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KnowRISK

Know your city, Reduce seISmic risK through non-structural elements

Prevention and preparedness projects in civil protection and marine pollution.
Prevention Priorities

Deliverable Report

Deliverable C4 – Portfolio: procedures for minimizing the risk of non-structural damages

Task C – Non-structural seismic risk reduction

Deliverable/Task Leader: EERC, IST, INGV/EERC

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Dissemination Level		
PU	Public	x
PP	Restricted to other programme participants (including the Commission Services)	
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Preface

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Abstract

Action C4 of KnowRisk Project, aims at helping buildings (Residential and No-Residential) owners and users, to find efficient ways to protect 'them from losses due to Non-Structural Elements (NSE's) damaged in the course of earthquakes.

To do so, a List of NSE's that may have a significant contribution to the building security and reliability will be constructed and, practical guidance's to retrofit' them will be suggested.

However, one believes that this is not sufficient to help target users of this task to decide about options and actions to proceed with NSE's protection.

With a high lack of perception about earthquake risk and about Benefits and Costs of Retrofitting Measures, owners and users will stay highly unwilling to invest, if benefits remain unclear and decisions hard to address and understand.

Being so, besides a simple List of NSE's and indications of means to protect' them, a Cost-Benefit approach will be devised and suggested, in order to provide the target audience with a Ranking, or with an Indicator of how Attractive can be the protection of each NSE. Besides that, the way Benefits and Costs will be addressed, will be simple to understand, transparent and adaptable to stakeholder's objectives and values.

Portfolio Optimization Strategies will be used to support such an objective.

Contents

1. Introduction

The aim of this *D4 Action* is the construction of a *List of Nonstructural Elements, NSE's*, that have a clear potential to increase losses during an earthquake and, at the same time, to provide buildings owners and users, means to reduce their damage potential.

For that, NSE's will be organized in a List, by *Class*, and within each *Class*, by *Categories* above which NSE's (components) will then be listed.

Besides their Class, Category and Name, their potential to raise losses in 3 main *domains {Life Safety; Property Loss; Functional Loss}*, is also indicated in a 3 levels Qualitative Scale *{High; Medium; Low}.* Besides that, an indication of the necessary skills to proceed with their damage potencial is also present, again in another 3 levels qualitative Scale *{ER: Engineering Required; NE: Non-Engineering Required; HM: Home Made}* is also provided. This is illustrated in Figure 1 (Extracted from Annex A).

Class	Category	Component	Life Safety	Property Loss	Functional Loss	Required Intervention
Architectural Components	**Canopies, Marquees, and Signs**	Canopies	H	H	M	ER
		Marquees	H	H	M	ER
		Sunshades	H	H	M	ER
	Ceilings	Ceiling moulding	-	-	-	-
		Ceilings applied directly to structure	M	H	H	NE
		Heavy stucco soffit	-	-	-	-
		light fixtures	-	-	-	-
		Suspended heavy ceilings	H	H	H	ER

Figure 1 – Ex of Main List of NSE's with potential to raise Seismic Risk.

This List will be, in a next step, completed with links to documents where the fastening procedures are explained in detail.

As explained further in this document, this List was mainly, but not only, obtained from FEMA E-74 (FEMA 2012). However, as also further explained, in order to help Users in deciding about Retrofitting, additional information not present, neither in FEMA neither in any other source found, was added in the course of this D4 Action. This was a *Constructed Indicator about Potential Attractiveness to Retrofit*. The aim of this new indicator came from the recognized necessity to help Users to understand and decide in the process to proceed with Retrofitting Actions and Options. The List as so constructed became as illustrated in the next Figure 2, also extracted from Annex A.

	Impacts					Intervention	Retrofit Attractiveness, High	
							Risk Matrix Like	MacBeth Like
Component	LS: Life Safety	PL: Property Loss	FL: Functional Loss	PL&FL	LS&(PL&FL)	RI: Req. Interv.	RLMI	MCDALI
Televisions and video monitors, wall-mounted	H	H	L	H	H	HM	H	1.00
Hazardous materials storage	H	M	H	H	H	HM	H	1.00
Computer and communication racks	M	H	M	H	H	HM	H	0.89
Fire extinguisher and cabinet	M	H	L	H	H	HM	H	0.89
Bookshelves	H	M	M	M	H	HM	H	0.88
Shelf-mounted items	H	M	M	M	H	HM	H	0.88
File cabinets	H	M	M	M	H	HM	H	0.88
Light duty shelving	H	M	M	M	H	HM	H	0.88
Ceilings applied directly to structure	M	H	H	H	H	NE	H	0.70
Air diffusers	M	H	L	H	H	NE	H	0.70
Flat bottom containers and vessels	M	H	M	H	H	NE	H	0.70
Flat bottom tanks and vessels	M	H	M	H	H	NE	H	0.70

Figure 2 – Ex of List of NSE's along with their Potential Attractiveness to Retrofit..

In this main text, explanation about the List Construction and Classification Procedures will be issued. This is complemented by two documents: i) in **Annex A**, the Full List of NSE's will be provided, along with procedures to restrain losses, Impacts of NSE's in several Criteria, and their Attractiveness to Retrofit will be also supplied, ii) in **Annex B**, the construction of the Attractiveness Indicators will be summarily exposed in such a way that each stakeholder will be free to obtain more adequate classifications by changing their Values and Objectives.

This adds an increased potential to support Decisions about Seismic Risk Containment by NSE's protection.

The List of NSE's, will be delivered in two formats: i) As a <*.pdf*> document and ii) in a Web application.

The portfolio, consisting of the List of NSE´s and the respective measures to reduce each NSE damage potential, will be available in digital format, in English. No paper version of the full portfolio will be done, as it would be a too lengthy document, of about 1000 pages. However a paper version of the most relevant NSE for households and offices will be built.

At this point in time, Action C4 is not yet finished. At the end of this Report, next steps are proposed.

2. Identifying Non-Structural Elements, NSE's, that can raise Seismic Risk, and solutions to reduce' it.

Despite the recognized importance of Non Structural Elements in Losses due to earthquakes, few works besides FEMA E-74, provide a global approach to the issue, providing not only practical guiding about fastening options as also qualitative information about impacts of damaged NSE's in criteria such as costs and safety. In fact, other publications exist but, almost all of them are FEMA Based, some of them providing few additions to what can be found in it. Exceptions were found in works more dedicated to the "Engineered Approach" providing insights, namely in the calculation of Inertial Forces that act upon NSE's, during earthquake shaking in order to support their design.

It may also be worth noting that from a scanning of FEMA E-74, it can be noticed that from 120 NSE's listed:

- ✓ Only 74 (~60%) have information about impacts and fastening solutions, and
- ✓ From those 74, only 20 (~25%) are classified as "Non-Engineering Required (NER)", most of them (17) being Furniture, Fixtures, & Equipment NSE's.
- ✓ 95% of Architectural Components and 86% of Mechanical NSE's are "Engineering Required" (ER), while 80% of Furniture, Fixtures, & Equipment NSE's are NER.

From this brief scanning, it becomes clear that the request of "economically feasible, easy to implement" is highly restrictive and mainly applicable to Furniture, Fixtures, & Equipment NSE's. It also becomes clear that in order to pursue the finding of solutions to restrain the possible impacts of NSE's in Seismic Events will require a clear willingness to pay.

Being so, comparing Costs & Benefits becomes a need in order to help stakeholders to best design their portfolios and adapt ‘them to their objectives and goals.

3. Stakeholders contribution to the Portfolio

As already stated, the List of NSE’s already gathered, allowed the identification of 120 NSE’s, most of them present in almost all other similar Lists produced in different documents (official and non-official ones). Nevertheless, all of these lists is a dynamic document that, at any time can change as new NSE’s became identified as “of interest” to this purpose.

On the other side, one can observe that, even if for HAZOP or FMEA purposes, their impacts on several Criteria becomes necessary to carefully identify needs for the investigation of “New (nonexistent) fastening solutions” and implementation. As so, a next step in this **D4 Action - Portfolio: procedures for minimizing the risk of non-structural damages,** seems to be the participation of Stakeholders in the classification of NSE’s already present in the 120 List, in what concerns Criteria such as the ones identified on FEMA E-74 and almost worldwide accepted in all other studies and publications:

- ✓ *Life Safety,*
- ✓ *Property Loss,*
- ✓ *Functional Loss*

Before proceeding, however, it is also worth noting that while 95% of the Architectural Components require Engineering intervention, amongst the Mechanical NSE’s, chances of finding NER (Not Engineering Required) can be about 15%. This can lead’ us to believe that among the yet not classified NSE’s ~ 50 records, some, with significant impact on Seismic Risk Reduction, may also be easy to restrain. These expectations are reinforced if one recalls that Mechanical NSE’s are the ones that, besides direct damages, they also have the potential to trigger cascading disruptions along interdependent systems (Such as systems critical for Function Reliability). By so, the engagement of Stakeholders in the Classification of the already Listed but not yet classified (~ 50) NSE’s may allow the identification, not only of NSE’s not yet Listed but that some of the already present in the List, may be easy to restrain with high Return on Investment.

Another strong reason to engage stakeholders in such a way, relates to the need of understanding stakeholder’s willingness to engage in Seismic Risk Containment in their facilities. Only a positive attitude will be supportive of spending further efforts in finding “Measures to Protect NSE’s in order to reduce Seismic Risk”. Nevertheless, the work already carried out, once delivered to them, can be considered sufficient. As it will be seen further in this document, 20 of the 74 Listed NSE’s, can be considered as possessing a particular combination of “Expected Low-Cost Intervention” & “High Impact” on Seismic Risk Containment, that is about 30% of them.

