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Seismic Vulnerability and Old Towns. A Cost-Based Programming Model

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Abstract: Vulnerability is a big issue for small inland urban centres, which are exposed to the risk of depopulation. In the climate of the centre-northern part of Italy, and in the context of the recent concentration of a high number of earthquakes in that area, seismic vulnerability can become the determinant cause of the final abandonment of a small town. In some Italian regions, as well as in Emilia Romagna, municipalities are implementing seismic vulnerability reduction policies based on the Emergency Limit Condition, which has become a basic point of reference for ordinary land planning. This study proposes an approach to seismic vulnerability reduction based on valuation planning for implementation within the general planning framework of the Faentina Union, a group of five small towns located in the southwestern part of the Province of Ravenna, Italy. This approach consists of three main stages: knowledge—the typological, constructive, and technological descriptions of the buildings, specifically concerning their degree of vulnerability; interpretation—analysis with the aim of outlining a range of hypotheses with respect to damage in case of a prospective earthquake; and planning—the identification of the courses of action intended to meaningfully reduce the vulnerability of buildings. This stage includes a cost modelling tool aimed at defining the trade-off between the extension and the intensity of the vulnerability reduction works, given the budget.

Keywords: urban fabrics; seismic vulnerability; critic analysis; cost modelling; urban preservation programming; building works programming

1. Introduction

The proposal contained within this contribution addresses the issue of reducing the seismic vulnerability of historic urban buildings with reference to the case of the city of Brisighella, Italy.

This research was conducted within the context of an agreement stipulated by the Union of Municipalities of the Romagna Faentina and the Department of Civil Engineering and Architecture of the University of Catania, Italy, the objective of which is a joint study on the seismic vulnerability of building aggregates in the historic centres of Brisighella, Casola Valsenio, Castel Bolognese, Riolo Terme, and Solarolo.

The research was multidisciplinary work that involved the disciplines of restoration, urban planning, and economic valuation assessment.

Economic-estimative evaluations deal with the issue of the seismic vulnerability of historical cities [1] in terms of a fundamental interest in the economic category of territorial capital and in its two forms: urban capital [2] and human capital. This scientific and methodological interest corresponds to the original civil commitment of economic-estimative evaluation with respect to distributive justice.

In the case of the redevelopment of minor historical centres, references to the notions of capital and distributive justice aim to answer one preliminary question: Is it worth it?

The answer to this dilemma involves questions concerning the way in which urban policies combine the need for capital in its urban form and the needs of capital in its economic essence.

With reference to these two needs, capital becomes an important interpretative filter in terms of the vulnerability of small urban centres [3]; the consistency of urban capital in terms of both volume and value is the main reason for the resilience of such centres. Marginal historic centres, especially those located in the mountain hinterland and characterised by poor accessibility, are condemned to the vulnerability trap. Seismic vulnerability, specifically, is not added to other vulnerabilities (social, economic, etc.), but rather constitutes a determining cause.

In the field of small urban centre vulnerability, the sciences of restoration and evaluation have common interests with respect to certain characteristics of architectural and urban heritage:

- The ability to endure, which is denoted as the resilience of the social-urban system; it is necessary to preserve its ability to continue to perform its essential functions or to survive during and after catastrophic events [4];
- Self-referentiality, or iconicity [5,6], which is ascribable to the material aspects (masonry and construction systems) that must be conserved in their own right, rather than on the basis of their functions or their appearance. Self-referentiality does not concern the present value of an artefact but, rather, the maintenance of its testimonial value, starting from its primary essence. Self-reference is a typical feature of the capital category under conditions of high tension in prices.

The resistance of a social-urban system to catastrophic events—that is, its resilience—depends on how much surplus social product have been set aside to maintain its security, that is, on the production or “renovation” fund designated for its structural consolidation.

A variety of different seismic vulnerability and risk analysis methods for unreinforced masonry structures indicate that having a high degree of vulnerability to earthquakes can also have remarkable socio-economic implications. Several studies have proposed an innovative holistic approach based on indicators related to physical exposure, social fragility, and the lack of resilience of urban areas; this could also involve geomatic tools (GIS), which would be able to describe the seismic risk results on the basis of scenarios of expected losses, but also on the basis of the probabilities of occurrence of predefined damage states [7,8].

Concerning the physical vulnerability of the built environment, many studies carried out on historic centres have presented relevant methodologies for assessing the vulnerability of the urban fabrics, both on an architectural scale and on an urban scale. In addition to the present study, some study cases have measured vulnerability by combining empirical and mechanical methodologies in order to structurally and typologically identify the buildings. In addition, an index-based method for masonry building aggregates has been applied [9]. The obtained vulnerability characteristics and the corresponding assessments provide relevant and consistent information in the form of typological capacity and fragility curves, which can be applied to urban areas presenting similar building classes [10].

This study exposes the methodology and the findings of the vulnerability assessment of the building heritage in the old town of Brisighella, referring both to the building aggregates and to the architectural units; starting from these results, it proposes an integrated model of analysis [11], evaluation and project initiation [12–16], aimed at outlining a variety of strategies for programming interventions to reduce vulnerability and, therefore, to optimize the urban policy choices.

2. Materials

2.1. Mitigation of Urban Vulnerability

The issue of urban vulnerability is studied in the specific context of the Emilia-Romagna Region with a wide range of approaches and tools that were only recently introduced to the regional planning aimed at reducing the urban seismic risk. The vulnerability is analysed according to two scales: that of the entire urban centre and that of the historic centre.

The aim is to ensure that, during a seismic event, an urban centre can persist, regarding both the efficiency of the main strategic activities for the recovery and the identity characteristics that distinguish it.

For the five municipalities of the "Unione Faentina", two studies were carried out: an evaluation of the seismic vulnerability of the historic centres agreement between the Union of Municipalities of Romagna Faentina and the University of Catania (approved with the official act N.132/2016 – scientific directors DICAR: Caterina F. Carocci, Salvatore Giuffrida; research team: Chiara Circo, Margherita Giuffrè, Luciano A. Scuderi, and Vittoria Ventura) and specific urban studies to define the Emergency Limit Condition (ELC), an urban scale analysis aimed at managing the behaviour of the settlement in the post-earthquake phase, carried out by the Technical Office of the Union of Municipalities [17].

The overlaying of the studies allowed an integrated project of intervention to be developed through which the economic evaluation illustrated in this paper was tested.

