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SEISMIC RISK OF BUSINESSES WITH ECONOMIC RESILIENCE AND COST-EFFECTIVENESS OF SEISMIC RETROFIT

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Abstract

Recent earthquakes in Italy have highlighted the importance of the risk assessment and management for productive activities, due to business interruption (BI) costs.
In order to estimate this risk properly, both direct (repair/replacement) and indirect (BI) losses should be quantified.
A recent study, calibrated on a real case study – a biomedical packaging company damaged by the 2012 earthquake in Emilia Romagna, Italy, which suffered direct damages and indirect losses and resumed business soon after (Donà et al. 2019, [1]) – has shown the significant impact of possible business recovery strategies in reducing the BI losses and thus the company's exposure for the various damage states (defined as in HAZUS-MH MR4, 2003).
In this paper, a parametric seismic risk assessment is presented for businesses with an exposure model equal to that obtained by [1] for the real case study, analyzing and comparing various types of structural vulnerability (from HAZUS 2003), seismic hazard and business recovery strategies. The risk estimates were then used to assess the economic justification of the seismic retrofitting of existing RC factories (not seismically damaged), through the discounted payback period of the investment, with respect to the vulnerabilities, hazards and recovery strategies examined. In low-to-medium seismic areas, retrofitting may or may not be cost-effectiveness depending on whether recovery strategies are considered or not. Finally, these estimates on the retrofit effectiveness, which take into account the effects of recovery strategies, are used to address a possible breakdown of the retrofit costs between the company that rents the factory and the building owner, which can be used as reference when the intervention is globally cost-effective and desired by both parties.

Keywords: Seismic Risk of Productive Activities, Resilience, Business Recovery Strategies, Profitability of Seismic Retrofitting.

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1 INTRODUCTION

Seismic risk assessment of productive activities is becoming an increasingly necessary research topic and a widespread interest in it has recently grown also in Italy, especially as a result of the 2012 earthquakes in Emilia Romagna.

One of the main reasons is the extremely high exposure of companies, i.e., the serious economic consequences of damage. Indeed, damages due to violent seismic events generally arrest production for a certain period, and this may result in significant reductions in revenues in the years following the event; generally, these losses are comparable in scale with repair or reconstruction costs ([2], [3], [4], [5]). Another crucial reason is the negative impact that a prolonged downtime of several productive activities located in the same region could have on the economy and community of that area in the short-to-medium term ([4], [6]).

Appropriate risk assessment methodologies, accounting for both direct and indirect losses, are therefore essential in order to manage this risk. In this regard, over the years, the Pacific Earthquake Engineering Research Center (PEER) developed a probabilistic performance-based earthquake engineering framework [7], to assess the occurrence probability of some loss parameters, based on the total probability theorem (i.e., it combines all the uncertainties in the definitions of seismic hazard, vulnerability, and exposure).

The term direct loss is used here to refer to repair or replacement costs due to structural, non-structural and content damage; other types of costs, such as downtime, are defined here as indirect (also according to other authors, e.g. [8]).

These losses are strictly related to the concept of resilience [9], which generally refers to the following action categories.

- Actions implemented before the adverse event, in order to reduce the frequency and magnitude of disasters and to strengthen the property for damage prevention or limitation [9]; based on these actions, resilience may be defined as the 'ability to prepare and plan for, absorb, recover from, or more successfully adapt to actual or potential adverse events' [10].
- Actions taken after the disaster has struck, with the aim to minimize the business interruption (BI) costs, i.e. the losses in the flow of goods and services provided by companies ([11], [12]).

Both types of actions are generally applied for productive activities in order to reduce the risk before any adverse event and to minimize losses after it; therefore, an appropriate risk assessment should consider the possible economic resilience actions (generally analyzed by economists and social scientists) in addition to the structural aspects, requiring a certain level of interdisciplinary knowledge. Among these actions, the business recovery strategies (BRSs) implemented by corporate managers after an earthquake-induced downtime are fundamental.

To date, only a few authors have performed probabilistic risk analyses assessing the indirect losses on businesses, despite financial stability of small-to-medium enterprises (SMEs) can be seriously threatened by downtime ([4], [13]). Moreover, although several authors have discussed the great potential of the BRSs (e.g. [14], [15]), no study was conducted on their effects in terms of risk reduction.

Therefore, this paper presents a novel study which aims to evaluate the effects of the BRSs on the seismic risk of businesses and therefore on the cost-effectiveness of the seismic retrofit, combining the main structural and economic aspects of SMEs. This study refers to a biomedical packaging company damaged by the 2012 earthquake in Emilia Romagna (Italy), recently examined by [1]. These authors proposed a general methodology to assess the effects of BRSs on the seismic risk of SMEs and provided an exposure model for the specific company analyzed, taking into account both direct and indirect costs. Based on this loss model, a parametric seismic risk assessment was carried out and presented in this paper, analyzing and comparing various structural vulnerabilities, seismic hazards and business recovery strategies. The risk estimates so obtained were then elaborated in order to assess the cost-effectiveness of the seismic retrofit of existing RC factories in various situations. Finally, for the case of companies that produce in a rented factory, a possible method for the breakdown of the retrofit costs between the company and the building owner is proposed, which is based on the specific benefit of both parties resulting from the retrofit intervention.

