11th International Conference on Structural
Safety & Reliability

June 16-20, 2013 – Columbia University – New York, NY

Natural Hazards vs. Decision-Making processes in buildings life cycle management

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ABSTRACT

Considering latest natural disasters and the worrisome increase of demographic phenomenon, the critical worldwide condition has pointed out the need for a different approach to handle natural hazards (mainly earthquakes) over time. Thence environment, building heritage and human life and losses due to natural disasters (e.g. earthquake) are relevant topics. Over the time, every building changes its dynamic response to both environmental actions and use loads: building's reliability decreases, while its vulnerability to natural (or man-made) hazards increases. Thence, the whole building's condition has to be deeply investigated. Raising the awareness on traditional low-tech construction techniques and materials characteristics leads to gain a right balance between the wealth of knowledge built up in the past and the advances of recent years. Therefore a development in new performing materials may provide environmental and life-time efficiency. This study points out the dramatic need for a review on existing structural design codes and regulations as well as on architects and engineers' duties in order to pinpoint lacks and prospects. Finally this paper suggests an approach that points out the life cycle management as the heart of intervention strategies on both existing and new buildings in order to ensure them a long life and deal with decision-making process.

Keywords: Decision-making Process, Earthquake, Ecology, Life Cycle Management, Seismic Vulnerability.

INTRODUCTION

In ancient times seismic phenomena were commonly considered supernatural events; they were blamed on divinities or on mythological figures or even to heroes and “holy men”.
However ancient scientists, like Aristotle, Pliny the Elder, Seneca, gave several interpretations of seismic phenomena. Based on the principles of nature and supported by practical observations, their theories looked for the causes of earthquakes.

By the early Twentieth century the study of earthquakes had just begun to achieve its modern form.
Investigators interested in the origin and effects of seismic events started to develop methods to measure both the actual intensity of the shaking and to pinpoint its root.
The development of advanced devices to aid in the recording, categorizing and forecasting of earthquakes and their effects is one of the main consequences of the international seismic pursuit.

Actually we admit that earthquake is a random, periodical event, driven by natural forces due to the evolutionary process of the planet we live on.

Since the Eighteenth century, we have become aware of the ecological meaning of the world: the need for maintaining the well-being balance between humans, species and the whole world. Thence the world can be seen as a cyclical kinetic system, based on energy, movement, exchange and transformation, where carbon dioxide plays a prominent part.

Currently public awareness of worldwide population growth has increased. This worrisome demographic phenomenon leads to an equally worrying growth of the size and number of villages, towns and cities.

This alarming situation draws attention to the necessity of taking care of environmental condition, building heritage and human life and last but not least reducing the losses due to earthquakes.

Moreover both the recent technical and scientific literature and natural disasters have pointed out the lack of suitable tools and strategies to deal with an efficient preventive intervention against seismic effects on constructions time after time and to face the emergency. Therefore nowadays problems related with Defence Against Earthquakes have to be evaluated regarding decisions, management and predictions.

On international scale methods based on Artificial Intelligence have been extensively applied to forecast hazard events, analyse and design structures (e.g. bridges and lifelines), assess buildings and manage post-disaster scenarios.

In Italy seismic events have pointed out a large deficit in structural measures for seismic design and protection. Moreover the necessity of introducing a different approach to seismic risk mitigation of existing building heritage is urgent. During last years a particular care for “minor buildings”, that were subject to wholesale replacement interventions on “reproducible” portions or that were subject to unfitting with building materials and historical and architectural characters additions or conversions, was added to the interest in architectural emergencies. Furthermore this behaviour led to a gradual structural security decrease due to gradual replacement of art of building's knowledge with punctual “standardized” interventions, compromising the building performance sometimes in an irreversible way.

While Japanese research dealt with strong seismic risk mitigation developing warning systems, technologies, advanced materials and devices, monitoring seismic activity in order to assure safety and reliability for environment, humans and buildings.

