Energy and Buildings 110 (2016) 149–158

Contents lists available at ScienceDirect

Energy and Buildings

journal homepage: www.elsevier.com/locate/enbuild

Does seismic risk affect the environmental impact of existing buildings?

Andrea Belleri*, Alessandra Marini

Department of Engineering and Applied Sciences, University of Bergamo, Italy

ARTICLE INFO

Article history:
Received 8 June 2015
Received in revised form 9 October 2015
Accepted 23 October 2015
Available online 27 October 2015

Keywords:
Embodied carbon
Operational carbon
Sustainable refurbishment
Lateral load resisting systems
Seismic risk

ABSTRACT

The building sector significantly impacts on the environment during every stage of the building life cycle. The necessary transition toward a carbon-neutral society is driving a growing attention toward the refurbishment of old buildings, fostering intervention measures with the twofold objective of reducing operational energy consumption, typically upgrading the thermal insulation, and ensuring the quality of the consumed energy by adopting renewable and sustainable energy in the supply chain, such as thermal and photovoltaic solar energy.

In seismic prone areas the vulnerability of existing buildings, not designed according to modern building codes, could hamper the efficiency of the solely energy refurbishment, besides representing a safety hazard. The present paper investigates a framework to quantify the influence of seismic events on the environmental impact assessment of buildings.

The investigated framework is applied to a selected building, considering the building as alternatively located in regions with different seismicity. As an example, the building environmental impact is evaluated, in terms of carbon footprint, in the case of two different scenarios: upon completion of an energy refurbishment only, and after a coupled intervention targeting energy refurbishment and seismic retrofit. The results show that, in case of energy refurbishment only, the building located in a high-seismicity region presents an expected additional annual embodied equivalent carbon dioxide due to seismic risk, which almost equals the annual operational carbon dioxide after thermal refurbishment.

1. Introduction

It is nowadays widely acknowledged that the building sector significantly impacts on the environment during every stage of the building life cycle. Particularly, in the European Union (EU), the building sector [1] consumes up to 40% of the total EU energy and produces 36% of the total EU greenhouse gas emission. In addition, the reduction of operational energy consumption of existing buildings represents a priority of current over-national policies in Europe [2], particularly in establishing long term strategies for the national building stock refurbishment and high level of energy efficiency standards of the refurbished buildings [3,4]. Considering the waste production, it is observed that the EU construction and demolition waste is about 33% of the total amount of waste [1], indicating that demolition and re-construction, especially if extensively practiced, is not a sustainable strategy to enhance the performance of existing buildings.

In Europe, the existence of a wide portion of the existing building stock requiring restoration, in order to improve energy performance and building comfort, represents a challenge for environmental sustainability. A vast majority of the buildings requiring refurbishment were mainly built after the Second World War to rapidly meet the pressing housing demand during reconstruction. These buildings are typically multi-story houses with reinforced concrete (RC) frame structure, characterized by poor architectural features, built in the absence of urban planning and with high operational energy consumption, mainly due to the poorly insulated envelopes and obsolete plant equipment and finishing.

The sustainable renovation of such buildings is typically addressed focusing on the reduction of the operational energy consumption and on the use of low-carbon materials in the refurbishment process, without accounting for the structural deficiencies, which could leave the building seriously unsafe and hamper the refurbishment investment, particularly in seismic prone areas; in fact the majority of these structures were built before the enforcement of modern seismic codes and before updated seismic classification of the European territory, and they are typically vulnerable with respect to seismic actions. Recent

---

* Corresponding author. Tel.: +39 035 2052 007.
E-mail address: andrea.belleri@unibg.it (A. Belleri).

http://dx.doi.org/10.1016/j.enbuild.2015.10.048
0378-7788/© 2015 Elsevier B.V. All rights reserved.