2 CASE STUDY, PRODUCTION PROCESS AND EXPOSURE MODEL

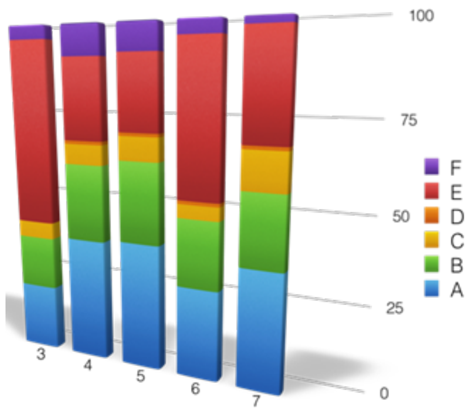
2.1 Case study and production process

The Emilia Romagna region is one of the most highly industrialized regions in Europe. Its industrial buildings are about 80,000, i.e., about 12% of all Italian stock; approximately 85% of these structures are built of reinforced concrete, and prefabricated ones represent two-thirds [6]. They are mostly single-storey buildings with isostatic schemes, constructed before 2003, when the territory of Emilia Romagna was first classified as a seismic zone (OPCM 3274 [16]); they were mainly designed for vertical loads, with roofs and floors without in-plane stiffness, secondary beams simply laid over the main ones, and the latter connected to the tops of pillars with hinges, thus being extremely vulnerable to seismic actions.

Because of this high vulnerability and the fact that the 2012 Emilia earthquake was characterized by several high-intensity shocks a few days apart, this seismic event resulted to be one of the most expensive Italian quakes and the worst natural disaster – with the greatest economic damage – in 2012 in Europe (estimated at about 12.6 billion euros by Swiss Re [17]).

Among the sources revealing the extent of this disaster are the AeDES forms, reporting building damage and safety level: the cumulative results (Figure 1) show that many buildings could not be used at all, either permanently, temporarily, or partially, after the event.

During a survey of companies damaged by the earthquake, a good representative case study was found in Mirandola: it is one of the leading Italian firms in the sector of packaging for pharmaceutical/medical products. This company was affected by the 2012 earthquake, suffered direct damages and indirect losses (due to business interruption BI), and resumed business soon after effectively applying the recovery tactics, such as outsourcing and delocalization (see later). Its production mainly consists of processing medical paper, Tyvek and plastic film, with the production process qualitatively represented in Figure 2. The final products of the company are mainly of two types: '*Finished Products*', i.e., those requiring all stages of processing, and '*Printed Products*', those not including plastic film (for further details see [1]).



Safety degrees

A = Safe / Usable
B = Temporarily Unsafe, usable with immediate intervention measures
C = Partially Unsafe
D = Temporarily Unsafe, to be reviewed in depth
E = Unsafe / Unusable
F = Unsafe for External Risk

Building uses

3 = Warehouse (tot=12329)
4 = Commerce (tot=2874)
5 = Office (tot=1228)
6 = Manufacturing (tot=2215)
7 = Receptive (tot=190)

Figure 1. Main results from AeDES forms, showing disastrous effects of 2012 Emilia earthquakes on buildings destined for various uses, including productive activities (data from [18]).

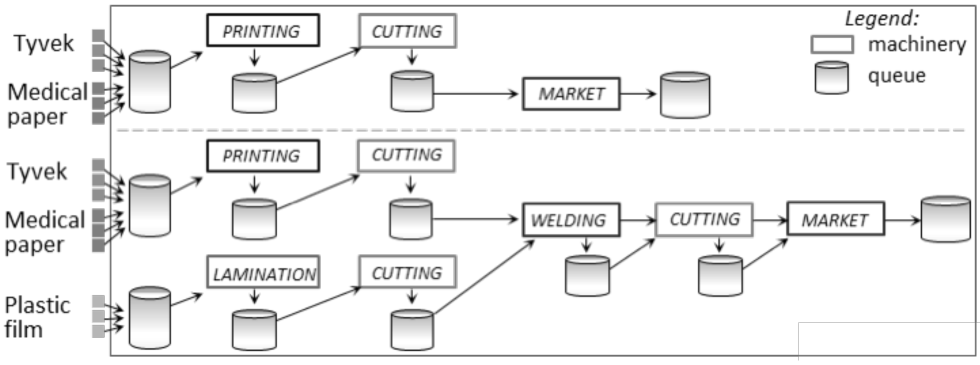


Figure 2. Outline of the production process of the company assumed as a case study (from [1]).

In order to define a company exposure model, the definition and calibration of an appropriate production model is necessary (i.e., raw material supply, production lines and functions, raw materials and finished product storage, etc.); such a model is essential for the subsequent simulations of production loss due to the earthquake-induced downtime.

The model used is this study is based on machine processing time and queue capacity: the latter affects the former when maximum capacity is reached. Although beyond the aims of this study, such modeling allows us to monitor the quantity of raw materials and processed products in queues and thus, for example, potential sufferings from lack of supply of raw materials (in the case of supply-chain simulation). The calibration of the production model, which includes the BRSs applied by the company, is reported in [1].

Two parameters to be defined in this step analysis are: product processing value (revenue per unit of raw material) and compound annual growth rate (CAGR). Based on the information reported in the financial statements (prior to the earthquake) and provided by the manager, these parameters (estimated as explained in [1]) were: 7.0 €/kg for *Finished Products* and 5.9 €/kg for *Printed Products*; CAGR was 5.3%.

Most of the analyses of this work were run with the code *RiskApp* (developed in Python), which supports simulation of production processes by using DES (discrete-event simulation) modeling. It also implements the main information reported by HAZUS-MH MR4 [19], e.g., vulnerability of buildings, machinery and contents, and BI time (depending on recovery strategy and type of activity). In addition, by accessing public sources of the company's financial statements, it allows us to estimate the company exposure and therefore its expected losses for various damage scenarios. Lastly, by implementing the hazard model of various events, it can also provide assessments for several kinds of risk.

2.2 Exposure model of the company

Because of the difficulty in collecting detailed economic information regarding indirect losses, a simple (but robust) deterministic loss model was assumed, which depends only on the damage state (DS) reached and the recovery strategy (BRS) adopted.

As regards the definition of the damage states, for this study we referred to HAZUS-MH MR4 [19]; these, which are associated with a specific damage ratio or repair cost ratio RCR (i.e., the ratio between the repair cost and the total replacement cost), are: "None" (RCR=0%), "Slight" (2%), "Moderate" (10%), "Extensive" (50%) and "Complete" (100%).