The US put its efforts into developing advanced methods based on fuzzy risk models with the aim of assessing earthquake damage, determining seismic hazard and decision making, analysing seismic inelastic response and design, analysing earthquake signal in time series, predicting strong seismic events in short-range. Thence ensuring a long life to buildings should be the main aim to carry out through an approach that points out the *life cycle management* as the heart of intervention strategies.

This issue emphasizes two more key points: *buildings vulnerability* and *health*. Moreover they are linked with the need to strength structures against future earthquakes.

The *seismic vulnerability* of a building system is briefly defined as its sensitivity to damage (SANDI, 1982; YAMAZAKI & MURAO, 2000; BACHMANN, 2002).

We must consider that the most of the existing buildings, also those built without seismic code, have an inherent lateral strength that may be sufficient for the building to resist moderate sized earthquakes with an acceptable degree of damage. Therefore we should be able to estimate a probabilistic measure of the damage caused to a building due to a given ground motion.

Then supposing a natural disaster strikes, the following questions come out:

1. Assuming a health building, how will it bear the strain? Which will be its damage degree?
2. Assuming a building in weak or very poor repair, how will it bear the strain? Which will be its damage degree?
3. Assuming a weak building due to natural aging or external causes, how much will the deterioration bear on its performance during the building service life cycle?

Repairing, *maintaining* and *fitting* become outright needs. Taking care of building’s conditions will reduce hazard occurrence both for structures and humans. Moreover emergency operations will be easier when a natural disaster happens. Whenever a building needs for a repair or a partial/whole components’ replacement, these interventions produce a CO_2 discharges increase affects the environmental impact. Referring to life cycle management, environmental impact due to maintenance/retro fitting actions must be taken into account in order to evaluate the real efficiency of any intervention strategy.

Therefore the *deterioration degree*, reached by an existing building at a certain time of its life, as much as construction *materials*, *technologies* and *typologies* and *environmental conditions* are the main parameters needed to define the structural behaviour connected with natural disaster occurrence. Considering seismic hazard, the probability that a strong earthquake affects a building is in direct ratio to the long-life of the building structures. Referring to regions of low to moderate seismicity, hazard due to earthquakes can be considered as relatively low. But the lack of preventive measures, which characterizes those areas, increases the vulnerability more and more. Thence the seismic risk, resulting from the product of the seismic hazard, the exposed value and the seismic vulnerability, becomes seriously high.

Furthermore the gap and independence between structural engineers and architects education is a critical topic. Although both play a major part in designing and building, they aren't inclined to cooperate. There is a dire need to develop a parallel design (BACHMANN, 2002). Architects deal mainly with aesthetic and functional aspects of design, while engineers provide a safe, efficient and economical system. Following the principles of interdisciplinary design, a close collaboration between architects and engineers should ensure an effective decision-making process as well as a sustainable buildings' life cycle management.

Suggesting a review on existing structural design codes as well as on architects and engineers' duties, lacks and prospects in actual design practice are pinpointed. Moreover this paper proposes an approach that points out the life cycle management as the heart of intervention strategies on both existing and new buildings in order to provide long life and develop a suitable decision-making process.

SUSTAINABILITY AND LIFE CYCLE CO_2 EMISSION

Every building has got its own identity: it is almost unique. The need for maintenance, repairs and asset renewals varies depending on several factors, such as the quality of construction, design details, environmental conditions and the standard of care given to the building. Anyway it has been proved that many buildings follow a similar pattern as they pass through different processes throughout their useful life: conception, construction, operation, fitting, mending, re-use, recycle and demolition. Understanding these stages enables to predict the future behaviour development of the structure and make decisions about operating strategies (maintenance, fitting, repairs and asset renewals).

Over the time, every building changes its dynamic response to both environmental actions and use loads: building's reliability decreases, while its vulnerability to natural (or man-made) hazards increases. Thence, taking into account the whole building's deterioration is necessary condition for an effective life cycle management. Considering seismic hazard, the probability that a strong earthquake affects a building is in direct ratio to the long-life of the building structures (OHMORI, 2010).

