new conceptual approach – Risk-Managed Performance-Based Building (RM-PBB) (Almeida *et al.* 2010b). This approach reinterprets and conciliates the principles of quality management, conformity assessment, performance-based building and risk management.

The proposed RM-PBB approach is grounded on an engineering perspective and aims at managing the whole range of requirements that relate to the technical performance of buildings. This approach complements conventional project management processes, such as those focused on time and cost. The underlying key principles of this approach are (Almeida *et al.* 2010a): 1) satisfaction of building end-users (society and individuals); 2) focus on the delivered product (whole building); 3) responsibility and liability of stakeholders participating in the building project; 4) end-user protection against non-conforming buildings; and 5) conveyance of information related with building technical requirements.

This paper aims to present a management framework that enables the practical application of the RM-PBB principles to the construction sector as a whole, and to the building subsector in particular, at transnational (e.g. EU member states level), national, regional and/or local levels.

Section 1 of this paper describes the methodology that was used to attain the final version of the RM-PBB framework. Section 2 summarizes the main benefits and practical implications of this framework for building projects' major stakeholders, such as authorities, owners, developers, end-users, banks and financial investors, amongst others. It also demonstrates how this framework may contribute to improving legal compliance or otherwise stated technical requirements throughout the planning, programming, design, construction and use phases of building projects. Following that, acknowledgments are presented. Bibliographic references and standards and guidelines which are mentioned throughout the text are presented in two separate subsections.

1. A framework for managing engineering risks in performance-based environments

This section describes the designing and developing of a framework for managing engineering risks in performance-based

environments – the RM-PBB framework. Namely, it describes the methodology undertaken throughout the design and development processes (sub-section 1.1) and its underlying premisses (sub-section 1.2). It also describes the selection, analysis, grouping and conciliation of the inputs to the design process (sub-sections 1.3 and 1.4) and presents a review and a verification of the resulting output (sub-sections 1.5 and 1.6). In the end, the developing process is also addressed (sub-section 1.7).

1.1. Methodology for designing and developing the framework

The quality, performance and risk approaches overlap and complement each other (Sousa *et al.* 2012; Srdic, Selih 2011; Almeida *et al.* 2010a). Moreover, if taken from an engineering perspective, they can be combined and successfully applied to building projects by means of a new RM-PBB approach. However, transferring the conceptual RM-PBB approach into practice requires an appropriate management framework.

Following the methodological options for research focused on the creation of new scientific knowledge in a competitive business environment, the methodology for designing and developing the framework for

Table 1. Issues covered by the authors in the 1960–2000 literature review

Issues	Initiatives	Proposing institutions	Reference document	Provenience	Conceptual approach
Performance-based model codes and standards	Nordic model	NKB	NKB (1978)	Regulatory	Performance
	Eighth-tiered model	IRCC	Meacham (2004a)	Regulatory	Performance and risk
	Performance system model	CIB TG37	CIB (2004)	Non-regulatory with regulatory influence	Performance and risk
	Description of performance of houses	ISO	ISO 22539 and ISO 15928	Non-regulatory with regulatory influence	Performance and risk
	Systems approach	NBS	Hattis, Becker (2001)	Non-regulatory	Performance
	Whole building functionality and serviceability	ASTM	ASTM (2000)	Non-regulatory	Performance
Standardized management principles, guidelines and systems	Functional and user requirements and performance of buildings	ISO	ISO 11863	Non-regulatory	Performance
	Quality management	ISO	ISO 9000 series	Non-regulatory	Quality
	Environmental management	ISO	ISO 14000 series	Non-regulatory	Quality
	OSH management	OIT	ILO-OSH: 2001	Non-regulatory	Quality
	Project quality management	ISO	ISO 10006	Non-regulatory	Quality and risk
International conformity assessment and auditing standards	Risk management	ISO	ISO 31000	Non-regulatory	Quality and risk
	Conformity assessment	ISO	ISO 17000 series	Non-regulatory	Quality
	Auditing	ISO	ISO 19011	Non-regulatory	Quality

managing engineering risks in performance-based building environments was based on a combination of the *systems approach* and the *actors approach* (Arbnor, Bjerke 2009; Olsson 2006).

The *systems approach* was used for the design process of the framework, in which the inputs were taken from system analysis. The resulting output of this initial process was a preliminary system model capable of describing, explaining and understanding the building subsector. The *systems approach* admits refinements and further developments of the preliminary outputs, just as the *process approach* promoted in ISO 9000 standards admits that the effectiveness of quality management systems may be improved.

The refinements and adjustments of the preliminary outputs were undertaken by using the *actors approach* – an approach in which individual motivations of the various stakeholders are taken into consideration in order to gain new insights. These new insights were used in the development of the final form of the framework and for establishing its seven interrelated elements.