Regarding the recovery strategies evaluated, these combine the tactics of "reconstruction" (i.e., company stops production, awaiting reconstruction), "relocation" (i.e., company temporarily continues production in alternative structures, to reduce BI time, awaiting reconstruction) and "outsourcing" (i.e., company asks external companies to produce in its place, to minimize BI time, awaiting relocation and reconstruction). For the tactics of reconstruction and relocation, HAZUS [19] provides information about BI times, which depend on the reached damage state; whereas, for the tactic of outsourcing (missing in HAZUS), we referred to the real experience of the company of the case study. All this information is summarized in Figure 3, which shows all the possible scenarios "damage-BI time" evaluated in this study. In particular, when production is resumed in relocation or outsourcing, this can be lower than expected one in ordinary circumstances, due to non-optimal configurations of work or to reduced availabilities of time and resources of external companies; therefore, various production ratios (with respect to the ordinary production) were assessed, resulting in the six BRSs listed in Table 1. For further details see [1].

The main steps to derive the exposure model, performed for all combinations between BRSs and DSs, were:

(*i*)- simulation of the production process for two years (to include the BI time of the DS Complete), starting from January 1 2012 and placing the seismic event on May 20 2012 (as in the case study), and calculation of the production loss;

(*ii*)- calculation of all losses, direct and indirect, including costs to implement the strategy.

As an example, Figure 4 shows the production trends associated with some BRSs for the DS Complete: the variation in production volumes between the strategies can be considerable.

As regards the second phase of analysis, all the cost items taken into account are briefly described in Table 2, relating to direct losses, and in Table 3, for indirect losses.

Regarding the direct losses of building and machinery, these depend on the repair cost ratio (RCR), associated with each DS, and on the related total replacement cost; the latter was estimated, for building, from the unit costs (€/m^2) of demolition and reconstruction reported in “Ordinance no. 57/2012” of Emilia Region (Italy) [20], whereas, for machinery, from the expertise documents of the case study.

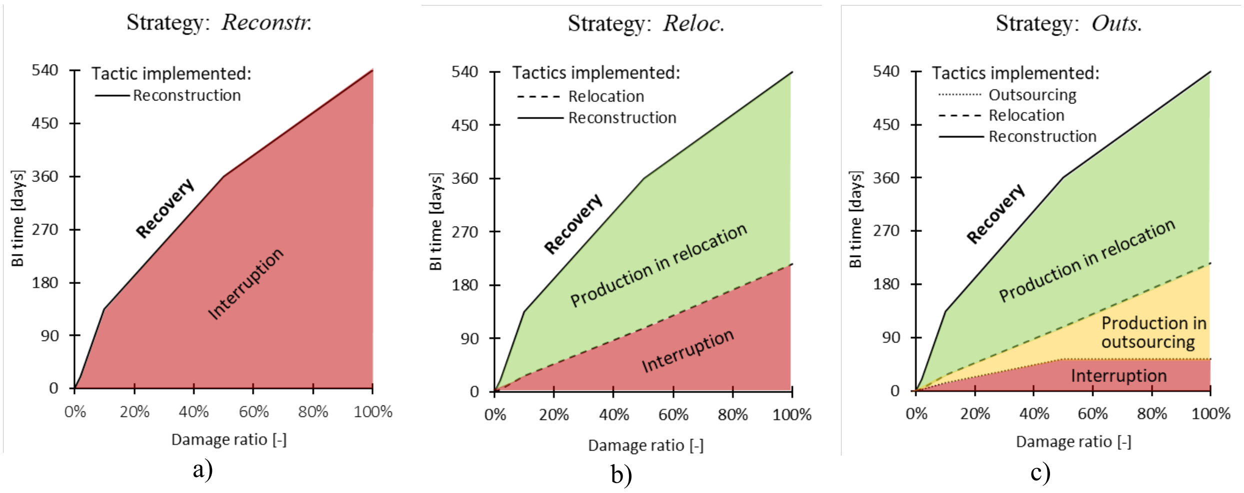


Figure 3. General business recovery strategies (BRSs) examined: a) ‘*Reconstr.*’; b) ‘*Reloc.*’; c) ‘*Outs.*’

Name of Recovery Strategy	Outsourcing	Relocation
Reconstr.	0%	0%
Reloc.75%	0%	75%
Reloc.100%	0%	100%
Outs.25%	25%	100%
Outs.50%	50%	100%
Outs.75%	75%	100%

Table 1: Production ratios with respect to the ordinary production for each recovery strategy (BRS) analyzed.

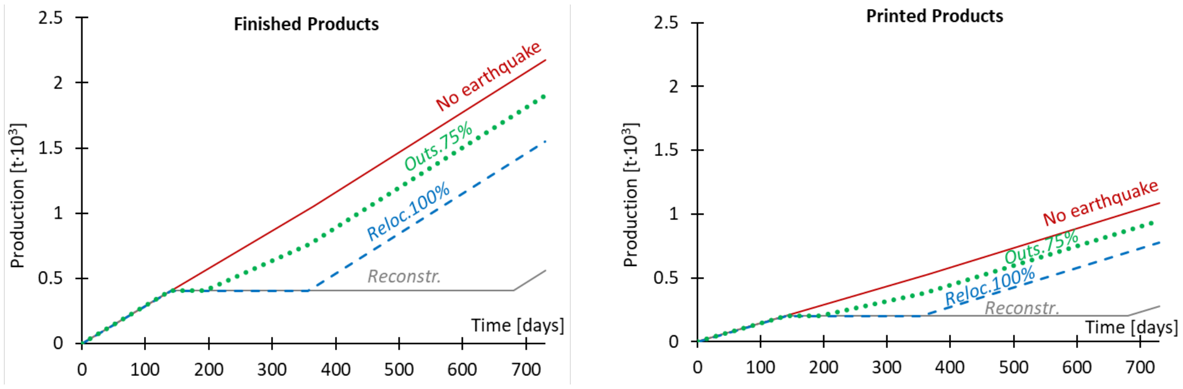


Figure 4. Examples of simulated production trends, without earthquake and for three recovery strategies, in the case of damage state Complete: a) *Finished Products*; b) *Printed Products*.