Furthermore for understanding and effectively evaluating the lifetime of a certain construction, the wholly behaviour of the building must be take into account: materials' environmental impact and deterioration degree, structures' health and vulnerability, natural site features and conditions. Indeed, whenever severe seismic damages bear the need for repairing or replacing, these interventions produce a CO_2 discharges increase affects the environmental impact.

Considering Life Cycle Energy analysis (LCEA), CO_2 emission due to construction materials manufacturing is crucial for assessing the environmental efficiency of any building. The most energy used in the production of building materials is derived from fossil fuels and embodied energy is a significant index of a material's impact on the carbon cycle. The embodied energy in a building varies with its features and location; it measures the total energy used to transform raw materials into ready to use building products. There are also recurrent embodied energy and recurrent embodied CO_2 emission of the materials added to the building by replacement, due to maintenance undertaken during the building's life cycle. Thereby the *Life Cycle CO_2 emission* ($LCCO_2$) is the building's CO_2 emission incurred during the production, use and removal of the building (SUZUKI and OKA, 1998).

Even if normally structural systems mix a series of different materials in assembly choice, secondary and non-structural elements, they usually used mainly one or two material. Some materials such as timber or stone have relatively low embodied CO_2 costs due to small amounts of CO_2-produced over the manufacturing process (e.g. extracting, sawing, drying and transportation). Otherwise materials like steel and glass have relevant embodied CO_2 costs due to very energy-intensive manufacturing processes with high levels of CO_2 emissions.

In ancient time local natural materials (e.g. stone) were the most used material in building. Now-a-days several new construction materials are available. Anyway the use of high-tech for developing construction materials doesn't always result in really performing and eco-friendly materials. A review on traditional low-tech construction techniques and materials characteristics should be necessary in order to gain a right balance between the wealth of past knowledge and the recent advances. Concerning this research, some interesting step forward has been made. Among them, a particular method recently developed in Japan and based on glass manufacturing principles combined with carbon dioxide and then epoxy resin can be mention (IMAGAWA, 2011). Strain capacity and mechanical properties, chemical, aging and heat resistance as well as electrical insulating properties are improved due to the specific chemistry of the thermosetting polymer. Once applied in building, this new material may provide several advantages: lightness, easiness in manufacturing, low

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cost, quickness, fire and waterproofing, and good thermal insulation properties. Moreover its use involves a low expenditure of energy and allows CO_2 responsible for global warming to exploit.

Mixing advanced material research with low-tech construction method, the concept of low impact and cost, easy erecting, efficient, performing and long-lasting building may advance.

Furthermore considering seismic prone region, CO_2-eco-structure's technology might be employ for building temporary houses in emergency as well as for consolidating areas affected by land subsidence.

VULNERABILITY AND LIFE-CYCLE MANAGEMENT

Seismic vulnerability of a building can be expressed by a global parameter, the vulnerability index (v.i.). Linearly combining certain partial indexes classifying structural and non-structural features of a building provide, the v.i. is defined. The v.i indirectly depends on building damage occurred over the system's service life. Furthermore there is a close relation between damage, v.i., environment impact and mechanic parameters.

A semi-empirical method for vulnerability index assessment has been applied in Italy to collect data about buildings condition as well as for statistically supporting the seismic risk evaluation and comparison (BENEDETTI, 1988; PETRINI 1993). Vulnerability index assessment involves few empirical parameters. Their validation depends on damages review over past earthquake. Considering building typology, construction materials, structural system's organization, building dimension and regularity and technical details (i.e. measured and observed characteristics), vulnerability models can be evaluated. Accuracy and significance of data collected for implementing vulnerability models depend on the degree of knowledge. Once required data have been collected, according to measurement and observation, they're ranked into a scale from A to D. Since each class refers to a numerical value, a partial index is provided. Then the partial index is modified by a confidence factor (Table 1).