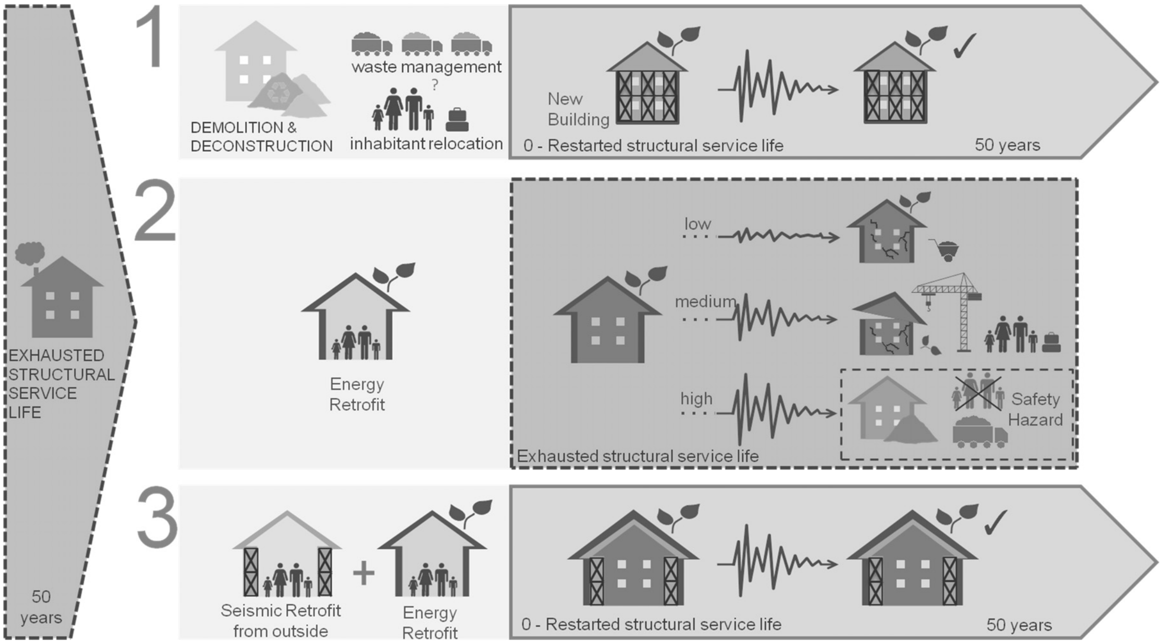

Fig. 1. Conceptual map of possible retrofit scenarios: (1) demolition and reconstruction; (2) sole energy upgrade and (3) coupled energy and structural renovation.

earthquakes in the Italian territory have emphasized this aspect, evidencing damage on many buildings, from residential constructions to monumental buildings [5] and industrial facilities [6], some of which previously undertook energy efficiency upgrades taking advantage of national subsidies. This situation highlights how, in the renovation process of existing buildings, in order to foster the transition toward an actually low-carbon society, the design-leading concept of eco-sustainability should be integrated by taking into account the assessment and mitigation of possible building structural vulnerabilities, especially in seismic prone territories.

Fig. 1 shows a conceptual map depicting three possible scenarios of an existing building requiring energy renovation measures. In addition, the building is considered vulnerable to seismic loads and having exhausted its structural service life; according to current building codes, the structural service life is typically 50 years for ordinary buildings.

The first scenario considers demolition and re-construction, given the extremely poor performance of the considered RC building stock. Upon completion of the intervention, the new building performance meets all up-to-date requirements on both energy consumption and structural safety; the new building end of life scenario includes selective dismantling and possible reuse or recycling of the construction materials. Noteworthy, however, if extensively practiced, demolition and re-construction may be not sustainable; indeed, the impact of such approach on the environment would be unbearably high, both in terms of raw material consumption and hazardous-waste production. Furthermore, this approach would require relocation of the inhabitants.

The second scenario depicts common interventions targeting the sole energy refurbishment. This solution does not provide extension of the structural service life, and structural safety is not guaranteed in the case of an earthquake. Depending on the intensity of the seismic event either small or extensive repair measures, inhabitants' relocation and building's collapse could be experienced. It is worth noting that such a renovation practice does not include structural safety and preservation of human life among its priority targets. Ultimately, in the worst case scenario, no virtuous recycling and reuse can be foreseen in post-earthquake emergency management, but rather all debris of collapsed constructions may be disposed in landfills, increasing the environmental impact of the end-of-life phase.

The third scenario considers a more innovative approach, which couples energy-structural renovation. In particular, the structural renovation regards the introduction of new lateral force resisting systems embedded in the building new, or improved envelope. This solution does not require inhabitants' relocation and meets safety requirements in the case of seismic loads. Noteworthy, the structural intervention allows lengthening the building structural service life, which would be left unchanged by any intervention aimed at upgrading the sole architectural and energetic performances; this integrated solution reduces the equivalent annual impact of the embodied energy given that the environmental load can be spread over a much longer time span.

The significance of accounting for seismic risk in the environmental assessment is also expressed in Fig. 2, where the energy consumption, operational cost, and carbon emission, among other variables, are expressed as a function of the building life (the time elapsed since its construction); the seismic impact is represented as an expected loss, expressed as annual energy consumption, being the seismic event uncertain in nature. Fig. 2(a) considers a building energy retrofit intervention (R_E) targeting the nearly zero energy building performance. This intervention does not affect the building seismic behavior, therefore if a seismic event (X) occurs during the building life, there is an additional cost associated to the building post earthquake repair, which represents the actualization of the expected seismic loss. Interestingly the graph shows that, depending on the relevance of the annual energy consumption associated to the seismic risk, the nearly zero energy performance could be only theoretically attained, whereas actual consumption could be higher. Noteworthy, typical procedures adopted to evaluate the environmental impact of buildings [7–10] neglect this contribution, which could have even a greater impact when considering the problem at the district level. Fig. 2(b) considers both building energy and seismic retrofit intervention ($R_{E,S}$). After the seismic retrofit the expected seismic loss is significantly reduced, therefore if a seismic event (X) occurs after the structural retrofit intervention, the additional cost due to the building repair is much lower than in the previous case. It is worth noting that,