Direct losses	Trend proportional to:	Data source
- Building losses (reconstruction/demolition costs)	Damage ratio	Ordinance no. 57/2012, Emilia Region (IT), Annex 2, '*Sfinge*' [20].
- Plant and machinery losses	Damage ratio	Appraisal report of case study

Table 2. Direct losses examined.

Indirect losses	Trend proportional to:	Data source
- Loss of profit (*LOP*)	Loss of turnover times gross profit ratio	Production process simulations with model calibrated on case study
- Rent and installation of temporary structures	Damage ratio and days of use	Appraisal report of case study
- Transfer of equipment	Damage ratio	Appraisal report of case study
- Production cost in outsourcing	Production in outsourcing	Appraisal report of case study
- Saving of factory rent (in case of rented factory)	Number of days for reconstruction	Revenue Agency database (IT) – OMI (real-estate market observatory) [21]
- Loss of market share	Production downtime	General management of case study

Table 3. Indirect losses examined.

Regarding the indirect losses, these strongly depend on the possible BRSs in addition to the DSs. Indeed, the loss of profit (LOP) – the main indirect cost – depends on the loss of turnover (LT), which is the loss of production volume time the processing value (see Section 2.1). In particular, LOP can be estimated in a simplified way by multiplying the loss of turnover by the gross profit ratio (GPR), as is generally done for LOP insurance policies (in Italy):

$$LOP = LT \cdot GPR = LT \cdot (GP / T) \tag{1}$$

$$GP = T - VC = T - (Rm + 0.7 \cdot Se + 0.11 \cdot Pe + 0.12 \cdot Daw + \Delta Mat + Pr + Op) \tag{2}$$

where GP is gross profit, T is turnover and VC represents variable costs, which are: Rm, raw materials; Se, services; Pe, personnel; Daw, depreciation, amortization and write-offs; ΔMat, changes in raw materials, semi-finished and finished products; Pr, provision for risks; Op, other operating expenses. These items can be found in the company's financial statement.

Other important indirect losses are the implementation costs of the BRSs, mainly due to: rental and installation of temporary structures, transfer of machinery and outsourced production. Loss of market share can also be a significant indirect loss for companies, as in this case.

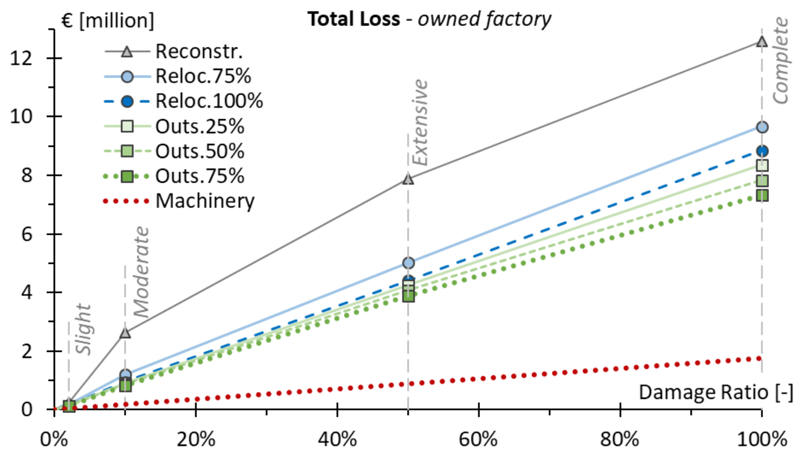


Figure 5. Company exposure model for the case of owned factory (see also [1]).

These costs were calibrated on the information collected from the expertise documents of the company of the case study, as it applied all the recovery tactics analyzed in this study. For further details, please refer to [1].

Finally, the global results from this parametric loss analysis, i.e. the exposure model of the company, are shown in Figure 5. This loss model is related to the case of an owned factory, i.e., it includes the direct costs associated with the building; similarly, but excluding these costs, the loss model was obtained also for the case of a rented factory (which will be used later for final cost-effectiveness evaluations on the seismic retrofit).

Figure 5 shows the company's total losses associated with all recovery strategies without machinery costs, and the machinery costs separately: this is due to the fact that, in general, building and machinery have different fragility curves associated with the same DS (see next section) and therefore the sum of their losses, for the same DS, is not conceptually correct. This figure shows that the effectiveness of BRSs increases when damage ratio (or DS) increases. *Reconstr.* is the strategy which differs most from the others, and *Outs.75%* the one that performs best. Looking at the total losses at DS Complete, including machinery costs, *Outs.75%* reduces the seismic losses by about 40% compared with Reconstr. and 15% compared with Reloc.100% in the case of an owned factory (these values become about 50% and 20%, respectively, in the case of a rented factory).

3 PARAMETRIC SEISMIC RISK ASSESSMENT

The previous loss model (for both cases of owned and rented factory) was used here to parametrically quantify the seismic risk of companies with the same exposure, but various vulnerability degrees and seismic hazards.

As regards vulnerability degrees, the HAZUS fragility curves of building and machinery (Figure 6) of category PC1 (i.e., 'precast concrete tilt-up walls') were used. These are provided for four types of seismic code (High-, Moderate-, Low- and Pre-Code) and defined for all the DSs mentioned above; in this study, building and machinery were associated with the same type of code.

The HAZUS manual [19] provides average information for aggregate and large-scale analyses and, therefore, it is suitable for the aim of this study; however, if the aim was the specific seismic risk of a specific company, the evaluation of the specific vulnerability of that company would be necessary.