If willingness to proceed with interventions in the already identified with the High *Benefit/Cost Ratio* came to show negligible, then, with the exception of special cases, there are no strong reasons to proceed with further investment in solutions finding.

4. The Portfolio Optimization Strategy

Deciding about Risk Mitigation Measures, especially in what concerns Seismic Risk, can be seen as a Game[1] of "*Certain Immediate Costs*" against "*Highly Uncertain and Future Benefits*". Besides that, the uncertainty about benefits, be' it from Natural or Epistemic sources, especially in the field of Seismic Risk, is difficult to reduce and, as so, in order to raise the *Benefits to Costs Ratio*, acting in the domain of costs and benefits seems to be a suitable candidate to initiate a useful approach to Seismic Risk Prevention.

Stated in another way, eliciting *Options* with *High Benefits to Low Costs Ratio* as a starting point, seems a useful way to help end users in the finding of Seismic Risk Protection Feasible Measures. That was our chosen approach to initiate this "Portfolio" **D4 Action - Portfolio: procedures for minimizing the risk of non-structural damages** in *KnowRisk* Project.

The chosen strategy, is no coincidence. In fact, Portfolio Optimization can be pursued (among others) by the approach theoretically proven and proposed by Lawrence Phillips and Bana e Costa (Phillips and Bana e Costa 2007), where the "*Benefits to Cost Ratio*" is used in order to Maximize Return-To-Investment (ROI) and to Prioritize Options under constrained or limited resources.

4.1. The Engineered & the Non-Engineered approaches

Even in this approach, eliciting Costs & Benefits is by its own a difficult, if not unsurmountable task, especially if one aims at simultaneously satisfying multiple end-users (target audiences), with specific objectives, budgets and priorities.

Costs of finding a detailed solution for a specific demand, will quickly grow far out the scope and budget of a project such as KnowRisk, once they often require the financial support for: Consultant fees (Design & Construction), Labor, Materials and Equipment, Permits, Inspection, Testing, … This approach even if suitable for Risk Containment in Complex or Highly Critical Facilities, it is often restricted to critical systems or system components in these facilities, requiring a detailed Risk assessment, encompassing i) From a pure point of view of Risk Analysis (Andrews and Moss 2002): HAZOP[2], FMEA[3], FMECA[3] studies, mathematical techniques such as ETA[4], FTA[4], DTA[4], Simulation and other Mathematical or Statistical Tools and ii) From the Engineering Point of view: at least, Seismic Hazard & Structural Dynamics, would necessarily came into play.

One could call 'it "Hard Way" or the "Engineered approach"

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[1] From the Set of Games Theory Domain.
[2] HAZOP, Hazard and Operability studdies.
[3] FMEA, FMECA, Failure Mode and Effects Analysis.
[4] ETA, Event Tree Analysys, FTA, Fault Tree Analysys, DTA, Decision Tree Analysis.

On the other hand, in opposition to such a sophisticated and Quantitative approach, a more Qualitative one, based on experience and existing knowledge acquired in the aftermath of real past events seems more appropriate, even because, as pointed out in the Action C.4 description, objectives were defined as:

- ✓ This portfolio will privilege solutions that are economically feasible, easy to implement and viewed as socially acceptable by building construction stakeholders and citizens.
- ✓ The portfolio will have as main end-users the building sector stakeholders, e.g. engineers, architects and building remolding small entrepreneurs and it will serve as a basic tool for the conception of a citizen Practical Guide,
- ✓ Expected results: A portfolio of procedures for minimizing the risk of non-structural damages in housing, schools, businesses and other facilities tailored to different end-users in the study area.

So, a "Soft approach" based on a "Quantitative Assessment of Costs & Benefits" will be used.

Being so, the engineered and the practical approaches to find retrofitting solutions can be seen as something like in the next illustrative example will be used.

Ex: The case of Pipe risers and Penetrations.

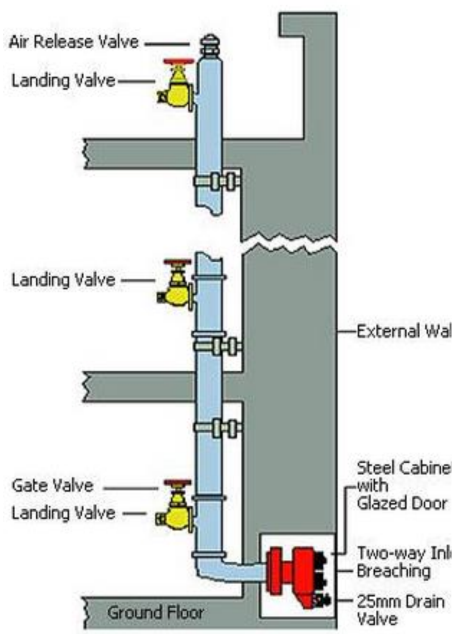

Figure 3 – Pipe risers

Figure 4 - Penetrations

These NSE's can pose severe risks in several situations. Not only to Human Safety (if hazardous fluids flow along 'them) but also to Function Continuity (if they belong to critical Functions). But at the same time, by their own nature, they can be highly vulnerable to differential drifts (structural or non-structural). Retrofitting 'them is viewed as ER (Engineering Required).

Box 1 – The Engineered Approach Example.

The Engineered approach.

1. Get the local Seismic Hazard, be' it in the form of Peak Ground Accelerations or using Strong Motion Records and respective Return Periods.
2. Proceed with Linear/Non-Linear, Static/Dynamic Engineering to derive expected Interstorey Drifts along the Buildings height, or, alternatively, for NSE´s vulnerable to acceleration, use empirical formulae to estimate mass acceleration at each building floor,
3. Proceed with Mechanical Engineering in order to devise Fragility Functions of these pipes, for Leakages and Ruptures,
4. Eventually, in order to incorporate Natural and Epistemic Uncertainty, use MonteCarlo Simulation,
5. Devise Direct Losses, Impacts and Damages Expectations and, if they are part of Critical Functions/Services for the Building, proceed with Algorithms to devise Propagation Effects. Alternatively, use FMEA, ETA, FTA or Multi Criteria Decision Aid (MCDA) (once Tangible and Non-Tangible Values may be present)
6. From the last findings, decide about their importance,
7. Upon that, if found required, design the protection measures to isolate these Pipes in such a way that the expected relative drifts can be accommodated.
8. Procced with their protection (or Not).

Box 2 – The Non-Engineered Approach Example.

The Non-Engineered approach.

1. Estimate maximum Drifts from experience and Common Sense,
2. Find their "(Qualitative) Global "Benefit-To-Cost Ratio" or the "Attractiveness to Retrofit Indicator" from the Portfolio,
3. Find possible solutions already proposed in the Portfolio (namely the ones retrieved from FEMA E-24, Page 6-263…272).
4. Procced with their protection (or Not).

4.2. The Cost / Benefits approach in the support of Portfolios design

If sensitiveness (vulnerability) of NSE's to shaking or displacements may be seen as an engineering issue, their importance is a subjective one. In fact, the importance of a single NSE can be completely different for the reliability of a residential building, an hospital, a school or a complex industrial facility. Once it is not feasible to address all of them in a single study, in the present case of KnowRisk Project, regular buildings (residential or commercial) will be the only ones addressed.

In such a case, again, FEMA E-74, once devised for the same scope, already provides a qualitative impact assessment of NSE's in such constructions, classified in a qualitative Ordinal 3 Levels Scale {Low; Medium; High} in the above-mentioned Criteria {Life Safety; Property Loss; Functional Loss}.

This allows, as a startup point, to build some simple rules that can help in the identification of the "Importance" of NSE's, which constitutes an important step in the Portfolio Design as a tool to help stakeholders in finding retrofitting priorities. In fact, this "importance" can be seen as the "Benefit" numerator of the Benefits-to-Cost Ratio. The "Costs" denominator of the Ratio, can, as a 1st step be indirectly represented by the degree of intervention required to address their fastening solution and implementation, starting with a basic classification based in the {"Engineered; Non-Engineered} class. However, in this 1st approach, and for methodology presentation, only the "Importance/Benefit" impact will be exposed.

Two approaches to devise the Benefits of NSE's protection from Seismic Events

As above addressed, there are, at least, to options amongst the selection of Models to devise the importance of protecting NSE's from Seismic Events: i) The "*Hard Way or the Quantitative Engineered approach*" and ii) the "*Soft, Qualitative, Non-Engineered*" one. Further simplifying, there exists a "*Qualitative*" and a "*Quantitative*" procedures choice.

If one looks at FEMA E-74, it can be observed that, even in such a detailed work, only a "Qualitative" approach was used. In fact, despite the already existence of many empirical formulae to quantify damages caused in NSE's by earth shaking or displacements due to seismic events[5], not only they do only cover a very small set of NSE's present in the 120 List, as the impact of their dysfunction is not covered in such works, namely because of the difficulties of applying MCDT[6] which constitutes a highly subjective issue, strongly dependent it the Value Systems (Objectives, Concerns, …) of the Decision Makers involved in each case (as in the House/Hospital example above referred).

Once again, by the same reasoning, a Quantitative approach to select NSE's for retrofitting portfolios, based in Qualitative *Risk Matrices* will be first presented. It will here be called, for the sake of simplicity the "*Risk Matrices Like*" approach.

Nevertheless, a second simplified procedure, *closer* to a Quantitative approach, will also be presented, based in MCDA/Macbeth[7] principles. It will here be called, for the sake of simplicity the "*Macbeth Like*" approach.

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[5] CynerG Project is one of many good examples.

[6] MCDT – Multi Criteria Decision Techniques.

[7] Bana e Costa, C. A., J.-M. d. Corte, et al. (2012). "MACBETH." International Journal of Information Technology & Decision Making 11(2): 359-387.