The study on the five historic centres of the "Unione Faentina" (Brisighella, Casola Valsenio, Castel Bolognese, Riolo Terme, Solarolo) was carried out in two phases.

In the first phase, homogeneous areas of the entire municipal territory with regard to the seismic vulnerability were identified, following a method established by the Department of Civil Protection and tested on Faenza and Solarolo in 2011 [18]. The second phase included the qualitative assessment of the seismic vulnerability of historical centres—identified as the most vulnerable areas of the urban fabric—following a procedure already tested on the historic centre of Faenza between 2011 and 2013. The aim was to define the criteria for the mitigation of the seismic vulnerability of the building aggregate with regard to the specific characteristics of each building fabric [19].

At the same time, the Technical Office carried out an analysis of the Emergency Limit Condition (ELC), introduced by the Italian Government Ordinance (OPCM n. 4007/2012), in accordance with Law n. 77/2009 art.11 "National plan for the prevention of seismic risk" for each of the five municipalities. The ELC is a municipal scale analysis set up based on the Civil Protection Plans and aimed at guaranteeing the functioning of the emergency management system in the post-earthquake phase. By definition, the ELC represents that limit condition for which, after the seismic event, the urban settlement loses all its functions (including residence) and preserves only the operation of most of the strategic functions for emergency management, their accessibility and connection with the territorial context. The ELC is, in fact, made up of strategic buildings, emergency areas, and the main links between the elements and the territorial context, as well as their interactions with the interfering elements [20].

The analysed emergency management systems, like the settlements they belong to, have a rather simple configuration. The connection infrastructures (roads) run across the urban centre, reaching strategic buildings inside the historic centre, or to its border. The small size of the centres, and the choice to place the strategic buildings in newly built areas outside the historic centres, imply a low presence of interfering structural aggregates.

2.2. The Historic Centre of Brisighella

The settlement of Brisighella rises from the slopes of the Tuscan-Romagna Apennines in the lower valley of the Lamone river. The first settlement, dating back to the end of the XIII century, consisted of a fortified nucleus, the current Rocca. In the 14th century, the fortification works were extended to the settlement of the "Borgo", creating an elevated arcaded path integrated into the houses for defensive purposes, (now Via degli Asini). During the 1400s, the nucleus expanded towards the valley, creating a new fortification wall beyond which, starting from 1500, the city developed.

The historical evolutionary process of an urban centre and the orographic peculiarities of its territory have greatly influenced the definition of the urban form, characterised by aggregates of townhouses built against the slope. The residential buildings have incorporated the ancient walls defining the unique configuration of the urban fabric.

3. Methods

3.1. The Analysis of the Seismic Vulnerability of the Historic Centre

The methodology used for the analysis of the vulnerability of the historic centres is based on the direct knowledge of the building aggregates and has been used often in contexts damaged by earthquakes [21] as well as under ordinary conditions [22]. The activities to be carried out are organized in three strictly connected phases: knowledge, interpretation, and project initiation.

The knowledge phase includes preliminary bibliographical research of the studies already carried out by the of Municipal Technical Office (MTO), which outlined the main evolutionary phases of the historic centre, and an on-site survey aimed at detecting all of the (constructional, typological, evolutionary) factors which may significantly affect, positively or negatively, the seismic behaviour of the urban fabric in its current configuration [23,24]. The elements that positively influence the seismic response (called resistance factors or strengths), such as the presence of anti-seismic devices, the good quality of the constructional technique, etc., and those that play negative roles (called vulnerability factors) are identified, with particular reference to the development of important damage mechanisms, such as the overturning of the façade. It should be noted that all of the information is collected within a direct survey of the urban fabric through observations from the outside of the building façades and the accessible courtyards.

Moreover, the survey highlights the specificities of the aggregates in terms of their use and construction technique, distinguishing from masonry residential buildings those constructed with reinforced concrete or another construction technique, and buildings with specialized functions, such as churches and historical palaces. The aim is to identify possible points of constructive discontinuity and the relationships of contiguity between buildings with different geometrical-structural characteristics.

This type of analysis conducted in the whole historic centre allows a map of the recurrent vulnerability and strength factors of the urban fabric to be obtained, constituting indispensable background knowledge for the definition of intervention criteria aimed at reducing vulnerabilities.

In the interpretative phase, the data collected on vulnerability and strength factors are critically selected with the aim of formulating a judgment on the mechanical quality of the urban fabric and therefore prefiguring the expected damage related to the precariousness observed.

In the project phase, the intervention criteria for the mitigation of vulnerabilities are established and, in the case of Brisighella, the economic evaluation of interventions with the aim of managing the public financial resources was carried out.

3.2. Vulnerability Reduction Assessment and Programming Model

The coherence between observations, assessments, and decisions in the planning of interventions for the reduction of vulnerability consists of the correspondence between (even quantitative) heterogeneous aspects and is therefore difficult to compare. On the one hand, there is public expenditure, which improves the resilience of the urban centre; on the other, there are benefits in terms of an increase in the value (private and public) of buildings and the urban fabric, as supposed by the program.

It is possible to distinguish between direct benefits, such as the seismic improvement of buildings and the increase in the overall resilience of the entire city and externalities [25–27], such as the increase in real estate market value, the perception of a greater sense of individual security, and so on.

From an economic point of view, the coherence between the value of investments and the value of security concerns two components of the calculation of seismic risk: hazard and exposure.

The measure of the hazard is affected by the randomness of the seismic event and by how this possibility is perceived by the public. This measure depends on two elements: the first, probabilistic, refers to the natural and geotechnical sphere (the probability of the seismic event); the second, instead, has a psycho-sociological and political nature. The political component of the dangerousness measure concerns the way in which the political-administrative system incorporates the geological evidence with the Urban Plan [28,29]. In this case, the Urban-Building Regulation of the Union of Municipalities of Romagna Faentina takes the ELC into account as a reference for ordinary planning.

The extent of the exposure varies according to the different "qualities of value" associated with the vulnerable buildings and their monetary measure, which allows planners and decision makers to compare the value of the security improvement with the value of the investment. This difficulty calls into question the effectiveness and completeness of the monetary measure, suggesting additional and alternative measures.

The economic-monetary measure of vulnerability can be carried out indirectly, starting from the critical observations and evaluations of the Restoration [30,31]. In such an inter-disciplinary context, and with reference to the urban centre as a whole, the works necessary to improve its resilience are selected, not only to guarantee the perfect integrity of the individual buildings, but also to prevent the urban centre from interrupting its basic functions. The convergence of two disciplines, restoration and urban planning, changes the objectives of both so that they become more specific and less ambitious.