The national contextualization of the seismic codes defined in HAZUS is necessary to apply this vulnerability information properly: the first code requiring a seismic design in Emilia was OPCM 3274 of 2003 [16], and therefore, buildings constructed in this area before 2003 may appropriately be associated with a Pre-Code. The factory of the case study, constructed in the 1970s, suffered a DS Extensive due to the main shock with PGA of 0.26g (on May 20 2012) and a DS Complete due to the aftershock with PGA of 0.29g (on May 29): this is well represented by the damage probabilities from HAZUS when a Pre-Code is used.

A simplified interaction between structure and machinery vulnerability was supposed, assuming a total loss of machinery in the case of a building-*DS* Complete. Specifically, a new fragility curve was obtained for the DS Complete of machinery, combining the probabilities of building-DS Complete and machinery-DS Complete assumed as independent events. This was the experience of the case study, and it is reasonable when the factory substantially shows an isostatic structural scheme with the possibility that the covering elements collapse on the machinery and when there is the presence of "clean rooms", which are very sensitive to structural damage and expensive to repair (for further information see also [1]).

For purposes of comparison, in addition to the low-moderate seismicity of Mirandola (case study), the seismicity of Cosenza (one of the highest in Italy) was also examined; for both sites, hazard was defined according to the Italian code DM-2018 [22] and to the SHARE Project ([23]; data from OpenQuake [24]), assuming a soil type C and a topographic category T1; Figure 7 shows these hazards associated with the nominal reference period of the building V_R, i.e. 50 years (according to DM-2018).

Expected losses were calculated (according to the PEER approach) for building and machinery separately (as they are associated with different fragility curves), and these two components were then added together; indirect losses were considered within the building risk. In particular, expected losses were evaluated for the whole range of interest of PGA, obtaining the "vulnerability-exposure" profiles of the company show in Figure 8 for all strategies and design codes examined. These profiles provide general information about the risk of a company, as they do not depend on the site hazard but only on the company's vulnerability and exposure; the results directly show the effectiveness of strategies in reducing the expected loss for each value of PGA, which is greater (like losses) for lower codes.

By introducing the hazard in the previous profiles, i.e., replacing the PGA values with the respective values of occurrence probability in a certain reference period, it is possible to obtain the "loss-exceedance" curves of Figure 9. The area subtended by these curves is the total expected loss EL, or company risk, related to a certain reference period T. As an example, Figure 9 shows these curves for the hazard of Cosenza (according to the SHARE Project, [24]), as the risk and therefore the effect of the strategies is greater, and for some reference periods T.

In particular, in Figure 9, the curves defined as "As-built" (i.e., without retrofit) refer to the vulnerability of the declared seismic code, whereas those defined as "Retrofitted" refer to the vulnerability after the retrofit intervention; such a retrofit is intended to increase the structural safety up to the level required by the current code (DM-2018 [22]), associated in this study with a Medium-Code for Mirandola (low-to-moderate seismicity) and with a High-Code for Cosenza (high seismicity), because of the differing structural vulnerabilities required by the code according to site seismicity. The difference between the subtended areas (EL) between "As-built" and "Retrofitted" curves corresponds to the risk reduction, or benefit, due to the retrofit.

Often, the risk is calculated with reference to V_R, i.e. the nominal reference period of the building, in terms of average expected annual loss (EAL); EAL is defined as EL, with the difference that the exceedance probability is defined on an annual basis, and therefore depends on V_R [25]. Instead, in this study, risk assessments were parameterized by examining incremental reference periods T, from 1 to V_R, and then calculating the total loss EL for each of them (see Section 4). The main reason is that the hypothesis of using the building for its entire reference life V_R (in the case of EAL) could be too restrictive for the company, from a "capital budgeting" perspective, in order to estimate the cost-effectiveness of the retrofit and thus the payback period (i.e., the period necessary to recover the investment); therefore, in order to estimate the annual benefit (By) due to the intervention, the procedure described in Section 4 – which is based on the total EL – was adopted instead of using the EAL parameter.

Other detailed information on the influence of the various vulnerabilities, recovery strategies and hazards analyzed on the seismic risk estimates at 50 years (V_R) can be found in [1].

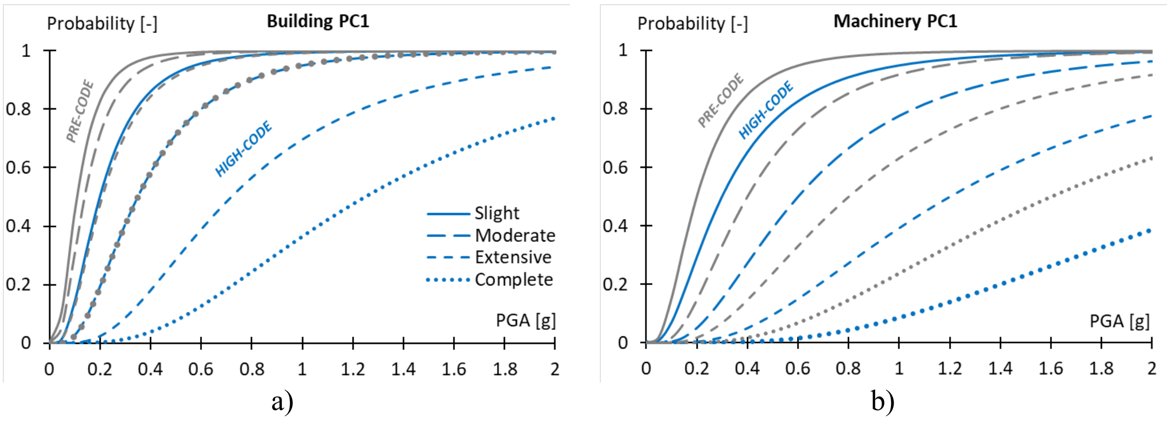


Figure 6. Examples of HAZUS fragility curves [19] assumed for this study: a) structure; b) machinery.