4.2.1. The "Risk Matrices Like" approach to identify the most influential NSE's in Seismic Risk

As it can be seen in Figure 5, extracted from the 120 NSE's List presented in Annex A, this is "All" the information available to help end-users select NSE's to retrofit, besides, of course, the proposed fastening solutions also accessible from this Portfolio together with FEMA E-74.

In the domain of the present problem (KnowRisk Project", the classic Portfolios Paradigm, can be stated by something like[8]:

"Taking into consideration: i) Hazard, ii) Life Safety Concerns, iii) Property Losses; iv) Functional Losses and v) Budget Constraints, what is the set of Interventions in these NSE's that Maximizes the return of the investment in Seismic Risk Reduction?"

#	Class	Category	Component	Life Safety	Property Loss	Functional Loss	Required Intervention
1	Architectural Components	Exterior wall components	Adhered veneer	H	H	L	ER
9	Architectural Components	Interior Patitions	Glazed	M	H	M	ER
32	Architectural Components	Chimneys and Stacks	Unreinforced masonry chimney	H	M	M	ER
33	Architectural Components	Chimneys and Stacks	Roof tiles	M	H	M	ER
35	Architectural Components	Freestanding Walls and Fences	Freestanding masonry wall or fence	M	H	M	ER
44	Mechanical, Electrical, & Plumbing	Mechanical Equipment	Suspended equipment	H	H	L	ER
92	Mechanical, Electrical, & Plumbing	Light Fixtures	Recessed lighting	H	M	M	ER
93	Mechanical, Electrical, & Plumbing	Light Fixtures	Surface-mounted lighting	H	M	M	ER
99	Mechanical, Electrical, & Plumbing	Elevators and Escalators	Escalators	H	H	H	ER
104	Furniture, Fixtures, & Equipment	Bookcases, Shelving	Library and other shelving	H	M	M	ER
111	Furniture, Fixtures, & Equipment	Computer and Communication Equipment	Televisions and video monitors, wall-mounted	H	H	L	HM
112	Furniture, Fixtures, & Equipment	Hazardous materials storage	Hazardous materials storage	H	M	H	HM
114	Furniture, Fixtures, & Equipment	Miscellaneous FF&E	File cabinets	H	M	M	HM
117	Furniture, Fixtures, & Equipment	Miscellaneous Contents	Shelf-mounted items	H	M	M	HM

Figure 5 – Extract Example of NSE's Listed in Annex A. Impacts: L:Low; M-Medium; H-High.

The formal (theoretical) answer can be found (among others) resorting to the already mentioned Phillips & Bana Theorem (Phillips and Bana e Costa 2007). However, the *Ratio Benefit-to-Costs* used in this approach is a Rational Number, which leads us to the domain of "Quantitative" assessments. However, as can be seen, and already stated, the information available to proceed is only "Qualitative", so, at this point, we will resort of "Risk Matrices" in order to find a "Quantitative / Ordinal Scale" that can indicate the Importance, or Benefit, of retrofitting each one of the Listed NSE's.

Once the Impacts of each NSE in the three criteria are mapped in the 3 Levels Scale {Low; Medium; High}, a Risk Matrix can be derived as now shown.

Aggregating Functional and Property Losses Criteria

1st, one can see that there exist 3 criteria. But Risk Matrices are bi-dimensional so, a 1st step requires the reduction from 3 to 2 criteria. The best candidates to do so are the "Loss" Criteria (Functional and Property).

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[8] Assuming that these Criteria were already identified as meaningful.

While Property Losses has a relatively straightforward meaning (mostly related to Monetary Losses), Functional Losses may be seen by different perspectives, depending on the building function:

- ✓ In the case of residential Buildings owned by their occupants, "Functional Interruption or Loss" may be mainly seen as a Social Impact related to "Homeless situation".
- ✓ In the case of residential Buildings rented by their occupants, "Functional Interruption or Loss" may, again, be seen as a Social Impact related to "Homeless situation", but it will be seen by the building owner a "Monetary Loss",
- ✓ In the case of Buildings where other non-residential functions are the core of some business, "Functional Interruption" may be directly translated by "Business Interruption", again with a strict relation with Monetary Losses.

This, we do believe, fully illustrates that the importance of Seismic damages are necessarily seen by different points-of-view, by different stakeholders, from which, a Universal Classification of their importance is not possible, being dependent on the Stakeholder for which the Portfolio is being addressed.

For this, and in a FEMA like approach, for now on in this work, we will privilege the problem of protecting NSE's in Residential Buildings, once "Housing" may be considered a Highly-Valued Function as it is possible to find some similarities in these buildings with "Schools", another highly valued Social asset of our society. Even so, for other assets or stakeholders, the problem formulation may be similar or even the same but with different values and priorities.

Now, we want to aggregate different options, with different impacts in the 2 criteria.

All the possible combinations are shown in Figure 6, with impacts mapped in the 3 levels qualitative scale {H-High; M-Medium; L-Low}.

From pure common sense, a Low Impact in both criteria, {L;L}, can be seen as a global Low Impact. Also from common sense, High Impact in both criteria, {H;H}, can be seen as a global High Impact. This allows a 1st approach to our Risk Matrix as illustrated in

Funct.	PL
H	L
H	M
H	H
M	L
M	M
M	H
L	L
L	M
L	H

Figure 6 – Impacts of NSE's dysfunction in Functional (Func.) and Property Losses (PL).

Func. Interrup. & Property Loss

Property Loss				
	H	?	?	H
	M	?	?	?
	L	L	?	?
		L	M	H
		Functional Interruption		

Figure 7 – Stage 1 of a Risk Matrix Like approach to classify Social/Monetary impacts of NSE's in residential buildings due to seismic events

But by Fundamental Axiomatic of Risk Matrices, namely from the "*Betweenness Axiom*" (Cox-Jr. 2008; Cox-Jr. 2009; Cox-Jr. 2009), cells connected to the Red-One cannot directly connect the Green-one without passing through an intermediary state. By so, from Figure 7 we evolve, without the need of further considerations, to Figure 8.

Func. Interrup. & Property Loss				
Property Loss	H	?	?	H
	M	M	M	?
	L	L	M	?
		L	M	H
		Functional Interruption		

Figure 8 - Stage 2 of a Risk Matrix Like approach to classify Social/Monetary impacts of NSE's in residential buildings due to seismic events

Now, {M;H} values can be assigned to the remaining (?) cells. Several classifications are possible and so, subjective judgment must be used. In absence of clear supportive arguments to differentiate among the importance of the two criteria, it was used an, even arguable, rule based in the binary "OR" operation such as: ? ="H" if "Property Loss is "H" OR "Functional Interruption is "H", leading to the final (possible & arguable) matrix as shown in Figure 9.

Func. Interrup. & Property Loss				
Property Loss	H	H	H	H
	M	M	M	H
	L	L	M	H
		L	M	H
		Functional Interruption		

Figure 9 – Social/Monetary impacts of NSE's in residential buildings due to seismic events.

Other possibilities may exist such as the ones in Figure 10.

Func. Interrup. & Property Loss				
Property Loss	H	M	H	H
	M	M	M	H
	L	L	M	M
		L	M	H
		Functional Interruption		

Func. Interrup. & Property Loss				
Property Loss	H	M	M	H
	M	M	M	H
	L	L	M	M
		L	M	H
		Functional Interruption		

Func. Interrup. & Property Loss				
Property Loss	H	M	M	H
	M	M	M	H
	L	L	M	M
		L	M	H
		Functional Interruption		

Figure 10 – Other (but not all other) possible Social/Monetary impacts of NSE's in residential buildings due to seismic events.

Aggregating Functional & Property Losses with Safety Criteria

In an analog way, a Risk Matrix aggregating Functional & Property Losses (FI&PL) with Safety (S) Criteria, another, also arguable, classification was constructed as shown in Figure 11.

Global Impact				
Safety	H	H	H	H
	M	M	M	H
	L	L	M	H
		L	M	H
		Func. Interrup. & Property Loss		

Figure 11 – Global (Aggregated) impacts of NSE's in residential buildings due to seismic events.

As before, other classifications are possible and arguable.

By the above procedures, at this point, all the 74 (of the 120) NSE's presents in the 120 List, have been assigned a Qualitative Indicator of their impact taking into account the 3 named criteria {Life Safety; Property Loss and Functional Impact}. The indicator is mapped in a 3 Levels Scale {H-High; M-Moderate and L-Low impact}. This classification is present in the NSE's List presented in Annex A.

Assigning NSE's a Benefits-to-Loss Ratio Like indicator

But, taking into consideration the already presented "Portfolio Paradigm", it is useful, even if difficult, to proceed with a "Cost" of devising and implementing safeguarding alternatives, in order to have NSE's classified in both "Benefits" & "Costs".

Of course, the implementation of solutions to retrofit NSE's is highly variable within them. This leads the process impactable at this state but, there are some shortcuts that can be explored.

From FEMA E-74, besides the impact of the NSE's dysfunction, another important indicator, even indirect, relates to the level of skills needed to find and implement the proposed retrofitting measures. There, a simple classification in a 2 levels scale is proposed {E-Engineered Required; NE-Non-Engineered Required}[9]. From inspection of the proposed retrofitting solutions, a 3^{th} level was assigned to the NSE's: The "HM: Home-Made". This classification was assigned to those solutions that can be seen as likely to be implemented by

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[9] Aldo a "P-Prescribed" classification is used in FEMA E-74. However, these cases not only are few as they are USA specific. By this reason, it was not considered at present moment.

a common citizen or a non-skilled technician with no much more than “Home Bricolage like aptitudes”. Again, a 3 Levels Scale, reflecting the easiness (or its absence) to implement the measures was created and the NSE’s classified in this criterion as {ER: Engineering Required; NE: Non-Engineered Required; HM: Home Made}.