The methodology for designing and developing the framework followed the *design and development* requirements of the ISO 9001 quality management standard (7.3), namely those related with *design and development planning* (7.3.1), *design and development inputs* (7.3.2), *design and development outputs* (7.3.3), *design and development review* (7.3.4), *design and development verification* (7.3.5), *design and development validation* (7.3.6), and *control of design and development changes* (7.3.7). Hence, the methodology involved the following steps:

- establishing the premises for designing and developing the framework: these premises safeguard and enable the demonstration of the robustness of the proposed framework;
- selecting the inputs for design and development: the main selection criteria was to give primacy to well-established initiatives deriving from the conceptual approaches of quality, performance and risk;
- analysing, grouping and conciliating the inputs for designing the framework: the most relevant aspects of the selected inputs were analysed in order to detect complementarities, organized into three groups and conciliated into a first proposal of the envisaged framework;
- reviewing the proposed framework: the output of the design process was submitted to an iterative review process for refining the inter-relations subsisting amongst the components and the elements of the proposed RM-PBB framework;
- verifying the robustness of the proposed framework: an examination of the design process output was undertaken in order to assess if the resulting framework held the intended robustness; and
- developing the proposed framework: upon termination of the design process, the seven elements of the proposed framework were subject to specific

developments in order to cope with the particular contexts in which they are to be applied.

1.2. Establishing the premises for designing and developing the framework

In order to control the design and development of the framework, a set of premises were established. These premises were used as guiding principles to be applied whenever a necessity of choice arose during the design and development process, in order to ensure and enable the demonstration of the robustness of the final outcome. The explanation for the robustness of the final outcome is presented in Table 2. This explanation has been adapted from FRISCO's guiding principles, options and choices for setting up a framework of information system concepts (IFIC 1998).

1.3. Selecting the inputs for designing the framework

The selected inputs for designing the framework gather international consensus and derive from conceptual approaches such as those of quality, performance and risk. Hence, the proposed framework is grounded on the policies, procedures and practices of relevant initiatives that were originated from the performance-based building concept, including performance-based model codes and standards such as the NKB Nordic Model (NKB 1978), the IRCC eighth-tiered model (Meacham 2004a), the CIB TG 37 Performance System Model (CIB 2004), the NBS Systems Approach (Hattis, Becker 2001), the ASTM Standards on Whole Building Functionality and

Table 2. Premises for designing and developing the framework

Robustness characteristics	Guiding principles for designing and developing the framework
Global consistency	Mitigate independent and incompatible portions of the framework by determining formal and well-established relations amongst the portions.
Generality	The resulting framework should be as generic as possible, but catering for details and specificities of various fields of expertise.
Simplicity	The whole and the parts of the resulting framework should be as simple and straightforward as possible (no unnecessary complexity).
Correspondence (with existing initiatives)	Use well established concepts from relevant management and engineering disciplines (avoid isolated conceptual outcomes that are incompatible with related disciplines), but only to the absolutely necessary level of detail.
Adaptability	Recognize the inevitable limitation in scope of the resulting framework, which should nevertheless serve as a conceptual foundation that can be adapted and extended to various scopes of application.

Serviceability (ASTM 2000) and the subsequent ISO 11863 standard on functional and user requirements and performance of buildings and building-related facilities, and also the ISO 15928 standard for the description of performance of houses (ISO/PAS 22539).

The proposed framework is also grounded in the most important standardized management principles, guidelines and systems. Namely, it takes into due consideration the requirements of the ISO 9001 for quality management systems, the ISO 14001 for environmental management systems, the ILO-OSH: 2001 for occupational safety and health management systems, the ISO 31000 for standardized risk management and the ISO 10006 for quality management in projects. The framework is also compatible with the essential features of the ISO 21500 guide for project management, which is presently under development.

Finally, the proposed framework is also based on internationally recognized principles of conformity assessment, in particular those established by the ISO 17000 series of standards, and also the auditing principles laid down by ISO 19011.

The various initiatives that have been used as inputs for designing the final version of the proposed framework are presented in Table 3.

1.4. Analysing, grouping and conciliating the inputs for designing the framework

Figure 1 depicts the historical progress and relations between the various initiatives that have been used as inputs

for designing the final version of the framework. These initiatives may be grouped into: 1) performance-based inputs (group 1); 2) standardized management principles, guidelines and standards (group 2) and; 3) conformity assessment and auditing standards (group 3). All these groups of initiatives, excluding the ISO 17000 series of standards on conformity assessment, have been explained and analysed previously by the authors (Almeida *et al.* 2010a).