PARAMETER		CLASS				WEIGHT
		A	B	C	D	
1	Type and organization of lateral force resisting system	0	5	20	45	1,00
2	Quality of lateral force resisting system	0	5	25	45	0,25
3	Conventional strength	0	5	25	45	1,50
4	Position of building and foundations	0	5	25	45	0,75
5	Horizontal systems	0	5	15	45	var
6	Horizontal layout regularity	0	5	25	45	0,50
7	Regularity in elevation	0	5	25	45	var
8	Maximum distance between parallel walls	0	5	25	45	0,25
9	Roof system	0	15	25	45	var
10	Non-structural elements	0	0	25	45	0,25
11	Current state of the building (damage, decay, etc.)	0	5	25	45	1,00

Table 1 Empirical Parameters gathered by GNDT Second Level Vulnerability Form, Vulnerability Classes, Confidence Factors and Weights for v.i. assessment.

Normalizing the weighted average of the eleven empirical parameters in Table 1, the global v.i. is assessed [1; 2]:

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$$I_{V_{masonry}} = \sum_{i=1}^{11} W_i * c_i \qquad (1)$$

$$I_{V_{norm}} = \frac{\sum_{i=1}^{11} W_i * c_i}{382.5} \qquad (2)$$

where W_i is the weight related to each vulnerability parameter and settled by the Gruppo Nazionale per la Difesa dai Terremoti of the Italian Consiglio Nazionale delle Ricerche (CNR-GNDT); c_i is the score related to each vulnerability class.

Structural systems usually lie in aggressive environments; thence they are naturally subjected to a deterioration of their mechanical properties. Since the system is weak from the degradation process, it is less able to withstand the applied actions. Therefore the damaged system tends to decrease its structural reliability and increasing system's vulnerability. When the reliability level reaches a lower value than the acceptable threshold, the system is no longer able to satisfy the requirements for which it was conceived and,

unless some maintenance or rehabilitation interventions are performed, the end of system's service life occurs.
The deterioration process can be considered as a loss of performance affecting a material system. Whenever deterioration reaches a given level, the system suffers a *"failure"* and a loss of performance.
Furthermore a sudden occurrence of a natural disaster may fatally compromise the already critically weak condition of the system.
Thus, the deterioration process may be defined as a *transition process* (GARAVAGLIA *et al*., 2004). Every transition depends on:

- Attack's magnitude (stress cycle)
- System's capability to withstand the attack.

Selective maintenance actions and/or rehabilitation can prevent hazardous conditions, improving structural performance and extending building's life span. Main maintenance and retro fitting interventions are:

a) *Replacing* all damaged members: the initial system reliability is wholly restored and future maintenance can be applied at constant intervals.
b) *Repairing* all damaged members: the initial system reliability is almost restored, future maintenance could be required at every closer interval.
c) *Replacing/repairing* several damaged members: the initial system reliability is just partially restored.

The assessment of the life-cycle performance of a deteriorated structure must base on a probabilistic analysis (Markovian approach) able to model the time-variant deterioration process over the time. The probabilistic approach can be associated to a Monte Carlo simulation implemented with a suitable deterioration modelling (GARAVAGLIA et al., 2012). In this way the combined system is able to simulate a huge number of possible damage evolutions of a certain structural typology over the time. On the base of deterioration analysis, several intervention scenarios can be proposed.
Considering design in an epistemological way, the *Possession Energy Theory* (IMAGAWA, Tsuboi Price 1999) can be introduced. This theory establishes an interdependent connection between the main features that define a building (*Material, Structure, Load, Joint, Cost, Durability, Erection*) and its performance under external loading conditions (*frame's own potential energy*). The relation is described through the following *Structural Design Function* (F_{ESD}) [3]:

$$F_y\{M_x S_y L_z J_n C_\alpha D_\beta E_\gamma\} \geq \begin{cases} \text{natural conditions} \\ \text{social environments} \\ \text{required performances} \\ \text{past and present designs} \end{cases} \qquad (3)$$