The economic evaluation expands the possibilities of the plan: once the cost of the works has been calculated (see Section 4.3), it is possible to provide a coherent multiplicity of budget allocation hypotheses.

In this case, given some conflicting variables, such as the completeness of the interventions and the extension of the area involved, it is possible to define the trade-off relationship to maximize the cost-effectiveness function.

This greater integration between observations, evaluation, and decision-making [32], and the expansion of the contents taken into consideration, consolidates the consensus and the success of the project [33].

In this sense, as we will propose in a further study, the public consensus is on the awareness "of the value of the overall life safety of the building's occupants endangered, the direct economic losses due to the cost of the building restoration, in addition to the anticipated downtime and other indirect sources of loss associated with the recovery of the building to its full functionality" [34].

The evaluation model, as mentioned, consists of a database that carries out all of the calculations and logical operations necessary to transform the dataset into information based on which the assessments select the best project options. This integration of cognitive functions allows scenario analyses at the building and urban scale to be carried out.

The model coordinates the structural, material, geometric, technological, typological, and maintenance characteristics of the units of study [35], Relevant for (a) characterising their static attributes (seismic vulnerability); (b) hypothesising the design aspects by selecting the interventions corresponding to each degree of vulnerability; (c) calculating the costs based on the definition of typical bundles of works for each of the façade units facing the public areas [36]; (d) adjusting the intensity and extent of the interventions; (e) mapping the interventions corresponding to each combination of intensity and extension of the interventions [37,38]; and (f) calculating the total cost for each hypothesis by defining the trade-off functions [39] between the intensity and extension of the interventions.

The proposed model aims to integrate the way in which the ELC is formed and proposes its possible extension, according to the advantages resulting for the urban centre as a whole.

3.2.1. Calculation of Vulnerability

The calculation of vulnerability consists of a measure of the risk that the façades of the buildings interfering with the evacuation and rescue routes may overturn and collapse, obstructing them and/or affecting the safety of the fleeing people and rescuers. This measure is particularly important for buildings included in the ELC that must withstand the earthquake without collapsing to guarantee the functionality of the paths that connect the strategic nodes.

Vulnerability is calculated for each individual Façade Unit (FU) facing the public spaces. An FU is the vertical portion of masonry of an external façade located between two orthogonal structural walls, whose behaviour is assumed to be independent of the others.

For each of them, by applying the dynamic structural analysis model developed by C. Tocci [40], a "numerical indicator of the ground acceleration level capable of triggering elementary overturning kinematic mechanisms" was calculated. This indicator is defined, consistently with the conceptual layout of the Technical Standards for Constructions (NTC 2008), as "the triggering multiplier of the motion due to overturning (α_0) of the wall", taking into account: (i) the presence and extent of tapers, (ii) the direction of the floor main beams (parallel or perpendicular to the façade wall), (iii) the presence of tie-rods, (iv) the effectiveness of bonding between the façade and the (orthogonal) shear walls" [41]. The vulnerability index depends on the following significant geometric and typological parameters:

S_1: The thickness of the ground floor wall;
H: The total height of the wall;
L: The distance between the shear walls;
N: The total number of floors;
p: The number of floors without tie-rods (counted from the top);
k: The direction of the main floor beams: (k is 1 or 3 if parallel or perpendicular to the façade); and
r: The bonding of the façade with the shear walls (r is 0 in cases where no bonding occurs at all).

The overturning load multiplier is expressed by different equations that we define as the basic configuration and the varied configuration, the former being characterised by the simultaneous occurrence of two circumstances: (i) the absence of tie rods $(N = p)$ and (ii) floor beams parallel to the façade $(k = 1)$, and the latter being characterised by the lack of one or both of the above circumstances: $(N > p)$ and/or $(k = 3)$. For both configurations, the contribution of façade bonding introduces an additional term.

The equations are the following:

$$\alpha_0 \approx (1 + r)\cdot\frac{S_1}{H}.$$

For the basic configuration, $(N = p)$ and $(k = 1)$.

$$\alpha_0 \approx (1 + r)\cdot 0.3\cdot\left(\frac{S_1}{H}\right)^{(1-\frac{n}{100})}.$$

For the varied configuration, $(N > p)$ and/or $(k = 3)$, where r and n are defined as

$$r = 0.001\cdot(9 - L)\cdot\frac{(p + 1)^2}{k}$$

$$\begin{cases} n = 72 & if\ N = p \\ n = 83 - 21p + 13\cdot(p + 1)\cdot\frac{(k-1)}{2} & if\ N > p \end{cases}.$$

Taking into account that the r factor (which quantifies the influence of bonding) applies only for $L < 9$ m, any form of bonding between the façade and the shear walls beyond this is substantially ineffective, and it can be assumed that $r = 0$.

The above equations show that the overturning load multiplier α_0 for each external wall is strongly dependent on the ratio $\alpha = \frac{S_1}{H}$ between the ground floor thickness of the wall and its total height, parameters that are both easily obtainable just by the external survey of the street façades.

The acceleration coefficient is assumed to act as an index of vulnerability [42] of each UF, to which the works directly and indirectly connected are associated: the former are aimed at avoiding their overturn; the latter are joint works, such as those for securing elements soaring above the roofs, e.g., the chimneys and the external and internal finishing works. This distinction is important for decisions [43,44] regarding the level of completeness of the program of interventions, as discussed below.

In the rows, the database contains in the rows all the FU, u_i, and in the columns all the characteristics necessary to calculate the acceleration that the ground must give to the building so that the façade crumbles down. A low acceleration coefficient indicates a high vulnerability, and vice versa [45].

As highlighted by relevant studies, the methodology used to characterise the structural vulnerability is well advanced nowadays and overcomes the acceleration coefficient [46–48].

3.2.2. Cost Calculation

Once the acceleration coefficient has been calculated and therefore the degree of vulnerability of each UF has been determined, logical and research functions associate it with safety measures, starting from the most common, up to the most consistent or invasive ones, such as inserting chains, filling of superficial lesions, integration of masonry damaged by passing lesions, introduction of reinforced masonry, securing of jutting and towing elements, and external and internal finishing works related to both walls and ceilings, articulated in a total of 36 items on a price list.