Performance-based model codes and standards (group 1) ensure common features in terms of the hierarchical structure, as well as the underlining philosophy and targets (Ang *et al.* 2005; Becker, Foliente 2005; Bukowski *et al.* 2001; Hattis, Becker 2001; Pilzer 2005; Szigeti, Davis 2005a; Visscher, Meijer 2006). Typically, the performance-based inputs are formatted into a hierarchical structure in which the top level expresses qualitative objectives that break down into various levels of sub-objectives and quantitative measures, which may also incorporate ‘deemed-to-comply’ prescriptive solutions. This format was adopted in performance-based building regulations and codes of various countries (e.g. Australia, Austria, Singapore, China, New Zealand, USA, Canada, Japan, Norway).

The quality and the risk approaches strengthen and complement the performance-based approach (Almeida *et al.* 2010a), namely regarding liability concerns arising from possible failures of a building that is designed according to performance-based principles (CIB 2004). In fact, it is not surprising that many countries are nowadays

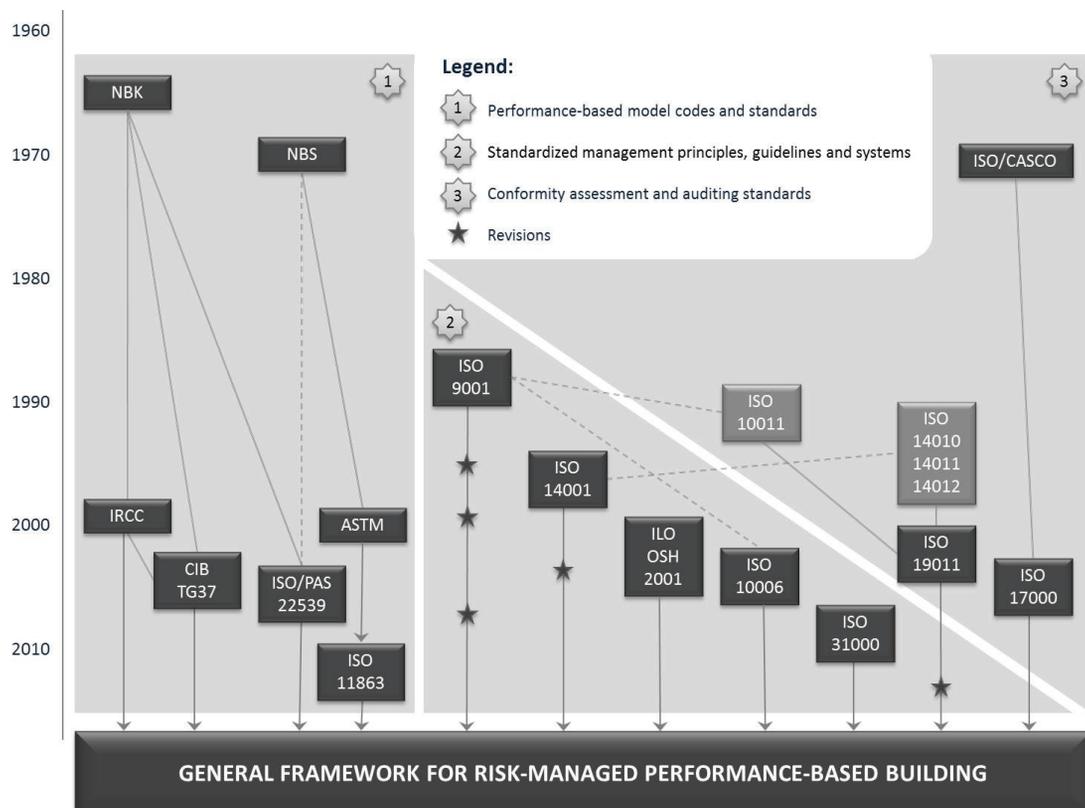


Fig. 1. Background of the final version of the proposed framework

Table 3. Contributions of inputs for designing the final version of the proposed RM-PBB framework

Performance-based inputs		Risk-based inputs				Quality-based inputs				
<i>RM-PBB framework elements</i>	Group 1 : Performance-based model codes and standards					Group 2: Standardized management principles, guidelines and standards	Group 3: Conformity assessment and auditing standards			
	Nordic Model	Eighth-tiered model	Performance System Model	Description of performance of houses	Systems Approach	Whole Building Functionality and Serviceability	Functional and user requirements and performance of buildings	Risk management	Project quality management	
1. Strategic management	–	–	–	–	–	–	–	Framework for managing risk	General requirements, some product realization requirements	ISO 17000 series of standards
2. Information modelling	Goals, functional requirements, operative or performance requirements	Goals, functional statement, operative requirements	Goal/objective, functional statement, operative/performance requirement	User needs, performance description, principles for describing performance	Physical parts of a building, user needs, objective	Objectives/goals, statement of requirements, operative/performance	Risk identification	Concept development	–	–
3. Technical programming	–	Performance or risk group, performance or risk level	Performance/risk level	–	–	Relative importance/criticality, performance or risk levels, indicators	Risk analysis	Scope development and control	–	–
4. Technical evaluation	Operative or performance requirements, verification, examples of acceptable solutions	Operative requirements, performance or risk criteria, deemed to satisfy solutions, performance-based solutions, verification methods	Operative requirement (measurable), criteria, verification	Parameters for the description of performance, evaluation frameworks, commentary	Criteria, evaluation, commentary	Audit/verification/assessment	Risk evaluation, risk treatment	Risk evaluation, risk treatment and control	–	–
5. Technical control	–	–	–	–	–	–	–	Risk identification, risk analysis, risk evaluation, risk treatment	–	ISO 17000 (selection, determination, review)
6. Technical auditing	–	–	–	–	–	–	–	Monitoring and review	Measurement and analysis	ISO 17000 (selection, determination, review), ISO 19011
7. Technical attestation	–	–	–	–	–	–	–	Recording the risk management process	Communication	ISO 17000 (attestation)

