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Could building replacements significantly contribute to seismic vulnerability mitigation at urban scale? Case studies of two typical swiss cities

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This paper contains an investigation on the potential decrease of seismic vulnerability related to building replacements for the cities of Sion and Martigny in Switzerland. Those two cities were identified for the present research based on the accuracy of the corresponding available information. Seismic assessment at urban scale was recently achieved for both cities and new buildings are systematically indexed according to the construction regulation of the canton of Valais (Valais). Sion and Martigny belong to the largest cities of the canton of Valais and this region is characterized by the highest seismicity within Switzerland. The investigation focuses on a 4-year period between 2016 and 2019. Cases for which an existing building is demolished and replaced by a new one were identified and checked. Those cases do not represent general practice. The majority of new buildings are built on free land. Consequently, the building replacement rate is too low to lead to a significant decrease of the seismic vulnerability at urban scale. In addition to the systematic appropriate seismic design of new buildings, retrofitting of existing buildings therefore remains the adequate strategy for seismic vulnerability mitigation. In case of replacement, low-rise buildings are generally replaced by mid-rise buildings. Moreover, unreinforced masonry buildings are usually replaced by reinforced concrete shear-wall buildings. This slightly impacts the building stock distributions but the seismic vulnerability is not significantly changed, since the demolished buildings are not the most vulnerable ones. Nevertheless, few obvious isolated vulnerability decreases occurred with respect to the demolition of soft-story buildings for instance. By contrast, seismic vulnerability may also be increased in the case where a new building is built against an existing one with a different story level and without an adequate seismic separation joint.

KEYWORDS

building replacement, seismic-vulnerability assessment, existing structures, seismic risk mitigation, urban seismic risk, seismic retrofitting

Introduction

Adequate seismic-design methodologies will protect human life and minimize damage to new buildings. From a general point of view, the replacement of potentially vulnerable existing buildings by new buildings may be considered as a contribution to seismic vulnerability mitigation. Retrofitting of the vulnerable existing building stock requires enormous resources, especially in terms of financial means (Acito et al., 2020). It is thus questionable whether retrofitting may be substituted by building replacements to decrease seismic vulnerability at urban scale. Ideally, retrofitting could be superseded by building replacements if the related rate is large enough. Most of the building stock should be replaced within a time frame of approximately 100 years with a building replacement rate of approximately 1%. Compared to 500 years, the corresponding reference return period of seismic hazard in building codes, such a time delay may be considered as reasonable, at least in moderate seismicity regions. However, it is the current urban-development policies that govern the building replacement rate and consequently the related seismic vulnerability decrease. Real decrease only occurs when a vulnerable existing building is demolished and replaced by a new one adequately designed for seismic action. Due to different reasons (e.g. economical, administrative or demographical) new buildings are however often constructed on free land and do not replace any existing buildings. In such cases, the global seismic vulnerability is only slightly improved since the potential vulnerable existing buildings remain among the building stock.

In regions characterized by a moderate seismicity, such as in Switzerland, a vast majority of existing buildings have been built without appropriate earthquake resistant features. The first adequate seismic requirements in the Swiss building code were only proposed in 1989. The large majority of the Swiss building stock has been built without any seismic considerations. Therefore, retrofitting strategies should be applied to the existing building stock to mitigate the seismic risk. However, as resources are limited a different approach should be used for existing buildings than from new constructions. Since 2004, the Swiss standards propose an approach based on risk (Vogel and Kölz, 2005). According to the SIA 269/8 (2017) building code (SIA 269/8, 2017), the minimal security level is defined in relation to the acceptable individual risk. Seismic retrofitting is mandatory in the case of a compliance factor under a minimal threshold value (minimal security level). For a compliance factor larger than this threshold, an evaluation based on proportionality principles is performed. It allows deciding whether the retrofitting measures are adequate or should be discarded. Such an approach ensures that the limited resources are appropriately allocated with the best impact on seismic vulnerability mitigation. However, considering the replacement of existing buildings by new ones, an alternative and minimalist approach could be proposed: leaving out existing buildings and focusing the efforts on new buildings only. Such an approach may

be reasonable only if the actual building replacement rate is large enough.

The issues addressed in this paper are related to the general framework of a more comprehensive research project dealing with the seismic vulnerability of the cities of Sion and Martigny in Switzerland. The seismic vulnerability at urban scale was already assessed for those cities which are the two main cities of the canton of Wallis (Valais). The Risk-UE methodology (e.g. Milutinovic and Trendafiloski, 2003; Risk-UE, 2003; Mouroux and Le Brun, 2006) was applied to both cities, considering the particularities of the Swiss territory in terms of seismicity and the specific features of the Swiss building stock (Lestuzzi et al., 2016; Lestuzzi et al., 2017). The reliability of the results was afterwards further improved by considering typological curves and accurate displacement demand prediction (Rota et al., 2008; Diana et al., 2018; Diana et al., 2021). The investigations were performed using building stock databases from 2015 surveys. The update of the databases for the subsequent 2016–2019 period provided the opportunity to study the building replacements and the related potential seismic vulnerability change. This paper focuses on common residential buildings for which accurate information is available within the considered period.