The elementary costs associated with the interventions on each façade unit are then aggregated to calculate the total cost of each hypothesis related to the ELC.

Each hypothesis related to the ELC is defined by varying the intensity of the interventions and/or their extension. The intensity depends on the degree of completeness of the interventions with the same extension; the extension is the number of FUs involved with the same degree of safety. The result is two cost functions, one intensive, $C(j)$, the other extensive $C(k)$ [49].

The intensive cost function relates the total cost of each FU and the type of intervention, which depends on the bundle of works b_{jk} associated with a single u_i. Each bundle includes works corresponding to the entries of the Emilia Romagna Region Official Bill of Quantities for the public works, $b_{jk} \in B$, where B is the set of all works referable to the activities done to reduce the vulnerability of the buildings included in the ELC hypothesis.

The b_{jk} package can contain more or less works, according to their different relevance levels. In fact, we can distinguish between those that are strictly necessary, j_n; those of primary public interest, j_p; the less invasive ones, j_v; and those that are more or less adequate, j_a.

By combining the five degrees of completeness j with the five safety degrees k, 25 different hypothetical strategies with increasing costs have been defined [50].

The extensive cost function relates to the number of FUs included in the ELC according to their vulnerability level, measured by the acceleration coefficient defined above. The FUs are grouped according to five thresholds, $k_{60\%}$, $k_{70\%}$, $\ldots$, $k_{100\%}$, delimitating five corresponding sub-ranges of the acceleration coefficient associated with each FU: $k_{60\%}$ defines the sub-range of the façades whose acceleration coefficient is lower than the minimum one (α_{min}) which corresponds to the highest vulnerability degree and the minimum number of FUs included; vice versa, $k_{100\%}$ corresponds to the largest number of façades. The intermediate degrees are defined by progressively adding up to α_{min} a quarter of the range $\alpha_{max} - \alpha_{min}$. Then, $k_{70\%} = \alpha_{min} + (\alpha_{max} - \alpha_{min}) \cdot 0.25$; $k_{80\%} = \alpha_{min} + (\alpha_{max} - \alpha_{min}) \cdot 0.50$; $k_{90\%} = \alpha_{min} + (\alpha_{max} - \alpha_{min}) \cdot 0.75$.

It should be noted that the evaluation of the degree of safety of the interventions proposed here is part of an "ex-ante" programming model. Checks on the effectiveness of the planned operations will be carried out in the future (ex-post) during the implementation of the program according to Ministerial Decree 58/2017 [51].

4. Application and Results

4.1. Map of Vulnerabilities and Strengths, and the ELC of Brisighella

The elements identified in the context of the field survey are represented by icons in the "Map of vulnerabilities and strengths of the urban fabric". Depending on the method used to acquire knowledge (observations from the outside), the vulnerability discussed here is related to the possible overturning mechanisms of the walls facing the street.

From the analysis emerged a general good state of conservation for the historic centre of Brisighella, which does not present cases of buildings with different masonry structures, because it was not subject to post-war reconstruction.

The map of Brisighella shows the recurring vulnerabilities and strengths in all five centres, such as the presence of tall buildings, which are more vulnerable to the overturning mechanism due to the number of uncontained outer walls, and volumes jutting out from the external fronts, which are more frequent in the rear façades of the buildings. Furthermore, the map illustrates some specific vulnerability factors, such as the constructional irregularities of some parts of the urban fabric due to the integration in the ancient city walls. The contiguity between very different geometrical and structural configurations (in terms of storey height, wall thickness, etc.) can constitute a weakness from a seismic perspective, and this should be taken into consideration in the context of a possible intervention.

The strength factors that characterise the urban fabric of Brisighella concern the widespread use of historic anti-seismic devices (e.g., metallic tie-rods and buttresses) and a good construction technique—as concerns its visibility from the outside.

The ELC of Brisighella, unlike the other municipalities analysed, is included in the historical urban fabric, since the main connection infrastructures cross the historical centre in a rather extensive way. For this reason, a high number of interfering structural aggregates was noted, which are those that, following an earthquake, could collapse on the escape routes identified in the ELC.

4.2. Intervention Criteria for Vulnerability Reduction

The interpretation of information related to vulnerabilities and strengths allows the prefiguration of the seismic damage mechanisms that can affect the analysed urban fabric (Figure 1).

The recurring issues to be faced in seismic risk reduction are clarified and the essential features of a mitigation strategy that is respectful of the constructional and urban peculiarities of the historic centres are specified. The intervention criteria are not expressed by technical details but rather by the objectives to which the intervention must aim, which allows a design freedom with only one indispensable restriction: respect for the constructive logic of the masonry technique as a guarantee of effectiveness and compatibility of the intervention with the historical building.

With reference to the vulnerabilities observed in the historic centre of Brisighella, the improvement of the seismic response is pursued by means of interventions aimed at control of the thrusts in the roofs and reduction of the thrusts of vaulted elements as well as improvement of the connections between walls and floors with particular regard to the containment of the façade walls.

These indications are valid for the entire wall structure of the historic centre of Brisighella and allow a general framework of actions to be implemented in order to define the preventive mitigation of the seismic vulnerability [52].

It follows that the overlapping of the levels of knowledge in terms of vulnerability, strengths and intervention criteria with the previsions of the ELC of Brisighella can help to identify the strategic interventions to be promoted by the public authorities within the historic centre—favouring coordinated management of the financial resources—and to define reward mechanisms to promote the implementation of private interventions.