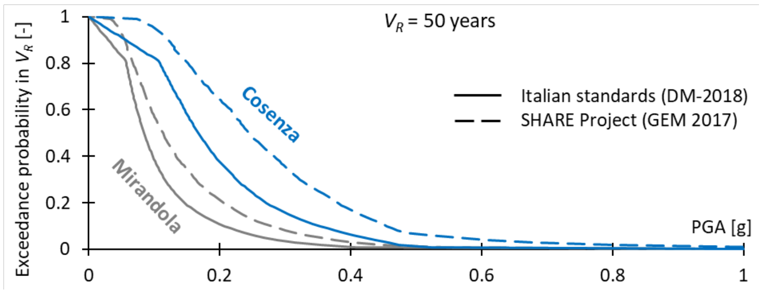


Figure 7. Seismic hazards examined (nominal reference period V_R of 50 years).

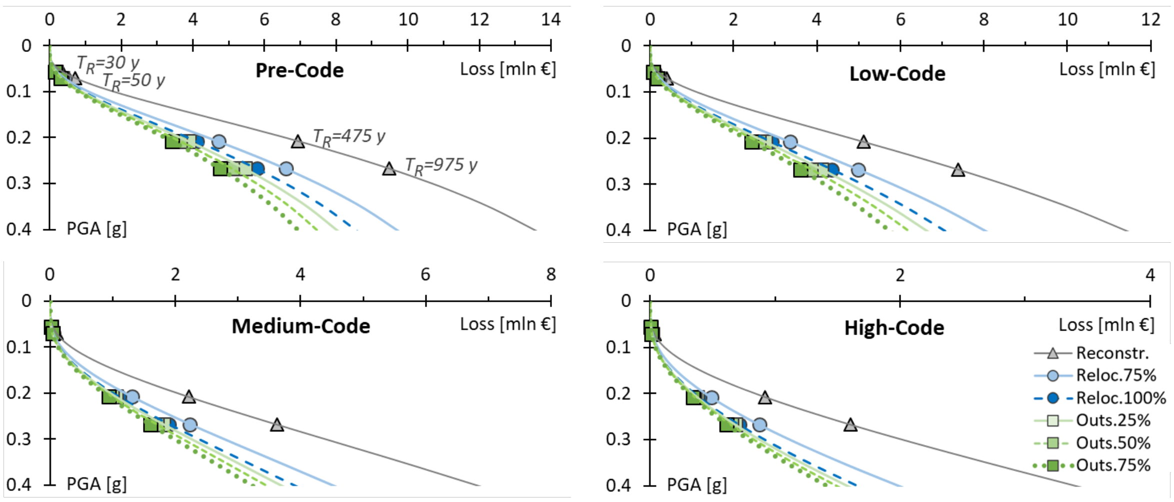


Figure 8. Company's vulnerability-exposure profiles, for all strategies and design codes; case: owned factory.

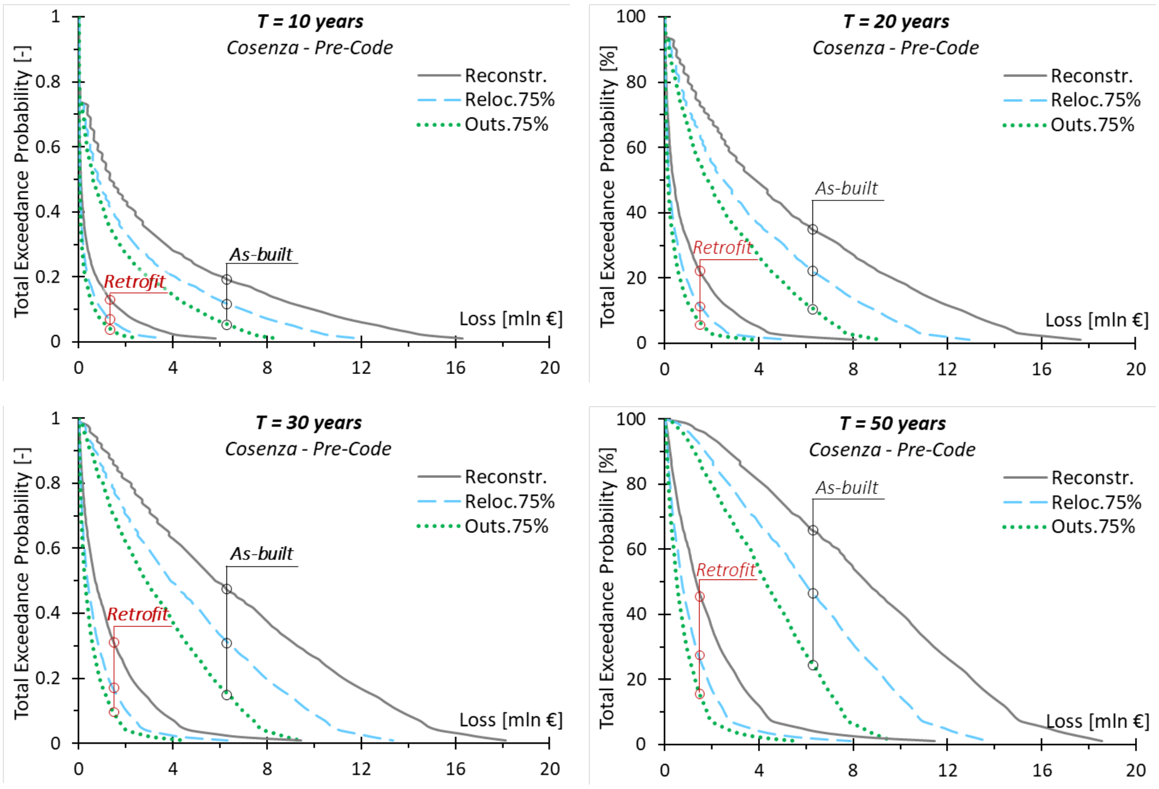


Figure 9. Loss-exceedance curves of the cases “As-built” and “Retrofitted”, for some recovery strategies, associated with the planning horizons T of 10, 20, 30 and 50 years (hazard according to SHARE [24]).