developing regulatory environments with the assistance of risk-informed performance-based regulations (IRCC 2010) and performance-based standards (ISO/PAS 22539; ISO 15928; Walker *et al.* 2010). The latter support the development of quality and risk management tools for dealing with the possibility of building failures. These tools are useful to assist end-users, authorities, financial institutions and insurance companies (or other risk takers of the kind) to support decisions based on information on the level of quality that is actually achieved by the delivered building product (expressed in terms of measurable performance and risk levels). There are several quality-based and risk-based standardized management principles, guidelines and standards (group 2) that may assist the development of such tools and, moreover, the issuance of an independent third-party demonstration of conformity, expressed in terms of engineering performance and risk levels.

Independent third-party demonstrations services may be provided by internationally or nationally recognized conformity assessment bodies. The ISO 17000 series of standards, together with the ISO 19011 auditing standard, constitutes an infra-structure (group 3) that aims at safeguarding societal values, such as the transparency, trust and respect, towards the development of stakeholder credibility, confidence and acceptance of the results of the activities performed by those bodies (ISO 2010). Figure 2 depicts the three synthetic functions into which all conformity assessment activities may be framed (ISO 17000):

- *selection*: preparation activities aiming at the collection or production of all the information and input needed for the subsequent determination function (e.g. sampling; selection of requirements, testing or inspection methods and scope of testing to be covered by laboratory accreditation; selection of locations or individuals to perform *determination* activities);

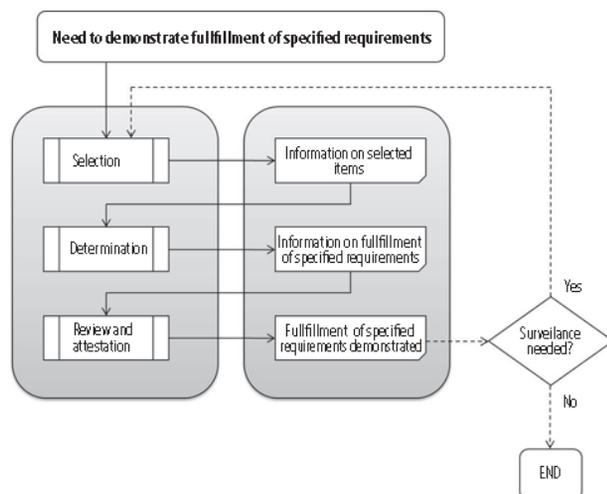


Fig. 2. Functional approach to conformity assessment (ISO 17000)

- *determination*: activities which are undertaken to develop complete information regarding the fulfilment of specified requirements by the object of conformity assessment or its sample (e.g. testing, inspection, audit, peer assessment, examination or analysis of a design or other descriptive information);
- *review* and *attestation*: the final stages of checking the structured output of determination activities, before taking the decision as to whether or not the object of conformity assessment has been reliably demonstrated to fulfil the specified requirements, conducing to a “statement”, or other means of communicating, that fulfilment of the specified requirements has been demonstrated, in a way that most readily reaches all of the potential users (e.g. declaration; certification; accreditation).

Conformity assessment may not end when *attestation* is performed, if a systematic iteration of the three synthetic functions is required to maintain the validity of the statement resulting from *attestation*. These iterations are driven by the needs of the users. For example, the levels of building performance are affected throughout its entire lifetime – thus the conformity status upon completion of the building may change over time. This means that a statement of conformity which is first issued upon completion cannot remain valid if the fulfilment of the specified requirements is affected.

The ISO 17000 series of standards is developed and maintained by the ISO/CASCO committee since 1970 and cover a wide range of conformity assessment activities. A list of some of the main guidelines and standards published by the ISO/CASCO committee, as well as their scope of application, is presented in Table 4.

The convergence of these 3 groups of inputs has been previously demonstrated by the authors (Almeida *et al.* 2010a), as well as their conciliation into the proposed general framework. A review of the final version of the proposed framework is presented next.