Pursuing similar reasoning used in the construction of the Risk Matrices above described, another one was designed as shown in Figure 12.

Priority				
Global Impact	H	M	H	H
	M	M	M	H
	L	L	M	M
		ER	NE	HM
		Required Intervention		

Figure 12 –Possible Priorities Assignment in the selection of NSE’s to Contain Seismic Risk.

Again, all the 74 (of the 120) NSE’s presents in the 120 List, have been assigned, by the above procedure, a Qualitative Indicator mapped in a 3 levels scale {H-High; M-Medium; L-Low}, indicating their presumed attractivity to proceed with retrofitting measures in order to contain Seismic Risk in Residential Buildings, Schools and also possible in many other Non-Residential but common buildings.

4.2.2. The “Macbeth/MCDA Like” approach to identify the most influential NSE’s in Seismic Risk

If the use of Qualitative Risk Matrices can be seen as a “soft” approach to Risk, in the opposite side towards Quantitative approaches, the MCDA can be seen as the more sophisticated one, especially when “Non-Tangible” values are present or when quantitative robust information cannot be accessible. By this reason, many authors resort to MCDA approaches, although, in many cases, this can be no more than a tentative illusion of robustness and knowledge.

MCDA requires, among others, a strong commitment from decision makers to get deeply involved in the process, once decision as so supported is strictly confined to their personal objectives and value systems. Being so, in a case like the present one, a “General Purpose” classification cannot be found. Even so, one can essay such an approach, restricted to the case of Non-Residential buildings and Schools, only to get some insight of how close Priorities as so devised came when compared with the previous methodology. Of course, subjective assumptions about Risk Behaviors and Criteria Tradeoffs have to be assumed.

The basics of the method will consist in finding the parameters of a "*Complete Additive Aggregation Function*" like $V = \sum_{i=1}^{n} w_i . u(i)$, being *V* the *Value* assigned to some option taking its *utility/value function u(i)* in Criterion *i* to which a relative importance W_i was assigned.

Being so, the problem involves:

1. Identifying the meaningful Criteria,
2. Assigning a value or a utility function *u(i)* to impacts of options in each criteria *i*,
3. Deriving the relative importance of each Criteria *i*, W_i.

Assuming that the relevant Criteria were already identified {Life Safety; Losses (Property and Function Interruption); Measures Costs (Finding and implementation)}, steps 2 and 3 were performed using Macbeth Software (Bana e Costa, Corte et al. 2005; Bana e Costa, Corte et al. 2012), and assuming:

- ✓ W_1(Safety) > W_2(Losses) > W_3(Costs)
- ✓ Two Convex Risk Prone Value Functions for Criteria {Life Safety and Function Interruption}, and a simple Linear Function to Criteria Costs.

While in Macbeth Software the procedure is more elaborated, in Figure 13 the basics assumptions are illustrated for convenience.

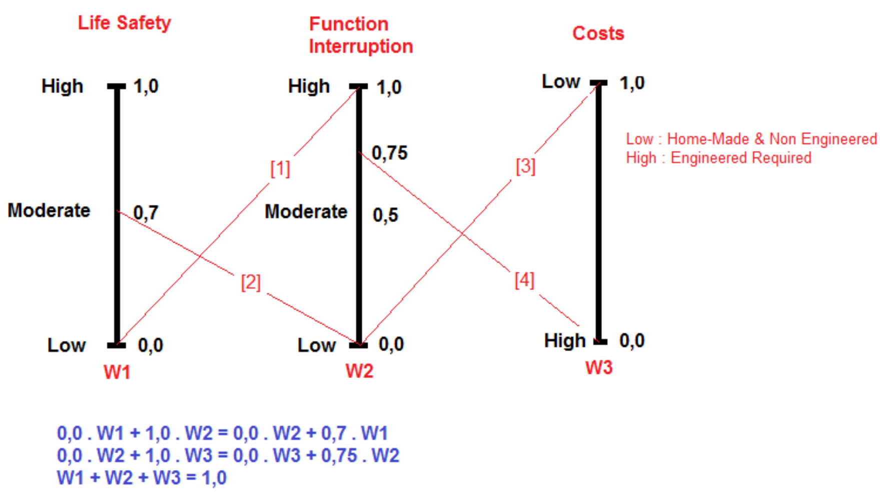

Figure 13- Illustration of Tradeoffs and value functions in a MCDA like procedure. NSE's with impacts [1] were considered equivalent to NSE's with impacts [2] and NSE's with impacts [3] were considered equivalent to NSE's with impacts [4].

The choice of Convex Value Functions in the Domain of Losses was assumed taking into consideration the *Risk Behavior* explained by D. Khaneman and A. Tversky , translated in their "*Asymmetric Value Function*" of (Kahneman and Tversky 1979; Khaneman and Tversky 2009).

The Tradeoffs between the several criteria, can be interpreted that (in this case fictitious) Decision Makers agreed in the prepositions that:

An Option [1] with Low Impact on Safety *u(1)=0*, and an High Impact on Business (or Function) Continuity, *u(2)=1* may be found to have a *similar value* as another, Option [2], with Moderate Impact on Safety, u(2)= 0,70, but with Low Impact on Business (or Function) Continuity, u(2)=0. This is equivalent to say that that Decision Maker (Stakeholder) is willing to sacrifice some amount of Safety (a decrease in Safety from Low Losses to Moderate Losses) in order to gain some increase in Business Continuity (or decrease in Business Interruption and Property Losses from High to Low). From that one can write:

$$V[1] = W_1.u(1) + W_2.u(2) = W_1.0 + 1.W_2$$
$$V[2] = W_1.0,7 + 0.W_2$$
$$V[1] = V[2] \Rightarrow W_2 = 0,7.W_1$$

Similarly, if the Decision Makers (Stakeholders) are willing to sacrifice some amount in Retrofitting Costs (passing from Low Investment to High Investment) in order to gain some increase in Business Continuity (Going from High Function Interruptions to High-to-Moderate ones), one can again write:

$$V[3] = W_2.u(2) + W_3.u(3) = W_2.0 + 1.W_3$$
$$V[4] = W_2.0,75 + 0.W_3$$
$$V[3] = V[4] \Rightarrow W_3 = 0,75.W_2$$

And, taking $W_1 + W_2 + W_3 = 1$

One gets to W_1=0,45; W_2=0,31 and W_3=0,24.

Once all parameters achieved, NSE's Retrofitting Priorities can be devised, as illustrated in Figure 14, and then used in Portfolio Optimization Strategies taking into account Budget Constraints, using V as the Benefits Numerator in the *Benefits-to-Costs Ratio Procedure*.

	Life Safety		**Property&Funcional Loss**		**Retrofitting Costs**		**Intervention Priority**
	W1= 0,45		*W2= 0,31*		*W3= 0,24*		$V = \sum_{i=1}^{n} w_i.u(i)$
NSE	**Impact**	**u(1)**	**Impact**	**u(2)**	**Impact**	**u(3)**	
1	Low	*0,00*	Low	*0,00*	Moderate	*0,50*	***0,120***
2	Low	*0,00*	Moderate	*0,50*	Low	*1,00*	***0,395***
3	High	*1,00*	Moderate	*0,50*	Low	*1,00*	***0,845***
4	Low	*0,00*	High	*1,00*	Moderate	*0,50*	***0,430***
5	High	*1,00*	Low	*0,00*	Moderate	*0,50*	***0,570***
6	Moderate	*0,70*	High	*1,00*	High	*0,00*	***0,625***

Figure 14 – Ranking NSE's Retrofitting Priorities using a MCDA Like Procedure

This illustrates not only the power but also limitations and the sensibility of sophisticated approaches, highly dependent on Decision Makers Values and Objectives, which may render such approaches inappropriate to *Universal Rules* that may be better gathered from repeated and large experience from wide and multiple real scenarios. The same argument can be found and deeper explained in (Mota de Sá, Oliveira et al. 2012; Mota de Sá, Oliveira et al. 2012; Oliveira, Ferreira et al. 2012).

Another shortcoming or restriction in the "Complete Additive Aggregation" used in MCDA came from the Theorem of "*Additive Independence*". That Rule requires that Tradeoffs between Criteria must be independent on the impacts in the remaining ones. In this example, the equations above shown about V[1]; V[2], V[3] and V[4] are only valid if it can be assumed that impacts in the other criterion do not invalidate 'them. Ex: The first set of Equations, leading to the Relative importance, Criteria Weights W_1 and W_2, must be valid independently of the impact on Criterion W_3.

The above considerations where here exposed mainly to illustrate the difficulties posed by the resorting to highly sophisticated methodologies but also, as already said, to gain some insight about the robustness of the findings achieved by the "Risk Matrix Like" Procedure 1st illustrated.

Of course, in a Committed Stakeholder Case-By-Case, the MCDA methodology cam be of high Value, not only clarifying Benefits and Costs but, even of higher importance and value, leading to Portfolio Optimization, Maximizing the Return of Investments (ROI) in Risk Containment even in the case of Short Budgets or weak willingness to invest.

Before finishing, it must be worth looking at a slightly modified example based on the above one.