4 COST-EFFECTIVENESS ANALYSIS FOR THE SEISMIC RETROFIT

The principal steps of this analysis are briefly summarized below.

- Calculation of the total benefit due to retrofitting as the reduction of the total expected loss (EL) between the cases “As-built” and “Retrofitted”, for the hazard associated with various reference periods or planning horizons T, i.e. from 1 year up to V_R, with 1-year steps.

- Calculation of the annual benefit, By, as the difference between the values of total benefit associated with subsequent values of planning horizons T.

- Calculation of the expected net present value (NPV) of the retrofit investment for all the T values examined. NPV is a measure of the intervention cost-effectiveness, and for this study it can be calculated as shown in Equation (3), i.e., as the difference between the sum of the present values of the annual benefits By(i) (i.e., annual risk reductions in years *i*) and the initial intervention cost I_0, over a reference period T; r_r is the real discount rate.

$$NPV = \sum_{i=1}^{T} \frac{1}{(1+r_r)^i} B_y(i) - I_0 \tag{3}$$

Therefore, the key information for this analysis is the discount rate and the retrofitting cost.

As for the discount rate, for this type of studies, it can reasonably be assumed equal to the yield offered by the risk-free financial assets at medium-to-long term; a reasonable estimate of r_r in the Italian context is 2% (www.dt.tesoro.it).

As regards the cost of the retrofit interventions, we referred to the information from the expert engineers who worked on these operations in the aftermath of the Emilia earthquake. In particular, costs are associated with two intervention phases; phase 1: restoration of connections for infills, pillars and secondary/main beams (to eliminate possible loss of support); phase 2: strengthening of vertical structures and foundations (to increase the safety level). In the case of industrial buildings not designed for seismic actions in Mirandola (before 2003), corresponding to a Pre-Code from HAZUS [19], the average retrofit cost per square meter was estimated as 145 €/m^2, which includes both intervention phases (see [1]). In a simplified manner and through expert judgment, these costs were then extrapolated to evaluate situations of different initial vulnerability and different hazard, as shown in Table 4; in particular, as already stated, the hazard of Cosenza requires reaching a lower level of vulnerability than that for Mirandola, resulting in higher retrofit costs.

The principal results are reported in Figure 10, where the values of NPV were conveniently normalized to the intervention cost I_0 and shown as a function of the planning horizons; the payback period T_0 is identified on the abscissa axis when NPV is zero.

These results show the significant influence of the recovery strategies (BRSs) on the effectiveness of the seismic retrofit; in particular, in the case of a Pre-Code, when the BRSs are taken into account, T_0 increases from about 20 to 40 years in Mirandola, making the retrofit no longer worthwhile (considering a typical planning horizon of 20 to 30 years), whereas T_0 increases from about 5 to 10 years in Cosenza, greatly reducing the retrofit effectiveness. In addition, for Cosenza, the seismic retrofit remains cost-effectiveness also applying the BRSs for the case of a Pre-Code, and for a Medium-code it is more worthwhile than that in Mirandola for a Pre-code.

The same type of analysis was finally replicated for the case of companies that produce in a rented factory. The aim was to quantify the specific benefits, due to the retrofit interventions, for both the company and the building owner. The results, shown in Figure 11 (a, b, c) similarly to those of Figure 10, are now expressed in terms of "gross" present value (PV) instead of net present value (NPV), because the share of contribution to the retrofit cost between company and building owner is not known in advance. From these results, the ratio between the specific benefits of both parties, i.e. the PV ratio, can be calculated; this is shown in Figure 11 d) for the various codes and recovery strategies examined.

	Pre-Code	Low-Code	Medium-Code	High-Code
Mirandola	145 €/m^2	*-25%*	retrofit level	-
Cosenza	*+25%*	145 €/m^2	*-25%*	retrofit level

Table 4. Seismic retrofitting costs assumed for this study (for further information see [1]).

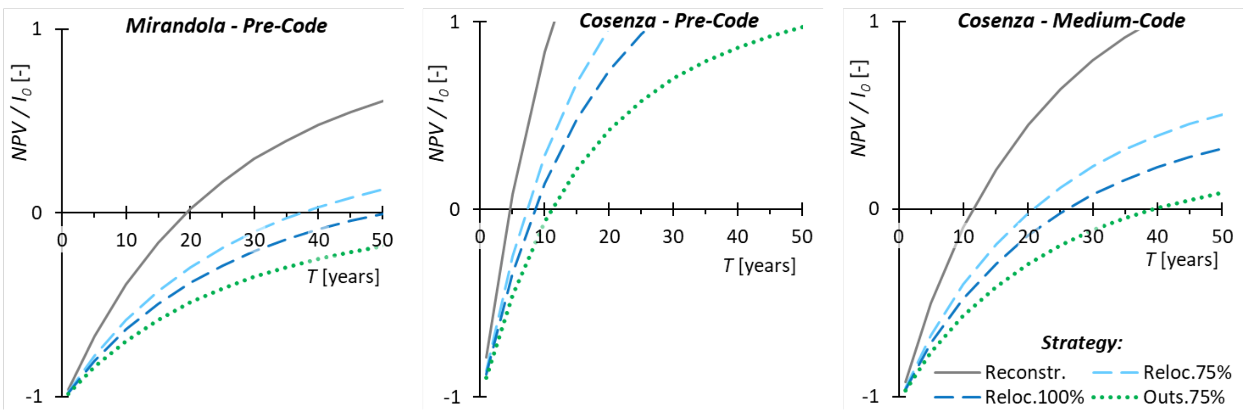


Figure 10. Ratio between net present value (*NPV*) and intervention cost (I_0), versus planning horizon (T), for some cases of seismic hazard (according to SHARE [24]) and vulnerability; discount rate $r_r = 2\%$.