1.5. Review of the proposed framework

The analysis of the selected inputs set the ground for forming three groups of inputs: 1) a first group of inputs that merges performance-based model codes and standards; 2) a second group that integrates standardized management principles, guidelines and systems; and 3) a third group that enables the incorporation of conformity assessment and auditing standards.

Efforts were undertaken towards conciliating the extrinsic differences and the intrinsic complementarities of these three groups (Almeida *et al.* 2010a). These efforts led to a first framework proposal (Almeida *et al.* 2010b), which, since then, has been further refined through an iterative process of reviewing the interrelations subsisting amongst the components and the elements of the proposed framework.

Fundamentally, the framework is twofold, as shown in Figure 3. It comprises a strategic and an operational component. The strategic component includes a single element (*element 1: strategic management*) that follows a

Table 4. List of international conformity assessment guidelines and standards

Subject	Guidelines and standards
Vocabulary, general principles and common elements of conformity assessment	ISO 17000, ISO 17001, ISO 17002, ISO 17002, ISO 17003, ISO 17004, ISO 17005
Guidance for drafting normative documents suitable for use for conformity assessment	ISO 17007
Certification of product, processes and services	ISO 17065, ISO 17067, ISO Guide 23, ISO Guide 28, ISO Guide 53
Code of good practice	ISO Guide 60
Mutual recognition arrangements	ISO Guide 68
Accreditation	ISO 17011
Auditing and certification	ISO 17021, ISO 17022, ISO 19011
Inspection	ISO 17020
Certification of persons	ISO 17024
Testing and calibration	ISO 17025, ISO 17043
Third-party marks of conformity	ISO Guide 27, ISO 17030
Peer assessment	ISO 17040
Supplier's declaration of conformity	ISO 17050-1, ISO 17050-2

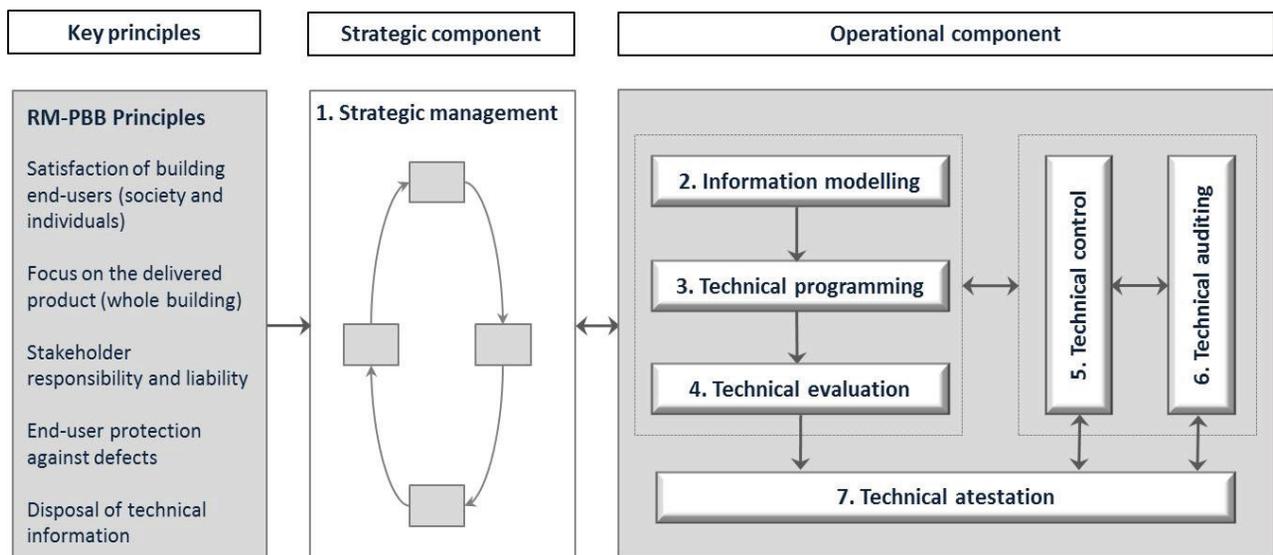


Fig. 3. Final version of a framework for managing the engineering risks of performance-based buildings

plan–do–check–act cycle (Deming cycle) in order to establish the basis (*act*), the planning (*plan*) and the organizational dispositions needed for the implementation of the RM-PBB approach (*do*), as well as for the monitoring and the reviewing (*check*) and the continual improvement of such implementation. The operational component comprises six elements (*elements 2 to 7: information modelling, technical programming, technical evaluation, technical control, technical auditing and technical attestation*) promoting the systematic application of the RM-PBB principles to the activities of the successive phases of a building project. These elements support activities such as the development and publication of technical regulations, the marketing of building projects, the design and construction of the performance-based buildings, the commissioning

and testing of the constructed facilities and the issuance of decision supportive statements of conformity.