The "≥" symbol means that the structure system defined by F_y agrees at least with local laws and it potentially satisfies the efficiency needs listed on the right side by higher design quality and performance. Thence the main aim becomes assuring the building life endurance as well as the system structural efficiency through an approach, which firstly deals with the assessment of the *potential energy possessed by a certain frame* (E_{ss}) [4]:

$$E_{ss} = \sum_{n=1}^{n} E_n * V_n = \left[\frac{kN}{m^2} * m^3\right] = [kN * m] \qquad (4)$$

where E_n is the material Young's modulus and V_n is the material volume. This energy depends on the natural forces (e.g. gravity, earthquake, typhoon, heavy snow, etc.) that act on the structure. Therefore the workload condition defines the frame performance under the effect of natural forces. Since the modulus of Young generally predicts how much a material sample extends under tension or shortens under compression, the abovementioned relationship also describes how each modulus of Young, defining the features of the materials that compose the building, works. A high modulus is important when a material, or more generally a building, is subject to impact load. Considering two buildings with the same volume of materials, the one has got a lower E_{ss} has got worse performance and efficiency, while the frame with higher E_{ss} does efficient workload.
Since materials have a potential impact on the environment, they influence the Life Cycle Energy use and the CO_2 emission and performance of any building. Thus, investigating the environmental efficiency of a building, the function of the whole initial embodied CO_2 emitted by the system is introduced [5]:

$$E_{CO_2} = \sum_{n=1}^{n} E_{CO_{2n}} * V_n = \left[\frac{kN}{m^3} * m^3\right] = [kN] \qquad (5)$$

where E_{CO2n} is the material initial embodied CO_2 emission, i.e. the amount of CO_2 emitted during the process of the material's manufacturing and V_n is the material volume.
Whenever a building needs repair or partial/whole components' replacement, these interventions produce an increase in CO_2 discharges. That rise in CO_2 affects the environment. Thus, referring to life cycle management of

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existing buildings, environmental impact due to maintenance/retro fitting actions must be taken into account in order to evaluate the real efficiency of each scenario's intervention.
Table 2 shows the close relation between construction materials and mechanical properties and structural behaviours:

MATERIAL	MECHANICAL PROPERTY	MECHANICAL BEHAVIOUR
Stone / Brick	axial force resistance	fragile
Timber	axial force resistance bending and shear force resistance	elasto-fragile
Iron	bending force resistance	elasto-plastic

Table 2 Relation between construction materials and mechanical properties and structural behaviours.

Then the third and final key-element of the *Possession Energy Theory,* that is the Cognitive Structural Frame Diagram, is introduced (Figure 1).

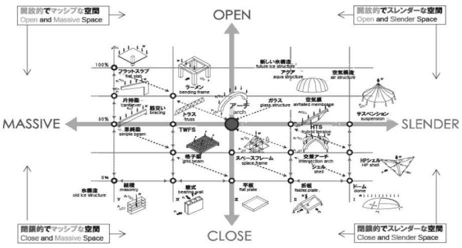

Figure 1 Cognitive Structural Frame Diagram

Basing on a Cartesian coordinate system where vertical axis represents the spatial opening (from close to open structures) and horizontal axis represents the massiveness (from massive to slender structures), buildings are considered as points belonging to the plane. Constructions place themselves into the Structure-Resistant Diagram. Thus frame's identity is defined and material-structural properties interrelation comes out. The Cognitive Structural Frame Diagram application enables to explain the mechanical behaviour of a building. Combining performance and system's structural efficiency analysis and environmental efficiency analysis, the global performance within general Life Cycle Management is investigated. Mainly caring for seismic hazard, this approach aids decision-making and problem-solving processes in intervention strategies' choice. Then, introducing and critically reviewing the notion of vulnerability index (v.i.) already developed in Italy, a combined approach of v.i., Possession Energy Theory and performance assessment of building in aggressive environment can be performed. Figure 2 shows the potential network system between Possession Energy Theory and vulnerability theory.