Features of the investigated cities

The city of Sion is the main city of the canton of Wallis with a population of about 35'000 inhabitants for a total of 3'600 buildings. Martigny is the second largest city with a population of about 20'000 inhabitants for a total of 2'500 buildings. The cities are approximately 30 km distant from each other.

Regarding seismic action, the earthquake hazard in Switzerland may be qualified as moderate compared to southern Europe. The largest peak ground acceleration specified in the building code is 1.6 m/s^2 for reference 475-years return period. The most seismically exposed region is located in the South-West part of the country, mainly corresponding to the canton of Wallis. The cities of Sion and Martigny are both in this highest seismic zone of Switzerland, zone Z3b (Figure 1).

Swiss construction and housing development

The construction and housing data for the country is collected and assessed by the Swiss Federal Statistical Office (FSO). According to FSO, Switzerland numbers around 1.8 million of residential buildings (Table 1). Specifically, 1.765 million was reported for 2020 (OFS, 2021). Over half this number are individual buildings. The construction of new residential buildings reaches annually about 12'000 buildings. The average annual value for the 4-year period from 2016 to 2019 reached 12'080 (OFS, 2021). According to those values, the annual rate for the construction of new residential

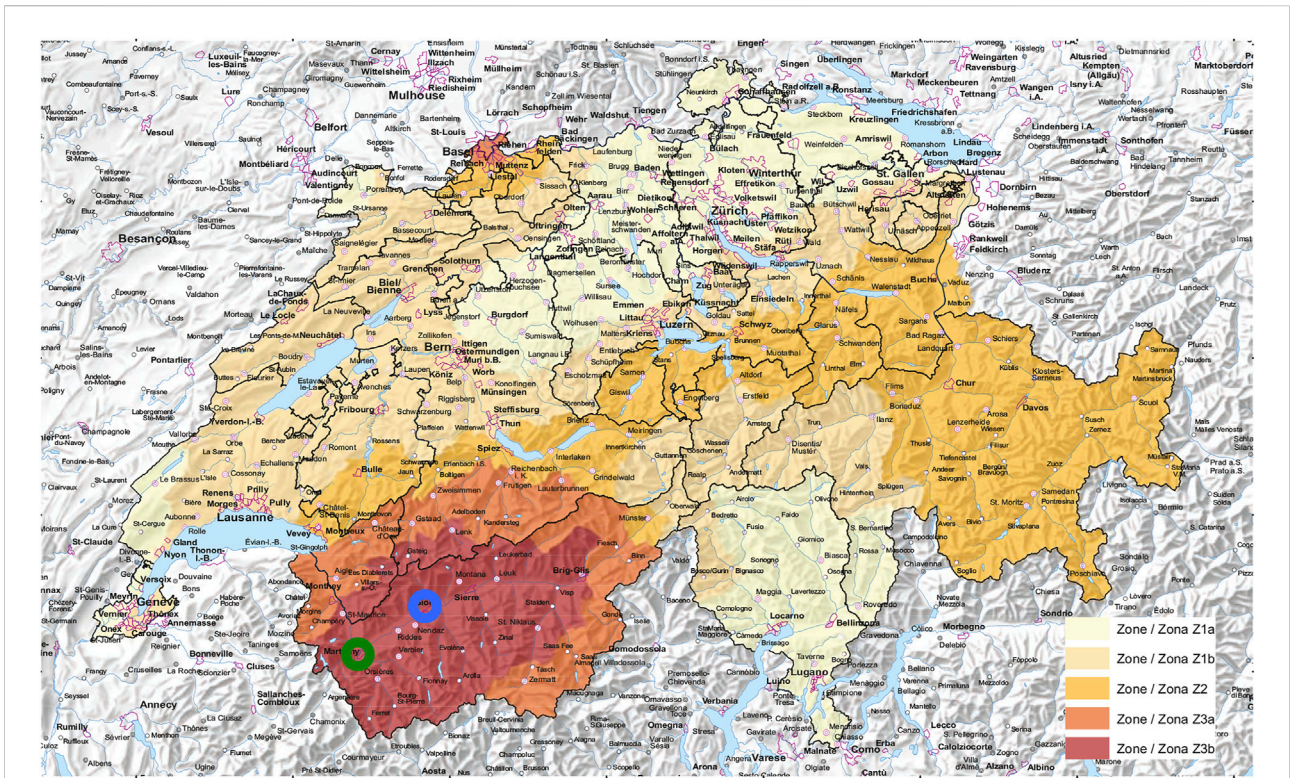


FIGURE 1 The five seismic zones in the Swiss building code (SIA, 2020) and the location of the investigated cities, Sion (blue circle) and Martigny (green circle).