In this new case, it was assumed that the stakeholder is highly averse to finance retrofitting programs. This can be modeled as shown in Figure 15. From the same system of equations one now gets: W_1=0,23; W_2=0,17 and W_3=0,60, *clearly reflecting the stakeholder high importance assigned to Retrofitting Costs in comparison with the remaining criteria. That is a Clear Aversion to Seismic Risk Containment.*

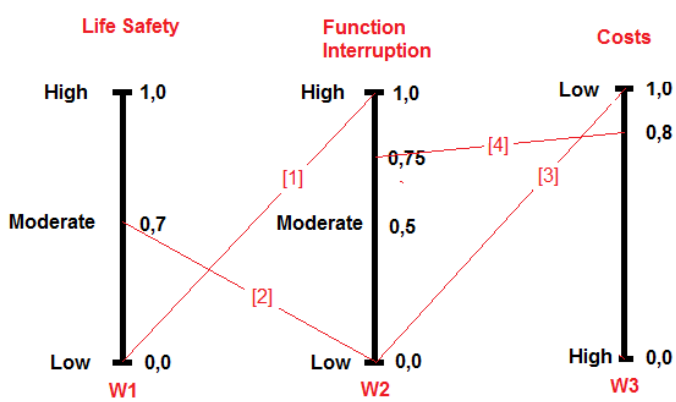

Figure 15 – Example of Retrofitting Investment Aversion.

Now, priorities come as shown in Figure 16.

	Life Safety		Property&Funcional Loss		Retrofitting Costs		Intervention Priority
	W1= 0,23		W2= 0,17		W3= 0,60		$V = \sum_{i=1}^{n} w_i.u(i)$
NSE	Impact	u(1)	Impact	u(2)	Impact	u(3)	
1	Low	0,00	Low	0,00	Moderate	0,50	**0,300**
2	Low	0,00	Moderate	0,50	Low	1,00	**0,685**
3	High	1,00	Moderate	0,50	Low	1,00	**0,915**
4	Low	0,00	High	1,00	Moderate	0,50	**0,470**
5	High	1,00	Low	0,00	Moderate	0,50	**0,530**
6	Moderate	0,70	High	1,00	High	0,00	**0,331**

Figure 16 – Case 2, Aversion to Invest in Risk Reduction

From this shift, and looking at Figure 17, one can observe:

1. Option 3, with High impact in Safety, a Moderate Impact in Function Continuity and showing a Low Cost of Retrofitting, remain as the Best one (the one with higher Ranking in both cases),
2. Option 1, with a Low Impact in Safety and Business Interruption and with High Retrofitting costs remain as the Worst one (the one with lower Ranking in both cases),
3. These two extremes seem clearly acceptable, however, among the remaining options:
4. Option 6, with a Moderate impact in Safety, a High impact in Business or Function Continuity and Losses, being the 2nd best choice in the 1st case, became the worst one in the 2nd case, reflecting the unwillingness to invest in Retrofitting.
5. Option 2, with a Low impact in Life Safety and only a Moderate impact in Function Continuity, being classified as the worst one, after Option1, became now the 2nd Best one immediately after Option 3, again reflecting the aversion now associated with retrofitting expenditures,
6. From both examples, also the discriminant power of the MCDA methodology, in this case reflected by the range and variability of V values assigned to the options, can be observed.

	Life Safety	Property&Funcional Loss	Retrofitting Costs	$V = \sum_{i=1}^{n} w_i.u(i)$	
NSE	Impact	Impact	Impact	Case 1	Case 2
1	Low	Low	Moderate	0,120	0,300
2	Low	Moderate	Low	0,395	0,685
3	High	Moderate	Low	0,845	0,915
4	Low	High	Moderate	0,430	0,470
5	High	Low	Moderate	0,570	0,530
6	Moderate	High	High	0,625	0,331

Figure 17 – Proneness (Case 1) and Aversion (Case 2) to Invest in Seismic Risk Reduction Ranking Comparisons

From this last example, on can observe MCDA as being a Powerful methodology, indeed, maybe because its sensitiveness to Decision Makers Values and Objectives. However, the same characteristic lead' it only usable if Stakeholders, as already said, are willing to play a reasonable effort in the decision modelling. In such a case, "***Decision Conferences***" (Phillips

2006) may be the best solution to proceed, however only in a case-by-case, with the Portfolio Task.

4.2.3. Comparison of Results about "Priorities Assigned to the Intervention in NSE's to reduce Seismic Risk, obtained by the two methodologies: The Qualitative Risk Matrix Like Procedure and the Quantitative Macbeth/MCDA Like one.

In order to compare the results obtained by the *Qualitative Risk Matrix Like Procedure* and the ones obtained by a *Quantitative Macbeth/MCDA Like*, Tradeoffs and Impacts were modeled like shown in Figure 18. There, HM relates to *Home-Made*, ER to *Engineered Required* and NE for *Non-Engineered Required*.

Here, again a Convex Shaped Value Function was assumed for the Life Safety Criterion, while for the remaining ones a Neutral Shape was assumed. A more Neutral Attitude for Retrofitting Costs was assumed, reflecting a more equilibrated attitude for this criterion, between the ones previously assumed in Cases 1 and 2. Here, it was assumed that stakeholders may be prone to accept going from Home-Made Retrofitting options to Non-Engineered Required ones in order to contain Impacts in Function Interruption to Moderate-High ones. From there, the Relative Importance of each Criteria (it's weight) came as: $W_1=0,37$; $W_2=0,25$ and $W_3=0,38$.

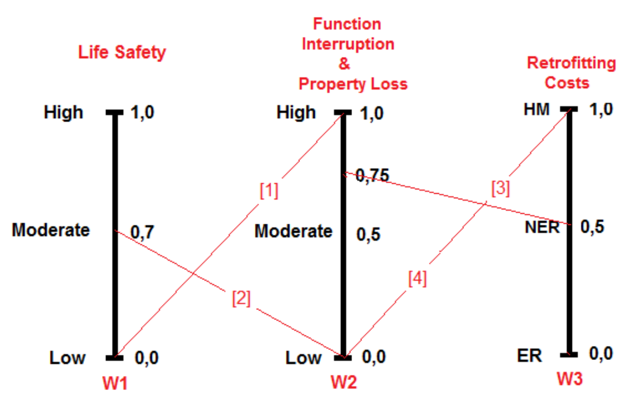

Figure 18 – Tradeoffs and Impacts for a MCDA Like procedure to evaluate the Attractiveness for Retrofit NSE's.

Now, the possible *Attractiveness for Retrofitting NSE's, RA*, obtained by the two methods are compared.

In the next Figures, RA Value is expressed by :

- ✓ LS&(PL&FL)&RI - The RA Value derived from the *Qualitative Risk Matrix Like Procedure.*
- ✓ McBeth Impact - The RA Value derived from the Quantitative Macbeth/MCDA Like Procedure.

In order to do so, an Analysis of Variance (ANOVA)[10] was carried on in order to validate the assumption that the Impacts {H; M; L} obtained by *LS&(PL&FL)&RI* (The Risk Matrix Like Procedure) have a unique correspondence with the Values of the *Macbeth Impact* obtained from this last procedure. Results[11] are here shown in Box 3.

Box 3 – ANOVA Tests for Results obtained by Quantitative and Qualitative procedures to Evaluate Attractiveness for NSE's Retrofit.

One-way ANOVA: Mcbeth Impact versus LS&(PL&FL)&RI

```
Null hypothesis         All means are equal
Alternative hypothesis  At least one mean is different
Significance level      α = 0,05
Equal variances were assumed for the analysis.

Factor Information
Factor          Levels  Values
LS&(PL&FL)&RI        3  H; L; M

Analysis of Variance
Source         DF  Adj SS   Adj MS  F-Value  P-Value
LS&(PL&FL)&RI   2   1,421  0,71073    39,00    0,000
Error          71   1,294  0,01822
Total          73   2,715

Model Summary

       S    R-sq  R-sq(adj)  R-sq(pred)
0,134996  52,35%     51,01%      48,52%

Means
LS&(PL&FL)&RI   N    Mean   StDev        95% CI
H              18  0,7652  0,1495  (0,7018; 0,8287)
L              14  0,3470  0,0941  (0,2751; 0,4189)
M              42  0,5330  0,1396  (0,4915; 0,5745)
Pooled StDev = 0,134996
```

Tukey Pairwise Comparisons

```
Grouping Information Using the Tukey Method and 95% Confidence
LS&(PL&FL)&RI   N    Mean  Grouping
H              18  0,7652  A
M              42  0,5330    B
L              14  0,3470      C
Means that do not share a letter are significantly different.
```

From the above Tests, it is possible to observe:

- ✓ The p-value = 0,000 by which the Null Hypothesis that the Mean Values of each Impact Class {H; M; L} obtained by the Risk Matrix Like Procedure are equal, is rejected. That is, The Mean values of their Attractiveness obtained from the MCDA Like Procedure are different for each Impact Class of the Quantitative Risk Matrix Like procedure.

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[10] The "*Equal Variances Hypothesis*" was previously tested and validated.
[11] Results obtained with ***Minitab*** ©

- ✓ The 95% confidence Intervals of the MCDA RA do not overlap: H [0,7018-0,8287], M [0,4915-0,5745] and L [0,2751-0,4189], again validating a good correspondence between results obtained from highly different methodologies.
- ✓ The Post-hoc Tests (Tukey and Fisher LS[12]) confirm the assumption that NSE's classified with different Degrees of Attractiveness to Retrofit, RA, obtained by the Risk Matrix Like Procedure, are in fact different. The Mean Value of the qualitative RA was found to be: High-0,7652; Medium-0,5330 and Low-0,3470.

4.2.4. Conclusions about the use of a Simplified Qualitative Method, based in Risk Matrices, to devise the Potential Attractiveness to Retrofit NSE's in order to reduce Seismic Risk.

From the previous exposition, it is possible to sustain that the *Risk Matrices Simple procedure* above designed, can be used with **robust results** to help Decision Makers / Stakeholders in the appreciation of the possible benefits of retrofitting NSE's in order to reduce Losses from Seismic Episodes, avoiding the need to engage' them in more sophisticated approaches that also demand from them a high commitment in the decision process.