The practical implications of these two components and its seven elements for the different stakeholders, throughout the various stages of a building project, are further described in the concluding remarks of this paper (Section 2). Additional details of the seven elements are presented in Almeida (2011), together with an example of application of the proposed framework to manage the engineering risks of performance-based building structures.

1.6. Verifying the robustness of the proposed framework

The background hypothesis for designing the framework was that overlapping conceptual approaches – such as

those of quality, performance and risk – could be taken from an engineering perspective and incorporated into a general management framework applicable to building projects (Almeida *et al.* 2010a).

The robust solution is a result of the combination of various initiatives present in these three conceptual approaches (Tables 1 and 3). The robustness of the framework was secured throughout its designing process. Table 5 shows that all relevant decisions and choices made along the different stages of the design process adhered to a set of pre-established guiding principles and, thus, demonstrates that the resulting framework holds the desired

Table 5. Verification of the robustness of the proposed RM-PBB framework

Robustness characteristics	Contribution of design stages to the robustness of the output
Global consistency	The careful <i>selection of inputs for designing the framework</i> assures global consistency in as much as it safeguards the design output from the influence of initiatives which have not been thoroughly tested, implemented or discussed.
	The <i>analysis of the inputs for designing the framework</i> enhances global consistency by unveiling underlying complementarities between the different inputs and, thus, by conforming links between the elements of the framework.
	The <i>grouping and conciliation of the inputs for designing the framework</i> strengthens even further global consistency by establishing explicit and formal links between the different elements of the framework.
Generality	The criteria used in the stage of <i>selection of inputs for designing the framework</i> safeguards generality because it excludes initiatives with narrow or very specific scopes.
Simplicity	The <i>grouping and conciliation of the inputs for designing the framework</i> promotes the synthesis of a wide range of apparently disconnected concepts into two single components of the framework (strategic and operational), which articulate seven inter-connected elements.
Correspondence (with existing initiatives)	All seven elements of the proposed framework were designed in a way that they retain strong correspondences with the conceptual approaches and with the initiatives in which they were inspired (Table 2).
Adaptability	The fact that the design of the framework is grounded on international and interdisciplinary conceptual approaches and broad scope initiatives testifies the possibility of applying the proposed framework to different management and engineering contexts (other than building projects).

characteristics of robustness (see Table 2 for a correspondence between the guiding principles and the associated robustness characteristics of global consistency, generality, simplicity, correspondence with existing initiatives and adaptability).

1.7. Developing the proposed framework

The general goal of the proposed framework is to enable the practical application of the RM-PBB approach and principles to the building sector. However, the first output of the design process is a proposal that is applicable to building projects only in general terms. Hence, each element must be developed and detailed in order to be applied to specific engineering contexts.

The proposed framework is generally applicable to the full spectrum of technical requirements of publicly or privately promoted building projects, whether the intended use of such buildings is residential or non-residential. In fact, this framework can be used to manage the increasing array of legal aspects for products, processes and services, including those related with safety and health, the preservation of the environment, and other individual or societal requirements that are not explicitly regulated or otherwise stated.

The seven elements of the proposed framework are compatible with the generic guidelines of ISO/PAS 22539 and thus articulate with all the performance-based requirements addressed in the various parts ISO 15928 international series of standards, including those that have correspondence with the basic performance-based requirements for construction works laid down by the Construction Products Regulation (Regulation EU No 305/2011 of the European Parliament and of the Council of 9 March 2011). Table 6 presents the correspondences between the performance-based requirements of these two documents.

Table 6. Correspondences between ISO 15928 attributes and CPR basic requirements

Attributes covered by the ISO 15928 standard for the description of performance of houses	Basic performance requirements laid down by the Construction Products Regulation (CE Marking)
Structural safety (ISO 15928-1:2003)	1. Mechanical resistance and stability
Structural serviceability (ISO 15928-2:2005)	
Structural durability (ISO 15928-3:2009)	
Fire safety (ISO 15928-4:2011)	2. Safety in case of fire
–	3. Hygiene, health and the environment
–	4. Safety and accessibility in use
–	5. Protection against noise
Operating energy (ISO 15928-5:2013)	6. Energy economy and heat retention
Sustainability (to be submitted as a work item)	7. Sustainable use of natural resources

In the case of the Construction Products Regulation, it must be noted that it states that “*construction works as a whole and in their separate parts must be fit for their intended use (...) throughout the life cycle of the works*” and also that when “*subject to normal maintenance, construction works must satisfy these basic [performance] requirements (...) for an economically reasonable working life.*” In this singular context, the quality of a building may thus be interpreted as the degree to which the building as whole adheres to the seven basic requirements laid down by the Construction Products Regulation. However, this particular regulation only addresses *construction products* for incorporation in a permanent manner in buildings and civil engineering works, or parts thereof, and not the construction as a whole.