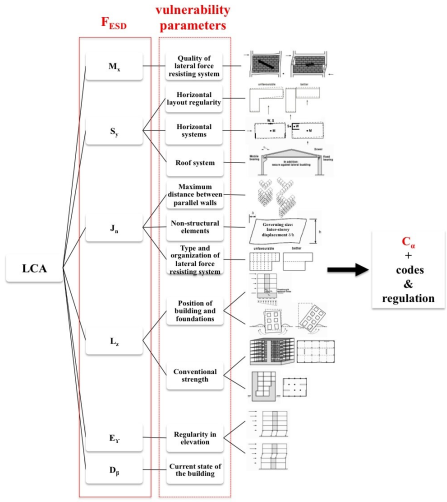

Figure 2 Network diagram explaining potential connection between Structural Design Function and vulnerability parameters.

Moreover any scenario must be economically evaluated too. Then optimal solutions may be considered in order to support decision-making process.

ARCHITECTS AND ENGINEERS

Design may be considered as a problem solving process where the need is the design request, and its solutions logically ensue (CHAKRABARTI 1993). Knowledge, materials and building processes are the design resources. Laws of nature, time, organizational and financial limitations are constrains. Furthermore the design process is influenced by both the environmental context and the different cultural back ground in which it takes place.
Less than two centuries ago, the "Master builder" performed the roles of both Engineer and Architect. Today, Structural Engineers and Architects almost work independently. Although they both make a key-contribution in designing and building, they don't cooperate together. In present practice design processes seriously suffer from the lack of synergy between the different disciplines involved in. This critical topic was already well known by Le Corbusier. In *Science et vie*

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(1960) he sketched a diagram, *Les Constructeurs*, which represents the relation between engineer's domain (hatched area) and architect's domain (dotted area) as two hands interlocking ten fingers horizontally at the same level (Figure 2).

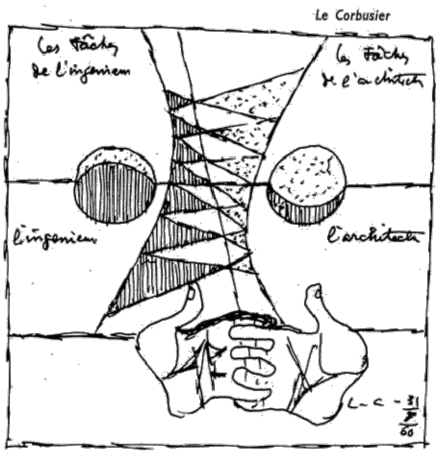

Figure 2 Relation between architect and engineer (Le Corbusier, 1960)

Le Corbusier proclaimed the right sharing of knowledge and language between architect and engineer: the main tasks of an architect are "*knowledge of mankind, creative imagination, beauty, freedom of choice*". Nevertheless he should reflect on the laws of physics. From the other side, the main tasks of an engineer are "*respect for physical laws, durability and strength of materials*"; furthermore he should reflect on human problems. Thence a collaboration based on a close co-existence may lead to a productive work. While the architect is mainly interested in the creative and visible sign of design, the engineer looks for the process of production and construction as well as for the optimal technical and structural solution.

Since projects are characterized by complex needs, a fruitful and interdisciplinary dialogue between professionals is the prerequisite for an efficient and economical parallel design. Professionals' work is inextricably linked and this close interaction results in aspects of structural engineering and architecture.

Table 3 shows some basic ground rules for interdisciplinary architect-engineer collaboration in new design process as well as in decision-making process for maintaining and repairing existing buildings.

DESIGN PHASES		ARCHITECT	ENGINEER
Research & Development + System Requirements	gaining agreements	X	
	investigating needs/potentiality & problems/constraints	X	X
	esteeming funds and finantial requirements	X	X
Conceptual Design	developing a general purpose structure (considering safety, environmental and performance efficiency, costs, aesthetic and function)	X	X
	selecting non-structural elements (safety, efficiency, costs, aesthetic and function)	X	X
Preliminary Design	evaluating environmental impact	X	X
	assessing system's preliminary performance and reliabitlity		X
	refining costs	X	X
Detailed Design	drawing	X	X
	analysing & testing performance and reliability		X
	reviewing fabrication feasibility		X
Building	inspecting construction site	X	X
	testing		X
Service	maintaining & repairing	X	X

Table 3 Collaboration between Architect and Engineer

QUESTIONS

Referring to what has been exposed up to now, some suggestions for future research development come out.