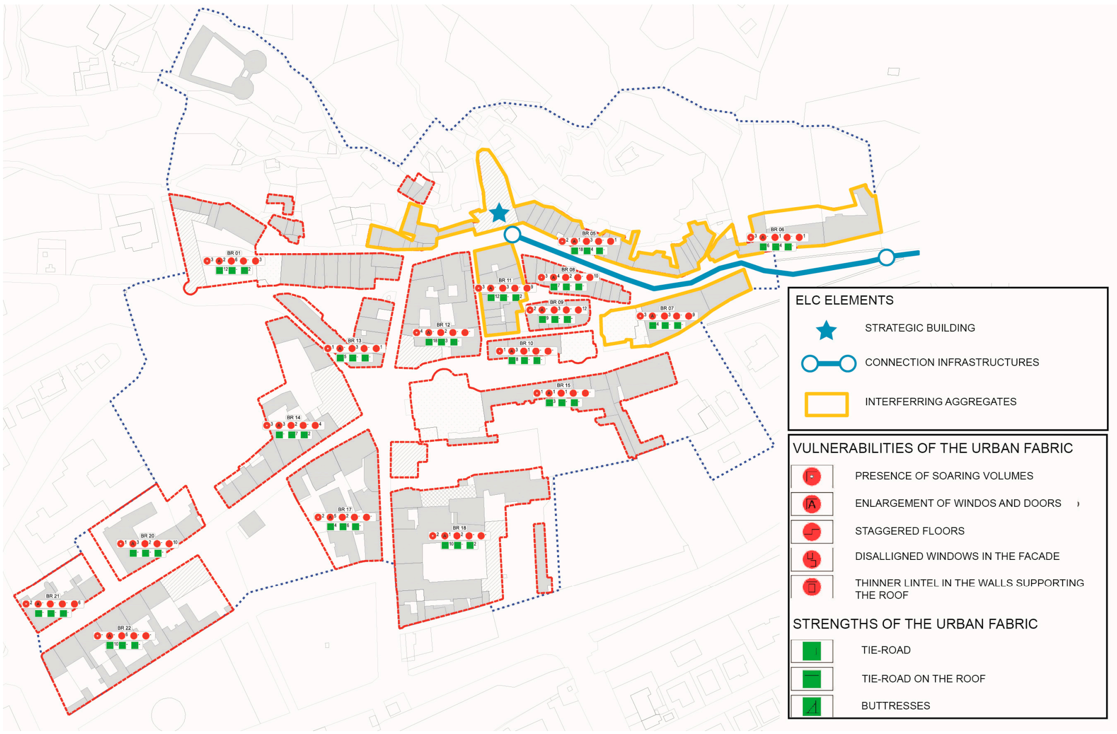


Figure 1. The Emergency Limit Condition of the historic Centre of Brisighella.

4.3. Valuation and Programming of the Interventions for Implementing the ELC

The information base used to calculate and select the interventions includes identification of the UF in the building complex to which it belongs (Block and Architectural Unit); land registry identification; type; façade units per aggregate; number of façades for each room; horizontal extension of the façade; wall thickness; room depth; surface of the room; number of floors above ground; gross surface area of the façade; heights of the different floors; average height of each floor; construction system; wall type; orientation of the structure of the floor with respect to the direction of the façade; soaring elements; braces, hypothesised to be required if the width of the front façade is greater than 6.50 m and the number of floors is greater than 1; the presence of chains; and the presence of injuries. In this study, the data were obtained from the documentation provided by the Union's Technical Office (Municipality of Brisighella) and by means of the quick inspections carried out on site.

The tendency to overturn of the façade was calculated according to (a) a pessimistic prudential scenario referred to as the basic configuration, quantified by the coefficient α_{0b}, and (b) an optimistic scenario referred to as the configuration changed and quantified by the coefficient α_{0v} (Table 1, Figure 2).

Depending on the degree of vulnerability of each of the 749 façade units analysed (only 685 need to be secured), the model identifies the interventions necessary for securing them. It should be noted that the interventions are not activated automatically and unambiguously, but based on the type of strategy that the decision maker chooses.

Table 2 lists the securing works according to the proposed vulnerability of the façade and to the Architectural Unit characteristics.

Table 1. Portion of the database displaying the calculation of the vulnerability indexes.

Calculation of the Acceleration Coefficient												
AU	FU	*S1*	*H*	*L*	*N*	*p*	*k*	*r*	*n*	Base (0) Varied (1)	Alpha0 b	Alpha0 v
1	1	0.4	6.3	8.1	2	2	1	0.0810	72	0	0.068	0.068
1	2	0.4	6.3	6.2	2	2	3	0.0828	72	1	0.068	0.150
1	3	0.4	3.2	6.3	1	1	1	0.1088	72	0	0.141	0.141
1	4	0.4	3.2	7.2	1	1	3	0.0244	72	1	0.130	0.172
1	5	0.5	3.2	6.2	1	1	3	0.0373	72	1	0.164	0.186
1	6	0.4	3.2	4.5	1	1	3	0.0595	72	1	0.134	0.178
1	7	0.4	6.3	4.9	2	2	3	0.1227	72	1	0.071	0.155
2	1	0.4	6.5	4.4	2	2	3	0.1377	72	1	0.070	0.156
2	2	0.4	6.5	3.0	2	2	3	0.1806	72	1	0.073	0.162
2	3	0.4	6.5	6.5	2	1	3	0.0339	88	1	0.064	0.222
2	4	0.4	6.2	5.7	2	2	3	0.1005	72	1	0.071	0.153
2	5	0.6	6.5	4.4	2	2	3	0.1371	72	1	0.106	0.175
2	6	0.5	9.1	8.2	2	2	3	0.0234	72	1	0.056	0.136
2	7	0.4	9.3	7.3	3	3	1	0.2672	72	0	0.055	0.055
2	8	0.4	10.1	5.6	3	3	3	0.1813	72	1	0.047	0.144
2	9	0.4	10.1	7.0	3	3	1	0.3200	72	0	0.052	0.052
2	10	0.4	9.2	6.3	3	3	3	0.1445	72	1	0.050	0.143
2	11	0.6	9.2	6.5	3	3	3	0.1333	72	1	0.074	0.159
2	12	0.6	9.2	5.2	3	3	3	0.2027	72	1	0.079	0.168
2	13	0.6	9.2	7.0	3	3	1	0.3232	72	0	0.087	0.087
2	14	0.6	12.8	7.0	4	4	1	0.5000	72	0	0.070	0.070
2	15	0.4	12.8	5.8	4	4	3	0.2683	72	1	0.040	0.144
2	16	0.6	12.9	7.8	4	4	1	0.2925	72	0	0.060	0.060
2	17	0.6	13.1	5.9	4	1	3	0.0420	88	1	0.048	0.216
2	18	0.4	13.1	8.9	4	1	1	0.0032	62	1	0.031	0.080
2	19	0.4	12.7	5.0	4	3	3	0.2160	72	1	0.038	0.139
2	20	0.4	12.8	7.8	4	3	1	0.1920	20	1	0.037	0.022
2	21	0.4	10.1	7.0	3	3	3	0.1077	72	1	0.044	0.135
2	22	0.6	8.9	6.2	3	3	3	0.1504	72	1	0.078	0.162
2	23	0.4	12.2	6.3	4	3	3	0.1445	72	1	0.038	0.132
2	24	0.4	13.9	6.5	4	3	1	0.4032	20	1	0.040	0.025
2	25	0.4	13.9	3.2	4	4	3	0.4850	72	1	0.043	0.165
2	26	0.4	13.9	3.9	4	4	3	0.4217	72	1	0.041	0.158

Figure 2. Map of the vulnerability of the Façade Units of the old town of Brisighella. The table classifies the Façade Units by vulnerability degree.