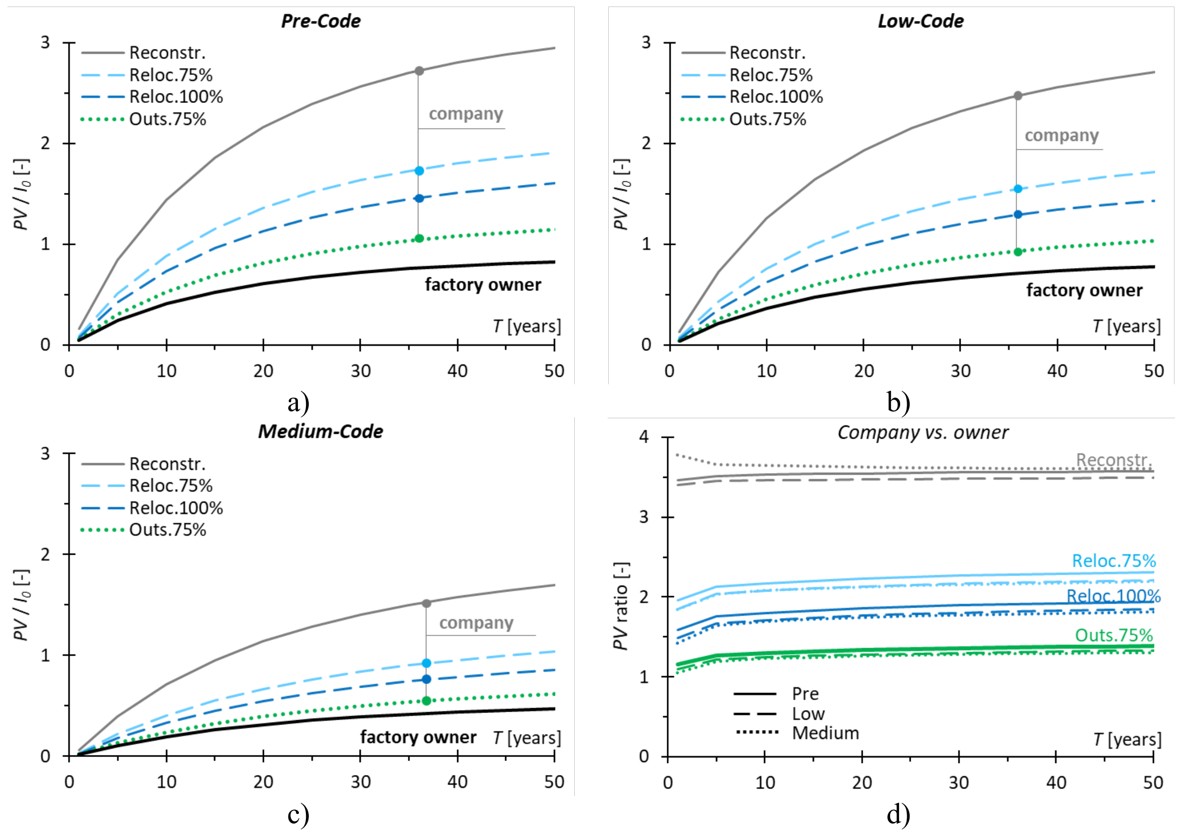


Figure 11. a-b-c) Ratio between gross present value (*PV*) and intervention cost (I_0), versus *T*, associated with the factory owner and the company which rents, and in the latter case for different recovery strategies; d) *PV* ratio between company and factory owner, versus *T*. Case of Cosenza (hazard according to SHARE [24]), r_r = 2%.

For interventions which are globally cost-effectiveness, this ratio could represent an objective parameter on which the breakdown of the retrofit costs can be based. Lastly, at least for this study, the PV ratio is only slightly influenced by the building vulnerability and the planning horizon (i.e., the seismic hazard), because the exposure is substantially the only factor that was changed in the risk assessment between company and factory owner (apart from the machinery vulnerability which is examined only for the company); for the same reason, instead, this ratio is greatly influenced by the recovery strategies.

5 CONCLUSIONS

- This paper presented a novel study aimed to evaluate the effects of the business recovery strategies (BRSs) on the seismic risk of businesses and, therefore, on the cost-effectiveness of the seismic retrofit, combining the main structural and economic aspects of small-to-medium enterprises (SMEs).
- This study referred to a biomedical packaging company damaged by the 2012 earthquake in Emilia Romagna (Italy), which suffered direct damages and indirect losses due to business interruption (BI), and resumed business soon after.
- Based on the exposure model specifically calibrated on this company (derived by [1]), a parametric seismic risk assessment was carried out analyzing and comparing various structural vulnerabilities, seismic hazards and business recovery strategies.
- The risk estimates so obtained were then elaborated in order to assess the cost-effectiveness of the seismic retrofit of existing RC factories in various situations; in

particular, the net present value (NPV) of the retrofit investment was evaluated for various planning horizons in order to estimate the payback period of the investment.

- For the case of companies that produce in a rented factory, a possible method for the breakdown of the retrofit costs between the company and the building owner is proposed, which is based on the specific benefit of both parties resulting from the retrofit intervention.
- Recovery strategies, not requiring any initial investment, are always worthwhile and thus generally applied; therefore, they should be considered for accurate estimates of risk, especially in cases of high vulnerability, as their influence is significant. This is very important also from an insurance perspective, in order to design rational (and competitive) insurance policies.
- Finally, in low-to-medium seismic areas such as Mirandola (IT), the seismic retrofit was appeared to be economically justified or not depending on whether recovery strategies are considered or not; instead, in highly seismic areas such as Cosenza (IT), the retrofit seemed generally cost-effectiveness, although the payback period of the investment was shown to be very dependent on recovery strategies.

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