Being so, the results obtained by this methodology where added to the List of NSE's (Presented in Annex A), as an indicator of *Global Attractiveness to proceed with Retrofitting*, which is not provided neither by FEMA neither by any other work found.

The simplicity and robustness of the method, also allows stakeholders to, in an easy way, modify NSE's impacts in the selected Criteria and, from there, to devise more personalized priorities, by so, better adapted to their Values and Objectives. The full procedure to do so, is presented in Annex B.

Nevertheless, the already found values of *RA* (*Attractiveness for Retrofitting NSE's)*, can serve as a starting point to support decisions for general Buildings Users/Owners, helping 'them to decide about Portfolio Optimization Strategies in order to Contain Seismic Risk.

Seismic Hazard, Exposed Assets Vulnerability and Impacts

The impacts here used, {High; Medium; Low} provided by FEMA E-24, assume a *High Seismicity*, as there expressed. Besides that, some sort of NSE's Vulnerability to accelerations and displacements is also imbedded in the proposed impacts. However, neither Hazard neither Vulnerability parameters are explicit there, once most of the information as so gathered is derived from past experiences in real earthquake scenarios, rather than from analytics procedures.

Being so, the impacts of NSE's in the 3 main criteria here assumed, are only valid to seismic shaking scenarios that in FEMA E-24 are considered as representative of "High Seismicity".

---

[12] Even not shown here, the *Fisher LS* Post-hoc Test also gave the same results.

If other ground shaking scenarios are to be considered, the List of NSE's presented in Annex A, must be readdressed.

In the Portuguese case, however, the shaking intensity able to induce Moderate-to-Extensive Structural Damages, where Nonstructural Damages are more likely to show, is in the range of Intensities VII-VIII[13]. By so, it was assumed that this can be considered compatible with the FEMA *High Shaking*, from which Impacts presented in Annex A are considered to be appropriate.

5. Next Steps

As said at the beginning of this document, at this point, Task D4 is not yet finished. A short checkup show that:

1. Whilst 120 NSE's were identified as potential disruptors of functional reliability and safety, only 74 of them have been classified in terms of impacts in Safety, Property Loss, Function Reliability, as in terms of necessary skills and effort to protect' them,
2. The List of the 74 NSE's already addressed, do not have, yet, attached to it, all the information about the NSE behavior, description and Retrofitting Details. This will be added in a next step.
3. Also as a next step, is the developing of the Web Based application to access and use the Portfolio.
4. The procedure used to devise their Attractiveness to Retrofit, may have to be adapted if final stakeholders, or target final users, feel the need to adapt criteria, objectives or values,
5. Final stakeholders, or target final users feedback about the current work has not yet been collected.
6. If found useful by stakeholders, then, the Phillips & Bana Procedure to Optimal Portfolios Construction[14] will then further explained and exemplified.

Being so, before proceeding, the last point 4 (Stakeholders feedback), above mentioned, seems to be the best *Next Step*, before proceeding with Task D4 refinement.

From that, clearer guidelines can be devised in order to proceed and finish D4 Action, once additional work over the already done, may show to be following an unsuitable path.

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[13] This preposition relies in the assumption that average Portuguese Building Stock can be characterized by buildings that initiate Nonstructural damages (Structural Damages in the Range of Moderate to Extensive) at PGA ~ 1,0 to 2,0 m/s^2, for the case of Earthquakes Type I (Far Sources) and Type II (Near Sources) respectively. Assuming, for Portugal, that $I(EMS) \sim 7{,}4 + Log_{10}(PGA_{m/s2})$, this shaking level corresponds, in Portugal, to Macrosseismic Intensities in the range ~ VII-VIII.

[14] Meanwhile, this amazingly simple but efficient procedure, can be found in the already cited bibliography under Phillips, L. D. and C. A. Bana e Costa (2007). Transparent prioritisation, budgeting and resource allocation with multi-criteria decision analysis and decision conferencing. Springer Science+Business Media.

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Annex A

NSE’s Lists, Impacts and Retrofit Attractiveness Rankings

ANNEX A1 – **Full List of NSE’s, Impacts on the 3 Main Criteria and Required Skills to devise and implement Retrofitting Options.**

ANNEX A2 – **List of Classified NSE’s according to their Potential Attractiveness to be Retrofitted.**

- **A2.1 NSE’s With Higher Potential Attractiveness to Retrofitting**
- **A2.2 NSE’s With Moderate Potential Attractiveness to Retrofitting**
- **A2.3 NSE’s With Lower Potential Attractiveness to Retrofitting**

ANNEX A3 – **List of Other NSE’s, referred but not classified neither with clear fastening solutions.**

ANNEX A1 – Full List of NSE's and their potencial to impact in the 3 Main Criteria.

Class	Category	Component	Life Safety	Property Loss	Functional Loss	Required Intervention
Architectural Components	**Canopies, Marquees, and Signs**	Canopies	H	H	M	ER
		Marquees	H	H	M	ER
		Sunshades	H	H	M	ER
	Ceilings	Ceiling moulding	-	-	-	-
		Ceilings applied directly to structure	M	H	H	NE
		Heavy stucco soffit	-	-	-	-
		light fixtures (candelabros)	-	-	-	-
		Suspended heavy ceilings	H	H	H	ER
		Suspended lay-in tile ceiling systems	M	H	H	ER
	Chimneys and Stacks	Roof tiles	M	H	M	ER
		Unreinforced masonry chimney	H	M	M	ER
	Exterior wall components	Adhered veneer	H	H	L	ER
		Anchored veneer	H	H	L	ER
		Glass Blocks	H	M	M	ER
		Glazed exterior wall system	H	M	M	ER
		Prefabricated panels	H	H	M	ER
	Freestanding Walls and Fences	Freestanding masonry wall or fence	M	H	M	ER
	Interior Patitions	Doors and windows	-	-	-	-

Full List of NSE's (cont)

Class	Category	Component	Life Safety	Property Loss	Functional Loss	Required Intervention
		Glass and window fixtures	-	-	-	-
		Glass cabinets	-	-	-	-
		Glazed	M	H	M	ER
		Heavy Interior Patition Walls	H	H	H	ER
		Large-panel glass panes with frames (as windows or infill walling material)	-	-	-	-
		Light Interior Patition Walls	M	H	H	ER
		Plaster				
	Interior Veneers	Stone and Tile Massonry Veneer	H	H	M	ER
		Tiles (ceramic, stone, glass or other) bolted on surface	-	-	-	-
		Tiles (ceramic, stone, glass or other) hung from hooks bolted to surface	-	-	-	-
		Tiles (ceramic, stone, glass or other) pasted on surface	-	-	-	-
	Parapets and Appendages	Architectural ornaments	-	-	-	-
		Balconies	-	-	-	-
		Parapets	H	H	L	ER
		Signes	-	-	-	-
		Unreinforced masonry parapets	H	H	L	ER

Full List of NSE's (cont)

Class	Category	Component	Life Safety	Property Loss	Functional Loss	Required Intervention
	Stairways	Stairways	H	M	H	ER
Furniture, Fixtures, & Equipment	**Bookcases, Shelving**	Bookshelves	H	M	M	HM
		Library and other shelving	H	M	M	ER
		Multi-level material stacks	-	-	-	-
		Racks and bookshelves (see table 11)	-	-	-	-
		Storage shelves	-	-	-	-
	Computer and Communication Equipment	Computer access floors and equipment	M	H	H	ER
		Computer and communication racks	M	H	M	HM
		Desktop computers and accessories	L	H	M	HM
		Televisions and video monitors, wall-mounted	H	H	L	HM
	Hazardous materials storage	Hazardous materials storage	H	M	H	HM
		Lab appliances and chemicals	-	-	-	-
	Miscellaneous Contents	Desktop, CounterTop items	L	H	M	HM
		Fire extinguisher and cabinet	M	H	L	HM
		Fragile artwork (heavy)	L	H	L	HM
		Refrigerators	-	-	-	-
		Fragile artwork (Ligth)	L	H	L	NE

Full List of NSE's (cont)

Class	Category	Component	Life Safety	Property Loss	Functional Loss	Required Intervention
	Stairways	Stairways	H	M	H	ER
		Shelf-mounted items	H	M	M	HM
		TVs	-	-	-	-
		Washing machines	-	-	-	-
	Miscellaneous FF&E	Demountable partitions	M	M	M	HM
		File cabinets	H	M	M	HM
		Miscellaneous furniture and fixtures	L	L	L	HM
	Storage racks	Industrial storage racks	H	H	M	ER
		Light duty shelving	H	M	M	HM
Mechanical, Electrical, & Plumbing	**Conveyors**	Conveyors	M	M	M	ER
	Ductwork	Air diffusers	M	H	L	NE
		Air-conditioning ducts	-	-	-	-
		Rainwater drain pipes	-	-	-	-
		Sewage pipelines	-	-	-	-
		Suspended ductwork	M	M	L	ER
		Water supply pipelines	-	-	-	-
	Electrical and Communications Distribution	Electrical distribution panels	M	M	M	ER
		Electrical raceways, conduit, and cable trays	M	M	M	ER

Full List of NSE's (cont)

Class	Category	Component	Life Safety	Property Loss	Functional Loss	Required Intervention
	Electrical and Communications Equipment	Antennas communication towers on rooftops	-	-	-	-
		Batteries and battery racks	-	-	-	-
		Communications Antennae	-	-	-	-
		Control Panels, motor control centers, and Switcgear	-	-	-	-
		Electricity cables & wires	-	-	-	-
		Emergency generators	-	-	-	-
		Monitor	-	-	-	-
		Photovoltaic power systems	-	-	-	-
		Server and main service panels	-	-	-	-
		Telecommunication wires	-	-	-	-
		Transformers	-	-	-	-
	Elevators and Escalators	Elevators	-	-	-	-
		Escalators	H	H	H	ER
		Hydraulic elevator	M	M	M	ER
		Traction elevator	M	M	H	ER
	Fire Protection Piping	Fire hydrant piping system	-	-	-	-
		Fire hydrant systems	-	-	-	-