Table 2. List of the proposed vulnerability of reduction works based on the vulnerability degree and the Architectural Unit characteristics.

Emilia Romagna Region Official Bill of Quantities for the Public Works			
Item Cod.	**Short Description**	**Unit of Measure**	**Unit Price**
F01100a	scaffolding assembly	sq. m.	€9.06
F01100b	higher freight scaffolding	sq. m.	€1.33
F01100c	scaffolding disassembly	sq. m.	€3.09
B02018b	tie rods: masonry perforations	m.	€36.59
B02021	tie rods: plates niches	sq. m.	€484.04
B02022	tie rods: plates	kg	€6.26
B02024	tie rods: implementation	kg	€9.24
B02025	tie rods: stake	kg	€7.79
B02026	tie rods: re-stringing	cad	€133.53
B02028a	tie rods: injection pressure drilling	m.	€18.74
A09002b	tie rods: countertop	sq. m.	€25.13
A20001	tie rods: countertop: painting preparation	sq. m.	€1.82
A20012c	tie rods: countertop: painting	sq. m.	€8.67
A20001	tie rods: wall: painting preparation	sq. m.	€1.82
A20002	tie rods: wall: grouting	sq. m.	€1.24
A20012c	tie rods: wall: painting	sq. m.	€8.67
B02002b	shear walls: reinforcement of existing masonries	sq. m.	€170.15
A05004a	shear walls: new masonry building	c. m.	€323.49
A20001	shear walls: painting: wall preparation	sq. m.	€1.82
A20002	shear walls: wall grouting painting	sq. m.	€1.24
A20012c	shear walls: painting: wall preparation	sq. m.	€8.67
B02006a	deep crack masonry integration	c. m.	€576.10
A08005d	deep crack masonry integration: external plaster	sq. m.	€24.23
A20007	deep crack masonry integration: external painting: wall preparation	sq. m.	€10.69
A20015b	deep crack masonry integration: external painting	sq. m.	€14.20
A08004d	deep crack masonry integration: internal plaster	sq. m.	€23.64
A20001	deep crack masonry integration: internal painting; wall preparation	sq. m.	€1.82
A20002	deep crack masonry integration: internal painting; wall grouting	sq. m.	€1.24
A20012c	deep crack masonry integration: internal painting	sq. m.	€8.67
B02009	injections	c. m.	€150.09
A08005d	injections: external plasters	sq. m.	€24.23
A20007	injections: external painting; wall preparation	sq. m.	€10.69
A20015b	injections: external painting	sq. m.	€14.20
A20001	injections: internal painting: wall preparation	sq. m.	€1.82
A20002	injections: internal painting: grouting	sq. m.	€1.24
A20012c	injections: internal painting	sq. m.	€8.67
market survey	chimney securing	each	€600

Figure 3 summarises the model of selection of the works according to the strategy and indicates the costs of the 25 strategies according to the degree of completeness and security; the graphs below show the trade-off functions between the degree of security (the extension of the ELC) and the completeness of the interventions on each FU and the related AU, for each amount of the total cost.

The completeness of the interventions is described in Figure 3a:

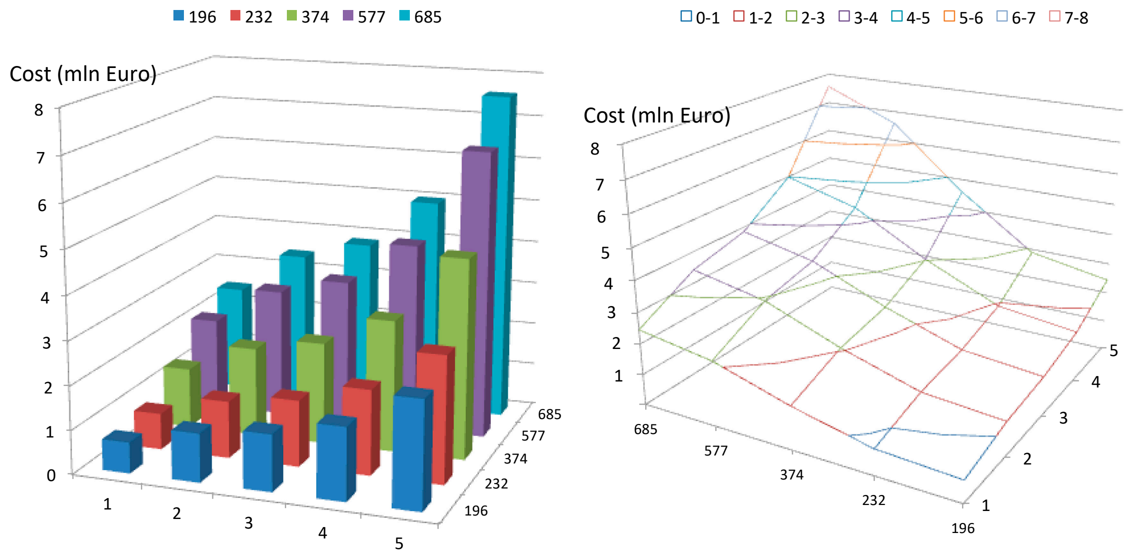
- Completeness degree 1 includes only the works that can be considered necessary, of public interest, of minimum security, and non-invasive;
- Completeness degree 2 includes the works that are necessary, of public interest, of minimum security, of maximum security for 70% out the total amount of the FUs, and non-invasive;
- Completeness degree 3 includes the works that are necessary, of public interest and of private interest for 50% out the total amount of the FUs, of minimum and maximum security, non-invasive and invasive;
- Completeness degree 4 includes the works that are necessary and unnecessary for 30% out the total amount of the FUs, of public and private interest, of minimum and maximum security, non-invasive and invasive;
- Completeness degree 5 includes all of the works.