This means that construction products that comply with this particular regulation (and thus bear the CE Marking) do not cause a negative effect upon the basic performance requirements of a building into which they are incorporated. However, one cannot necessarily deduce the same conclusion regarding the building as a whole, for the building as a whole is a complex dynamic system (Gielingh 2008). Complex dynamic systems like buildings embrace several interacting physical subsystems (e.g. foundations, superstructures, plumbing, roofing), which in their turn are composed by building elements (e.g. beams, slabs, pipes) that function in an isolated manner or in combination with other elements, within or without the same building subsystem, and, finally, by construction products (e.g. concrete, etc.), which

are manufactured, supplied and processed towards being incorporated in a permanent manner in those buildings elements (Fig. 4).

In other terms, even if all construction products used in a building project bear CE Marking (or any other type of demonstration of conformity), there are still planning, design, construction and maintenance procedures that must be properly managed and executed so that all basic performance requirements of a building may be fulfilled. The proposed framework covers all such relevant procedures and may be used by the management and the engineering practitioners in their daily practice towards assuring and attesting that buildings as a whole comply with regulated or otherwise stated performance requirements. Figure 4 illustrates the outreach of the proposed framework and its global development, as compared to the narrower outreach of the mandatory CE Marking (laid down by the Construction Products Regulation).

Conclusions

Several authors have identified the need to strengthen decision making capacity of the various stakeholders in the building sector (Lützkendorf, Lorenz 2006), and hence strengthen the capacity for responsibility of these actors in face of an ever-increasing global market place (IRCC 2010).

Table 7 presents a suggested hierarchy of responsibility of the most relevant stakeholders interacting throughout all phases of a building project linked to the seven elements of the proposed framework.

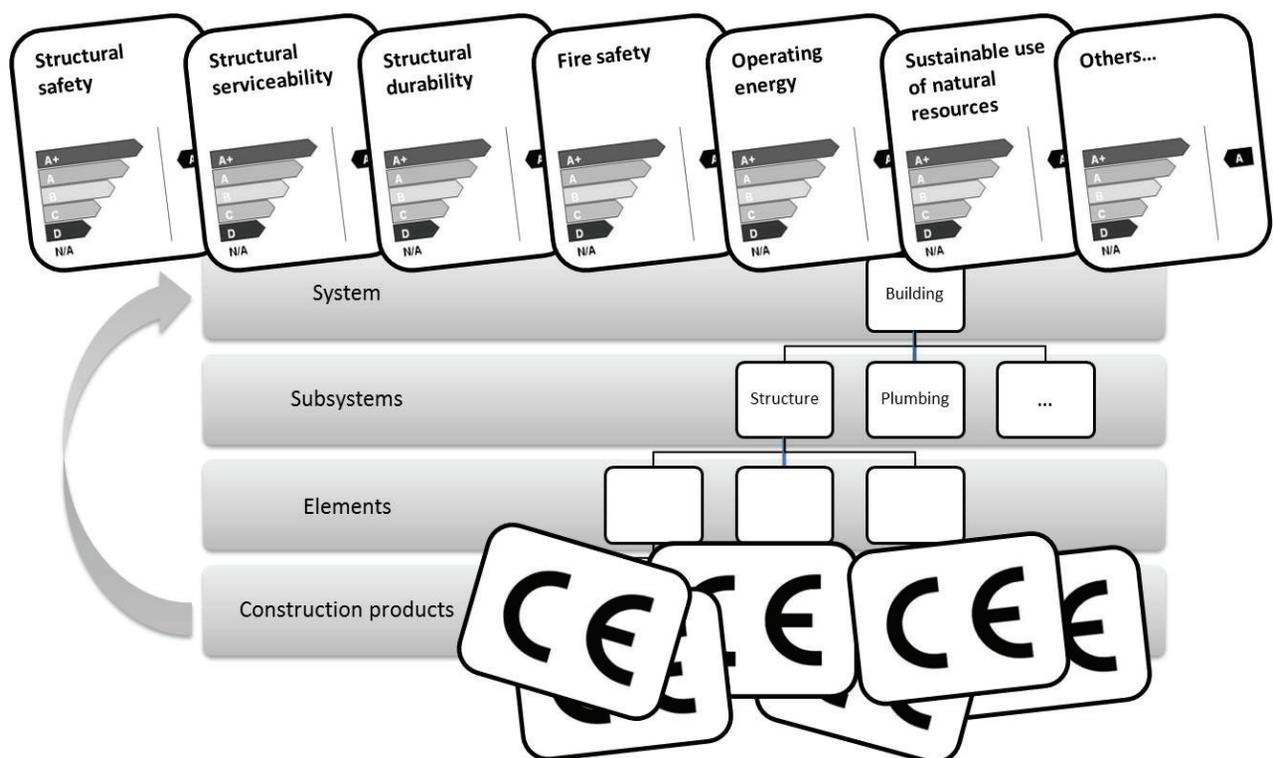


Fig. 4. Outreach of the proposed framework

Table 7. Applicability of the seven elements of the proposed framework

Hierarchy of responsibility of participant stakeholders in a building project	Phases of the building project				
	Strategic planning	Programming	Design	Construction	Use
authorities and official bodies	1, 2, 3				
owners and their representatives		3	6, 7	6, 7	6, 7
banks and insurance companies	1	3	6, 7	6, 7	6, 7
conformity assessment bodies		3	4, 5, 6, 7	5, 6, 7	5, 6, 7
designers		3	4, 7		
builders and suppliers		3			
end-users		3			7