Full List of NSE's (cont)

Class	Category	Component	Life Safety	Property Loss	Functional Loss	Required Intervention
		Hazardous materials piping	-	-	-	-
		Nonhazardous materials piping	-	-	-	-
		Suspended fire protection piping	M	H	H	ER
	Fluid Piping, not Fire Protection	Hazardous materials piping	M	M	M	ER
		Nonhazardous materials piping	H	H	H	ER
	Light Fixtures	Heavy light fixtures	H	M	M	NE
		Pendant light fixtures	H	M	M	NE
		Recessed lighting	H	M	M	ER
		Surface-mounted lighting	H	M	M	ER
	Mechanical Equipment	Boilers, furnaces, pumps, and chillers	M	M	H	ER
		Diesel Generators	-	-	-	-
		General manufacturing and process machinery	M	H	H	ER
		HVAC equipment suspended in-line with ductwork	L	M	M	ER
		HVAC equipment with vibration isolation	L	M	M	ER
		HVAC equipment without external vibration isolation	L	L	L	ER
		Suspended equipment	H	H	L	ER

Full List of NSE's (cont)

Class	Category	Component	Life Safety	Property Loss	Functional Loss	Required Intervention
		Water pumps (small)	L	L	L	ER
	Pressure Piping	Flexible connections, expansion joints, and seismic	M	M	M	ER
		Floor-mounted supports	M	M	M	ER
		Gas pipelines	-	-	-	-
		In-line valves and pumps	M	M	M	ER
		Other fluid pipe systems	-	-	-	-
		Penetrations	-	-	-	-
		Pipe risers	M	M	M	ER
		Roof-mounted supports	M	M	M	ER
		Suspended pressure piping	M	H	M	ER
		Wall-mounted supports	M	M	M	ER
	Storage Tanks and Water Heaters	Compressed gas cylinders	H	M	M	ER
		Flat bottom containers and vessels	M	H	M	NE
		Flat bottom tanks and vessels	M	H	M	NE
		Gas Cylinders	H	H	L	ER
		Structurally supported tanks and vessels	M	H	M	ER
		Structurally Supported Vessels	M	H	M	ER
		Water heaters	H	H	L	ER
		Water Tanks (small)	-	-	-	-

ANNEX A2 – List of Classified NSE's according to their Potential Attractiveness to be Retrofitted

A2.1 NSE's With Higher Potential Attractiveness to Retrofitting

		Impacts					Intervention	Retrofit Atractiveness, High	
								Risk Matrix Like	MacBeth Like
Class	**Component**	**LS: Life Safety**	**PL: Property Loss**	**FL: Functional Loss**	**PL&FL**	**LS&(PL&FL)**	**RI: Req. Interv.**	**RLMI**	**MCDALI**
Furniture, Fixtures, & Equipment	**Televisions and video monitors, wall-mounted**	H	H	L	H	H	HM	H	1,00
Furniture, Fixtures, & Equipment	**Hazardous materials storage**	H	M	H	H	H	HM	H	1,00
Furniture, Fixtures, & Equipment	**Computer and communication racks**	M	H	M	H	H	HM	H	0,89
Furniture, Fixtures, & Equipment	**Fire extinguisher and cabinet**	M	H	L	H	H	HM	H	0,89
Furniture, Fixtures, & Equipment	**Bookshelves**	H	M	M	M	H	HM	H	0,88
Furniture, Fixtures, & Equipment	**Shelf-mounted items**	H	M	M	M	H	HM	H	0,88
Furniture, Fixtures, & Equipment	**File cabinets**	H	M	M	M	H	HM	H	0,88
Furniture, Fixtures, & Equipment	**Light duty shelving**	H	M	M	M	H	HM	H	0,88
Architectural Components	**Ceilings applied directly to structure**	M	H	H	H	H	NE	H	0,70
Mechanical, Electrical, & Plumbing	**Air diffusers**	M	H	L	H	H	NE	H	0,70
Mechanical, Electrical, & Plumbing	**Flat bottom containers and vessels**	M	H	M	H	H	NE	H	0,70
Mechanical, Electrical, & Plumbing	**Flat bottom tanks and vessels**	M	H	M	H	H	NE	H	0,70
Mechanical, Electrical, & Plumbing	**Heavy light fixtures**	H	M	M	M	H	NE	H	0,69
Mechanical, Electrical, & Plumbing	**Pendant light fixtures**	H	M	M	M	H	NE	H	0,69
Furniture, Fixtures, & Equipment	**Desktop computers and accessories**	L	H	M	H	H	HM	H	0,63
Furniture, Fixtures, & Equipment	**Desktop, CounterTop items**	L	H	M	H	H	HM	H	0,63
Furniture, Fixtures, & Equipment	**Fragile artwork (Ligth)**	L	H	L	H	H	HM	H	0,63
Furniture, Fixtures, & Equipment	**Fragile artwork (heavy)**	L	H	L	H	H	NE	H	0,44

A2.2 NSE's With Moderate Potential Attractiveness to Retrofitting

Class	Component	Impacts LS: Life Safety	PL: Property Loss	FL: Functional Loss	PL&FL	LS&(PL&FL)	Intervention RI: Req. Interv.	Retrofit Atractiveness, Moderate Risk Matrix Like RLMI	MacBeth Like MCDALI
Furniture, Fixtures, & Equipment	**Demountable partitions**	M	M	M	M	M	HM	M	0,76
Architectural Components	**Canopies**	H	H	M	H	H	ER	M	0,62
Architectural Components	**Marquees**	H	H	M	H	H	ER	M	0,62
Architectural Components	**Sunshades**	H	H	M	H	H	ER	M	0,62
Architectural Components	**Suspended heavy ceilings**	H	H	H	H	H	ER	M	0,62
Architectural Components	**Adhered veneer**	H	H	L	H	H	ER	M	0,62
Architectural Components	**Anchored veneer**	H	H	L	H	H	ER	M	0,62
Architectural Components	**Prefabricated panels**	H	H	M	H	H	ER	M	0,62
Architectural Components	**Heavy Interior Patition Walls**	H	H	H	H	H	ER	M	0,62
Architectural Components	**Stone and Tile Massonry Veneer**	H	H	M	H	H	ER	M	0,62
Architectural Components	**Parapets**	H	H	L	H	H	ER	M	0,62
Architectural Components	**Unreinforced masonry parapets**	H	H	L	H	H	ER	M	0,62
Architectural Components	**Stairways**	H	M	H	H	H	ER	M	0,62
Furniture, Fixtures, & Equipment	**Industrial storage racks**	H	H	M	H	H	ER	M	0,62
Mechanical, Electrical, & Plumbing	**Escalators**	H	H	H	H	H	ER	M	0,62
Mechanical, Electrical, & Plumbing	**Nonhazardous materials piping**	H	H	H	H	H	ER	M	0,62
Mechanical, Electrical, & Plumbing	**Suspended equipment**	H	H	L	H	H	ER	M	0,62
Mechanical, Electrical, & Plumbing	**Gas Cylinders**	H	H	L	H	H	ER	M	0,62
Mechanical, Electrical, & Plumbing	**Water heaters**	H	H	L	H	H	ER	M	0,62

A2.2 (cont)

Class	Component	Impacts LS: Life Safety	PL: Property Loss	FL: Functional Loss	PL&FL	LS&(PL&FL)	Intervention RI: Req. Interv.	Retrofit Atractiveness, Moderate Risk Matrix Like RLMI	MacBeth Like MCDALI
Furniture, Fixtures, & Equipment	**Demountable partitions**	M	M	M	M	M	HM	M	0,76
Architectural Components	**Suspended lay-in tile ceiling systems**	M	H	H	H	H	ER	M	0,51
Architectural Components	**Roof tiles**	M	H	M	H	H	ER	M	0,51
Architectural Components	**Freestanding masonry wall or fence**	M	H	M	H	H	ER	M	0,51
Architectural Components	**Glazed**	M	H	M	H	H	ER	M	0,51
Architectural Components	**Light Interior Patition Walls**	M	H	H	H	H	ER	M	0,51
Furniture, Fixtures, & Equipment	**Computer access floors and equipment**	M	H	H	H	H	ER	M	0,51
Mechanical, Electrical, & Plumbing	**Traction elevator**	M	M	H	H	H	ER	M	0,51
Mechanical, Electrical, & Plumbing	**Suspended fire protection piping**	M	H	H	H	H	ER	M	0,51
Mechanical, Electrical, & Plumbing	**Boilers, furnaces, pumps, and chillers**	M	M	H	H	H	ER	M	0,51
Mechanical, Electrical, & Plumbing	**General manufacturing and process machinery**	M	H	H	H	H	ER	M	0,51
Mechanical, Electrical, & Plumbing	**Suspended pressure piping**	M	H	M	H	H	ER	M	0,51
Mechanical, Electrical, & Plumbing	**Structurally supported tanks and vessels**	M	H	M	H	H	ER	M	0,51
Mechanical, Electrical, & Plumbing	**Structurally Supported Vessels**	M	H	M	H	H	ER	M	0,51
Architectural Components	**Unreinforced masonry chimney**	H	M	M	M	H	ER	M	0,50
Architectural Components	**Glass Blocks**	H	M	M	M	H	ER	M	0,50
Architectural Components	**Glazed exterior wall system**	H	M	M	M	H	ER	M	0,50
Furniture, Fixtures, & Equipment	**Library and other shelving**	H	M	M	M	H	ER	M	0,50
Mechanical, Electrical, & Plumbing	**Recessed lighting**	H	M	M	M	H	ER	M	0,50
Mechanical, Electrical, & Plumbing	**Surface-mounted lighting**	H	M	M	M	H	ER	M	0,50