1. To effectively tackle the effects of natural disasters a careful review of design codes and regulations is dire.

2. Considering building life cycle as well as building environmental efficiency, an improved approach combining v.i. assessment with *Possession Energy Theory* and performance assessment of deteriorated building may lead both funds' investment and optimal management policies (risk and emergency assessment and design process). To help in reaping the advantages of the combined approach, one key step will be to practically apply the new method to some cases-study in seismic prone regions. Thus decision-making and problem-solving processes in intervention strategies' choice will be effectively evaluated.

3. Analysing whether and how different materials for infill-walls influence the whole energy performance of

construction may enable to investigate the effects on repair and maintenance actions as well as to lead decisions within design process.

4. Referring to weak configurations of building (e.g. soft-first-story configuration), consider a typical seismic scenario where the earthquake occurrence carries out the whole building's rigid behaviour due to the infill walls and just the first story's lateral deformation. Investigate how acting (e.g. retrofitting/reviewing materials) on the building in order to decrease its vulnerability.

CONCLUSIONS

The critical worldwide condition has pointed out the dire need for a different approach to handle natural hazards (mainly earthquakes) over time and to arrange a careful and interdisciplinary design process. Thence building life cycle management, environmental impact and life safety protection are relevant.

Shape (i.e. structure and dimension) and performances change due to the steady passing of the time and the natural aging; at the same time, space like environment, as well as space like frame or volume, influences the life-span of the building: an aggressive environment deteriorates building's mechanical properties; while awkward structural conditions may overload the whole structure and/or cause serious structural damages. Both these problems decrease building's performance and fatally compromise its reliability. This paper proposes the Life Cycle management as the heart of intervention strategies on existing buildings is investigated. Switching from existing buildings to new constructions, the optimal solutions' evaluation within design decisions may ensure the right balance between environmental impacts, costs and durability of buildings. Implementing maintenance and vulnerability assessment to the evaluation should finally complete and improve the efficiency of the decision-making process. Considering deterioration of structures due to aggressive environment, environmental impact of materials and seismic hazard, buildings long life is pursued.

The Possession Energy Theory and an original building's performance assessment based on Markov probabilistic approach, associated to a Monte Carlo simulation implemented with a suitable deterioration modelling have been explained. Thus, critically reviewing Italian v.i. assessment, a combined approach of v.i., Possession Energy Theory and performance assessment of building in aggressive environment for managing building Life Cycle and design process has been suggested.

Referring to the service life of a system, environmental impact due to maintenance/retro fitting actions must be taken into account in order to evaluate the real efficiency of any intervention scenario. Life span evaluation has pointed out the potential efficiency gained from low-tech and new performing and eco-friendly materials' application in building design. Thus, a good balance between long-life, efficiency and environmental impact can be achieved. The economical investigation of different scenarios should support and define decision-making process.

Comparing and combining different approaches may provide and improve the method for forecasting structures performance, managing maintenance, retrofitting and whatever intervention strategies. Thus future developments of tools and methods for seismic risk and post seismic mitigation, seismic vulnerability assessment, damage and vulnerability survey, reliability evaluation in post-seismic emergency, preventive maintenance, seismic emergency and rehabilitation management would be crucial for all earthquake prone regions around the world.

Through Le Corbusier's words a review on Architects and Engineers' duties in order to pinpoint lacks and prospects within their relation has been introduced. There is the dire need to look for an Engineer with the understanding and wisdom of architectural/aesthetic issues as well as an Architect with the ability to implement structural engineering knowledge in architectural design. They should be aware they have to cultivate multidisciplinary knowledge as part of their professional activity and respect anyone else's contribution an/or opinion in order to provide a successful synergic design. This collaboration must start at the earliest conceptual design stage when choices are made, which are crucial for seismic resistance and vulnerability of the building.

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