The seven elements of the proposed framework address the various motivations and needs of the most relevant stakeholders of a building project, namely those briefly described below, which are based on a critical review of several publications that, somehow, address this subject (Becker, Foliente 2005; Bukowski 2003; Carlo *et al.* 2010; Garcia, Hanus 2004; Huovila 2007; ISO 10006; ISO 19011; ISO 21931-1; Lützkendorf *et al.* 2005):

- *authorities and official bodies* are provided with effective strategies to promote construction quality and protect end users (both individuals and the society) against non-conforming buildings and to acquire technical information concerning the exposure of buildings to the risk of damage (as well as that of the environment, property, health and life); these stakeholders are also provided with tools to communicate decisions and ensure compliance with its intents;
- *owners and their representatives* are empowered with the possibility to specify the levels of risk and/or levels of building performance deemed acceptable and/or desired in earlier stages of the building process and also with a robust communication interface that facilitates interactions with the various participants throughout the different phases of the building project (designers, constructors, property managers, authorities, banks, insurance companies, technical controllers and auditors, etc.), which results in improved programming and procurement strategies and effective solutions to share the risks of building projects;
- *banks and insurance companies* are provided with adequate risk related information, which can support better initial lending decisions and more rigorous calculations of insurance premiums, which therefore may lead to higher revenues;
- *conformity assessment bodies* (independent third parties) benefit from a consistent, explicit and harmonized infrastructure to guide and support the conformity assessment activities that must be carried out throughout the various stages of a building

project (technical control, technical audits, technical inspections, testing);

- *designers* are equipped with performance-based procedures that are easily incorporated into current engineering design and calculation methods, enabling them to comply and/or exceed applicable technical regulations or other type of demands;
- *builders and suppliers* are granted with an explicit understanding of the technical demands of owners and end-users of building projects and are thus capable to better comply or exceed mandatory and non-mandatory technical requirements; these stakeholders may also benefit from fewer barriers to innovation and from a proactive and preventive environment induced by conformity assessment activities (such activities value quality efforts, contribute to the mitigation of building defects and lead to lower post-construction repair costs); and
- *end-users* can be presented with a warranty that the building fulfils the negotiated level of quality or performance or risk and are endowed with concise information that enables the comparison of concurrent alternatives in the building market.

The way in which these seven elements address the different phases of a building project is described in detail in Almeida (2011), namely by means of an example of application of the proposed framework to building structures. This example of application covers the building attributes addressed in parts 1 to 3 of the ISO 15928 standard for the description of performance of houses (structural safety, structural serviceability and structural durability). Further applications of the RM-PBB framework are envisaged for all other attributes addressed by the ISO 15928 standard (e.g. fire safety, operating energy, sustainability).

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Nuno Marques ALMEIDA. He is an Assistant Professor at Technical University of Lisbon (IST) in the Department of Civil Engineering and Architecture, where he teaches Construction Management. He has practical experience in the planning, execution and control of public and private construction projects. His areas of interests include construction management, infrastructure asset management, quality and occupational safety and health management, technical control, performance-based buildings and risk management.

Vitor SOUSA. He is an Assistant Professor at Technical University of Lisbon (IST) in the Department of Civil Engineering and Architecture, where he teaches Construction Management. He has practical experience in the designing and modelling wastewater systems. His areas of interests include project management, in particular risk management, and hydraulic structures modelling, namely using computer fluid dynamic (CFD) codes.

Luís Alves DIAS. He is an Associate Professor at Technical University of Lisbon (IST) in the Department of Civil Engineering and Architecture, where he teaches Construction Management. He is the Vice-President of the ISSA-Construction Section and collaborator of the International Labour Organization (ILO – Program SafeWork) and the International Training Centre of Turin. His areas of interests include construction management, quality management, and occupational safety and health in construction.

Fernando BRANCO. He is a Full Professor at Technical University of Lisbon (IST), head of the Construction Sector in the Department of Civil Engineering and Architecture, where he teaches Construction Technology. He is President of the European Council of Civil Engineers (ECCE) and Vice-president of the International Association for Bridge and Structural Engineering (IABSE). He has co-authored five books and over 200 scientific papers and has been a Consultant for major Public Works in Portugal.