Kind of works	Completeness degree 1	2	3	4	5
necessary	1	1	1	1	1
unnecessary				0.3	1
public	1	1	1	1	1
private			0.5	1	1
min security	1	1	1	1	1
max security		0.7	1	1	1
not invasive	1	1	1	1	1
invasive		1	1	1	1

(a)

Number of fixed Façade Units	Completeness degree 1	2	3	4	5
196	0.71	1.11	1.29	1.65	2.44
232	0.83	1.30	1.52	1.95	2.89
374	1.39	2.04	2.33	3.03	4.57
577	2.10	2.96	3.33	4.34	6.60
685	2.46	3.42	3.84	4.99	7.57

(b)



(c) (d)

Figure 3. (**a**) Combination of security and completeness; (**b**) table of total cost for each strategy given by the combination of the two above mentioned performances; (**c**) graph of the total costs of each of the 25 strategies displayed in table (**b**); (**d**) 3D isocost functions displaying the trade-off between completeness and the number of façades involved for each level of cost.

A further function of the model is mapping the 25 different strategies of vulnerability reduction providing information on the FU for which the intervention is necessary (given by the position of the bubbles in the map) and a graphic representation of the cost (given by the dimension of the bubbles), as sampled in Figure 4 displaying four of the 25 strategies. In this figure, the position of the strategy on the isocost graph is shown. The sequence represents four strategies with increasing costs due to the simultaneous improvement in completeness and security.

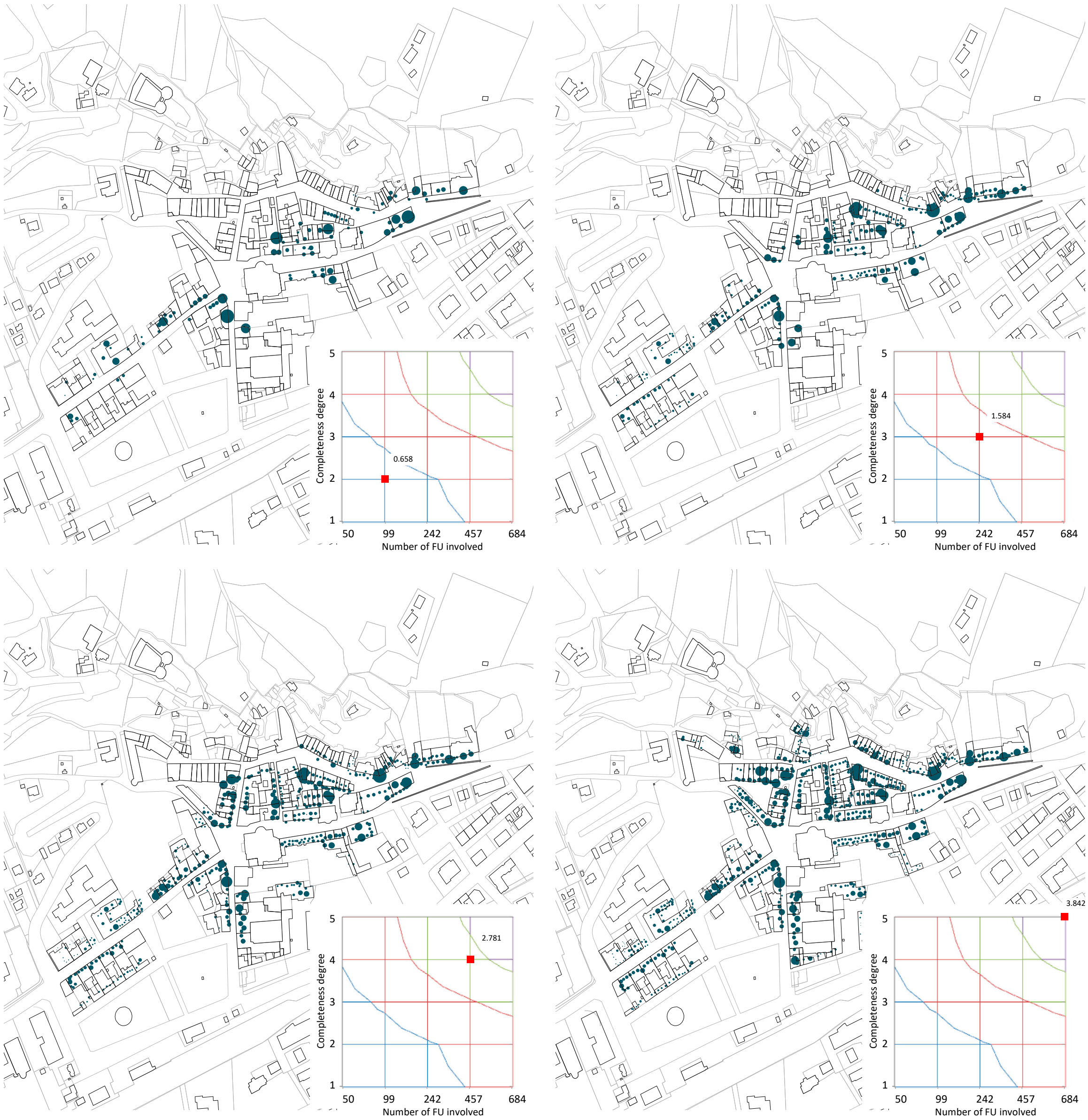


Figure 4. Mapping of the different layouts of the strategies having an increasing total cost.

In Figure 5, instead, the strategies displayed are those having approximately the same cost so that they differ regarding the completeness and security degree.