A2.2 (cont)

Class	Component	Impacts LS: Life Safety	PL: Property Loss	FL: Functional Loss	PL&FL	LS&(PL&FL)	Intervention RI: Req. Interv.	Retrofit Atractiveness, Moderate Risk Matrix Like RLMI	MacBeth Like MCDALI
Mechanical, Electrical, & Plumbing	**Compressed gas cylinders**	H	M	M	M	H	ER	M	0,50
Furniture, Fixtures, & Equipment	**Miscellaneous furniture and fixtures**	L	L	L	L	L	HM	M	0,38
Mechanical, Electrical, & Plumbing	**HVAC equipment without external vibration isolation**	L	L	L	L	L	ER	M	0,00
Mechanical, Electrical, & Plumbing	**Water pumps (small)**	L	L	L	L	L	ER	M	0,00

A2.3 NSE's With Lower Potential Attractiveness to Retrofitting

		Impacts					Intervention	Retrofit Atractiveness, Low	
								Risk Matrix Like	MacBeth Like
Class	Component	LS: Life Safety	PL: Property Loss	FL: Functional Loss	PL&FL	LS&(PL&FL)	RI: Req. Interv.	RLMI	MCDALI
Mechanical, Electrical, & Plumbing	**Conveyors**	M	M	M	M	M	ER	L	0,38
Mechanical, Electrical, & Plumbing	**Suspended ductwork**	M	M	L	M	M	ER	L	0,38
Mechanical, Electrical, & Plumbing	**Electrical distribution panels**	M	M	M	M	M	ER	L	0,38
Mechanical, Electrical, & Plumbing	**Electrical raceways, conduit, and cable trays**	M	M	M	M	M	ER	L	0,38
Mechanical, Electrical, & Plumbing	**Hydraulic elevator**	M	M	M	M	M	ER	L	0,38
Mechanical, Electrical, & Plumbing	**Hazardous materials piping**	M	M	M	M	M	ER	L	0,38
Mechanical, Electrical, & Plumbing	**Flexible connections, expansion joints, and seismic**	M	M	M	M	M	ER	L	0,38
Mechanical, Electrical, & Plumbing	**Floor-mounted supports**	M	M	M	M	M	ER	L	0,38
Mechanical, Electrical, & Plumbing	**In-line valves and pumps**	M	M	M	M	M	ER	L	0,38
Mechanical, Electrical, & Plumbing	**Pipe risers**	M	M	M	M	M	ER	L	0,38
Mechanical, Electrical, & Plumbing	**Roof-mounted supports**	M	M	M	M	M	ER	L	0,38
Mechanical, Electrical, & Plumbing	**Wall-mounted supports**	M	M	M	M	M	ER	L	0,38
Mechanical, Electrical, & Plumbing	**HVAC equipment suspended in-line with ductwork**	L	M	M	M	M	ER	L	0,13
Mechanical, Electrical, & Plumbing	**HVAC equipment with vibration isolation**	L	M	M	M	M	ER	L	0,13

ANNEX A3 – List of Other NSE's, referred but not classified neither with clear fastening solutions

Class	Category	Component
Architectural Components	Ceilings	Ceiling moulding
		Heavy stucco soffit
		light fixtures (candelabros)
	Interior Patitions	Doors and windows
		Glass and window fixtures
		Glass cabinets
		Large-panel glass panes with frames (as windows or infill walling material)
	Interior Patitions	Plaster
	Interior Veneers	Tiles (ceramic, stone, glass or other) bolted on surface
		Tiles (ceramic, stone, glass or other) hung from hooks bolted to surface
		Tiles (ceramic, stone, glass or other) pasted on surface
	Parapets and Appendages	Architectural ornaments
		Balconies
		Signes
Furniture, Fixtures, & Equipment	Bookcases, Shelving	Multi-level material stacks
		Racks and bookshelves (see table 11)
		Storage shelves
	Hazardous materials storage	Lab appliances and chemicals
	Miscellaneous Contents	Refrigerators
		TVs
		Washing machines

ANNEX A3 (cont)

Class	Category	Component
Mechanical, Electrical, & Plumbing	Ductwork	Air-conditioning ducts
		Rainwater drain pipes
		Sewage pipelines
		Water supply pipelines
	Electrical and Communications Equipment	Antennas communication towers on rooftops
		Batteries and battery racks
		Communications Antennae
		Control Panels, motor control centers, and Switcgear
		Electricity cables & wires
		Emergency generators
		Monitor
		Photovoltaic power systems
		Server and main service panels
		Telecommunication wires
		Transformers
	Elevators and Escalators	Elevators
	Fire Protection Piping	Fire hydrant piping system
		Fire hydrant systems
		Hazardous materials piping
		Nonhazardous materials piping
	Mechanical Equipment	Diesel Generators
		Gas pipelines
		Other fluid pipe systems
		Penetrations
	Storage Tanks and Water Heaters	Water Tanks (small)

Annex B

Constructing a Qualitative Global Indicator of Attractiveness to Protect NSE's, from Seismic Episodes, *RMLI*, by the Risk Matrix Like Procedure,

and

Assignment of a Real Valued Global Indicator of Attractiveness to Protect NSE's, from Seismic Episodes*, MCDALI*, by the Quantitative MCDA Like procedure.

Constructing a Global Indicator of Attractiveness to Protect NSE's, *RMLI*, by the Qualitative Risk Matrix Like Procedure

Table 1 – Symbology

H	High Impact	**ER**	Retrofitting Needs: Engineered Required (High Skills)
M	Medium Impact	**NER**	Retrofitting Needs: Non-Engineered Required (Medium Skills)
L	Low Impact	**HM**	Retrofitting Needs: Home Made (Low-No skills)

Aggregation of Function Interruption & Property Loss, *FI&PL*

Func. Interrup. & Property Loss				**FI&PL**
Property Loss	**H**	H	H	H
	M	M	M	H
	L	L	M	H
		L	**M**	**H**
		Functional Interruption		

Figure 1 - FI&PL {H; M; L} Indicator, constructed by the Aggregation of FI&PL.

Aggregation of Safety & (Function Interruption & Property Loss), S&*FI&PL*

Safety&Func. Interr.&Prop.Loss				**S&FI&PL**
Safety	**H**	H	H	H
	M	M	M	H
	L	L	M	H
		L	**M**	**H**
		Func. Interrup. & Property Loss		

Figure 2 - S&FI&PL {H; M; L} Indicator, constructed by the Aggregation of S&FI&PL..

The Global Indicator of Attractiveness to Protect NSE's, *RMLI*

Aggregation of Safety & (Function Interruption & Property Loss) & Required Intervention, S&*FI&PL&RI*

Safety&Func. Interr.&Prop.Loss&Req. Interv.				**S&FI&PL&RI**
S&FI&PL	**H**	M	H	H
	(Ctrl)	M	M	H
	L	L	M	M
		ER	**NE**	**HM**
		Required Intervention		

Figure 3 – RMLI {H; M; L} Indicator, constructed by the Aggregation of S&FI&PL&RI.

Results are shown in Annex A, under the RMLI {H; M; L} column.

Assigning a Real Valued Global Indicator of Attractiveness to Protect NSE's, *MCDALI*, by the Quantitative MCDA Like procedure

The procedure, illustrated in Figure 4 – Global Model (Tradeoffs & Impacts) for the MCDA Like procedure., was devised by the construction of the following a Complete Additive Aggregation Function as:

$$MCDALI = \sum_{i=1}^{3} W_{i.} u(i)$$

- ✓ **Impact on Life Safety,** was *mapped by a Convex value Function u(1),*
- ✓ **Impact on Function Interruption and Property Loss,** was *mapped by a Neutral value Function u(2),*
- ✓ **Impact on Retrofitting Costs,** indirectly **represented by the Required Intervention, RI** *mapped by a Neutral value Function u(3).*

Criteria Weights, W_i, were derived by assuming that:

1. *Option [1] is equally Attractive as Option [2]* and
2. *Option [3] is equally Attractive as Option [4].*

Value Functions *u(i)* and Criteria Weights, W_i are shown in Table 2.

Table 2 – Value Functions and Criteria Weights.

Value Functions, u(i)	Low	Mod	High
u(1)- LS	0,00	0,70	1,00
u(2) - FI&PL	0,00	0,50	1,00
	ER	NER	HM
u(3) - RI	0,00	0,50	1,00

Criteria Weigths	W_i
W_1- LS	0,37
W_2 - FI&PL	0,25
W_3 - RI	0,38

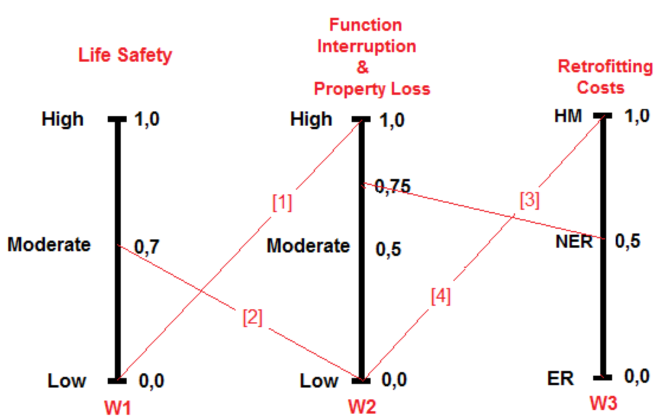

Figure 4 – Global Model (Tradeoffs & Impacts) for the MCDA Like procedure.

MCDALI **Values are found in Annex A under MCDALI Column.**