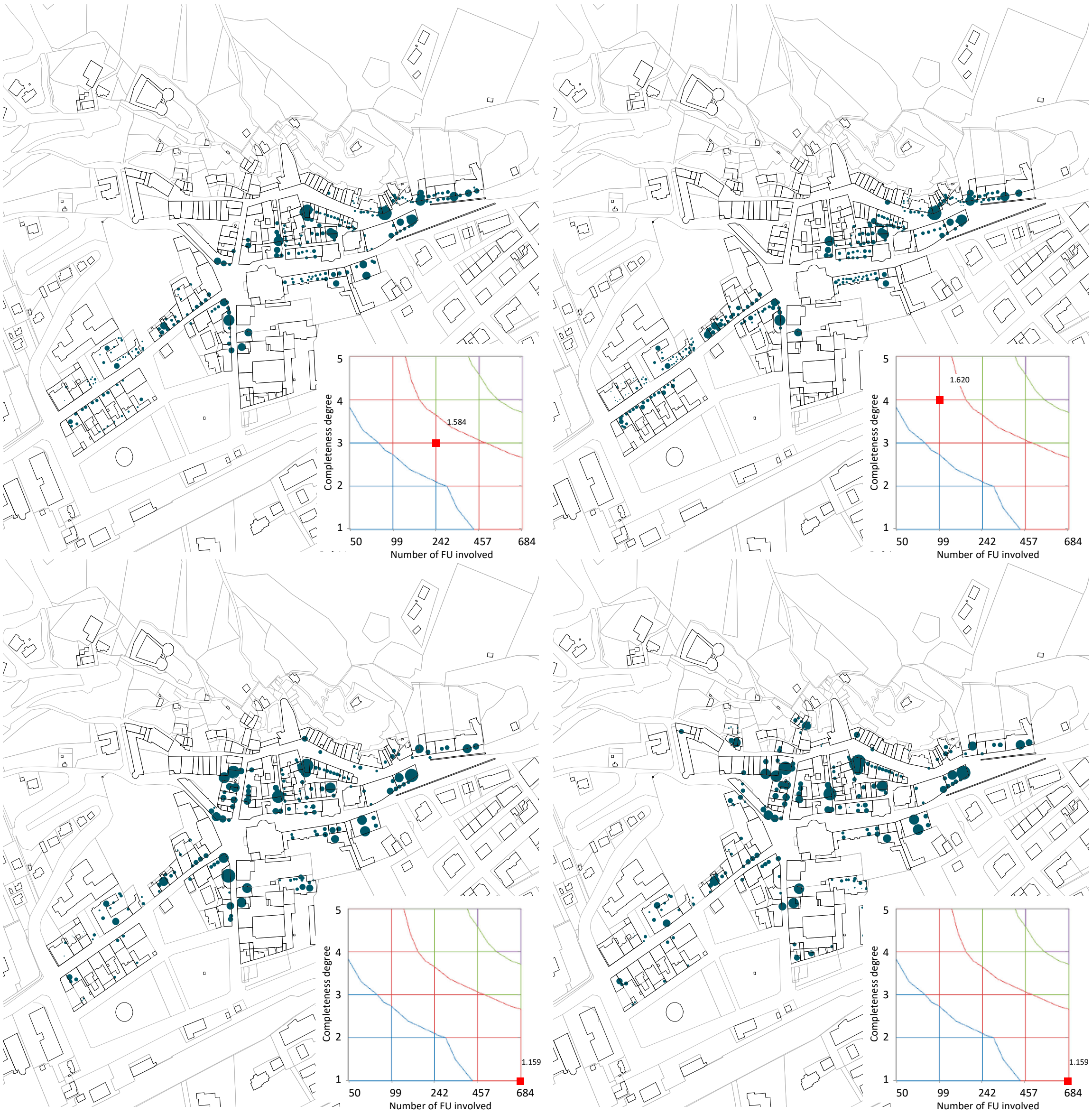


Figure 5. Mapping of the different layouts of the strategies with (approximately) the same total cost.

5. Discussion and Conclusions

The proposed model outlined a wide range of possible options concerning how to combine the overall degree of security corresponding to the number of buildings secured (from 196 to 685 FU out of 749) and the budget to cover the total costs (from 0.71 to €7.57 million). The different possible mixes of values contained between these extremes correspond to precise "statements" on the degree of resilience of the urban organism, on the access to safety, which depends on the social subjects to whom the advantage of safety will be granted, and to the extent and value of the resilience of the urban organism acknowledged by the administration.

The central scenario envisages that 374 FUs can be secured by means of average completeness level interventions, having a total cost of €2.33 million.

The table and the diagram, taken along the main diagonal, measure how the cost increases as the resilience and completeness of the interventions increase. If, on the other hand, the table and the diagram are traversed along the isocost function, the trade-off relationships between the completeness of the interventions and the degree of resilience for the same budget (that means for each different isocost function) and for each amount are shown.

The combination, integration, and consequentiality of factual, axiological and decisional aspects shows how this study considers ELC as an opportunity to go beyond its original purpose and its immediate significance. The ELC is an informative and normative device intended to provide a minimal ability to adapt the urban fabric so that it does not lose its identity. The case of Abruzzo, in which most of the cities comprised in the seismic crater have been evacuated for a long time, is an example of the different ways in which responsibility can be distributed among the spheres of proactive and reactive policies [53,54].

The two variables—the costs and degree of completeness of the interventions—in fact, allow the political-decisional profile of the ELC regarding the allocation of advantages and responsibilities between private and public actors to be identified.

The urban centre in its entirety achieves the requirement of resilience only when the ELC is fully realized—therefore, from the moment when all the buildings included in it are secured. For this reason, it is necessary to coordinate the interests and motivations of all owners of the assets involved.

Furthermore, there is no doubt about the unequal distribution of the positive externalities associated with the ELC. In particular, the sudden succession of significant catastrophic events in central Italy has made the seismic risk a piece of evidence with significant symbolic implications, since it involves the overall landscape dimensions of a settled community [55,56].

The presence of these externalities allows the local administration to start negotiations on the works to be subsided, and, as a consequence, on the dimensions of the incentives [57] according to the general trend of the urban policies focused on the trade-off between efficiency and fairness [58].

Therefore, the natural completion of this study will concern the measurement of the exposure, that is, the evaluation of the vulnerable assets, in terms of the joint value of the human and urban capital. This evaluation allows the costs of the seismic retrofit to be compared with the advantages of safety and to provide further evidence to formalize the equalization model.

The planning of the seismic retrofit at the urban scale, in fact, requires a well-structured public–private partnership, capable of capturing all benefits coming from both the avoided reconstruction costs [59,60], and any real estate externalities [61–66], to be taken into account in order to redistribute the added value generated in terms of resilience of the settled community as a result of the seismic retrofit program coordinated by the public.

This aspect is relevant, especially in historical urban contexts characterised by settlement complexity, structural fragility, typological and formal inertia, and a low population density. These characteristics can influence the answer to the original question: "Is it worth it?"

In this study, we tried to understand how the involvement and coordination of measures, judgments, and decision profiles allows the typical object-based approach implied by the ELC to be overcome. This, in fact, is attributable to a "prescriptive grammar" (it says what needs to be done), while the proposed approach is attributable to the logic of "generative grammar" (it says what can be done).

The proposed pattern, instead, implements an "axiological approach" that integrates natural, environmental, and technological aspects, with cultural, landscape, and political decision issues. Such an approach expands the way in which the original question can be answered.

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