TABLE 1 Overall figures of buildings and dwellings in Switzerland (OFS, 2021). For new construction the values correspond to the average figures for the 4-year period from 2016 to 2019.

Topic	Total (2020)	New construction/year	Demolished/year
residential buildings	1.77E+06	12,080	4000
dwellings	4.64E+06	50,870	

buildings is about 0.7%. Moreover, about 4'000 buildings are demolished each year. If each demolished building is replaced by a new one, the building replacement rate is about 0.23% per year only. Therefore, the current urban development in Switzerland leads to a global building replacement rate clearly under 1% per year.

The figures indicated above are directly related to the general population development in Switzerland. The population in Switzerland is steadily growing since 1950. According to FSO, the Swiss population reached about 8.67 million inhabitants in 2020 (OFS, 2020). The population has nearly doubled since 1950 and this growing corresponds to an average annual rate of about 1% per year. This rate is larger than the one related to the construction of

new residential buildings which is about 0.7% (see section above). However, this value should be compared with the annual rate for construction of new dwellings. According to FSO, Switzerland numbers around 4.64 million dwellings (OFS, 2021). The construction of new dwellings reaches annually about 50'870 dwellings (average annual value for the 4-year period from 2016 to 2019, OFS, 2021). Consequently, the annual rate for construction of new dwellings reaches 1.1% and compares well with the annual population growth rate. Those figures also indicate that the current general trend of urban development in Switzerland is mainly focused on the construction of mid-rise buildings containing several dwellings, which also corresponds to current concerns regarding sustainable development.

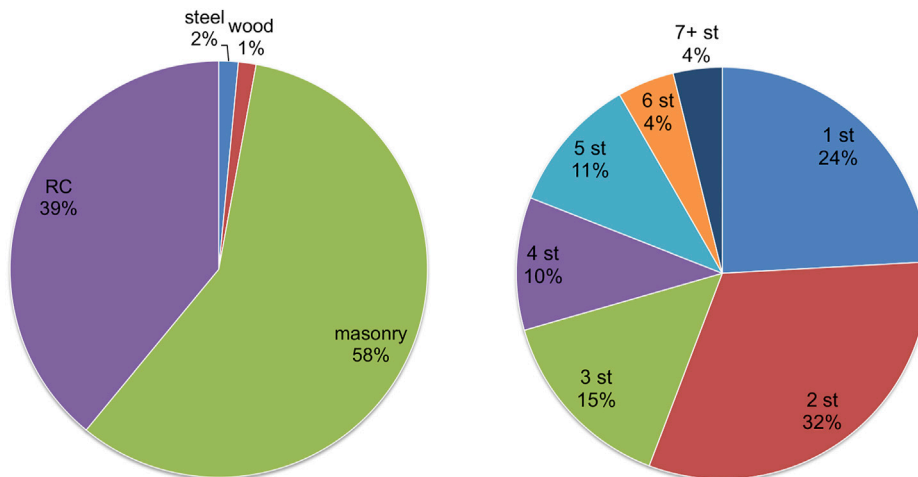


FIGURE 2

Overall distribution of building material (left) and building height (right) for Sion (Lestuzzi et al., 2016)

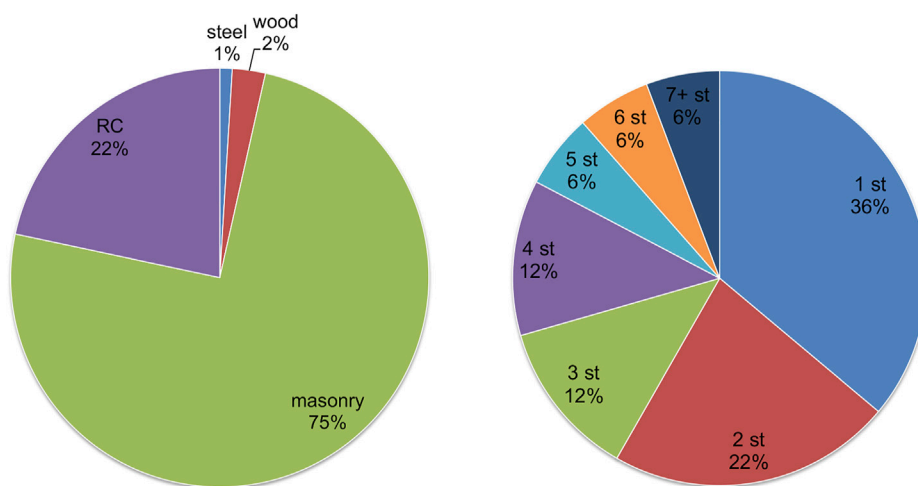


FIGURE 3

Overall distribution of building material (left) and building height (right) for Martigny (Lestuzzi et al., 2016)

The Swiss building stock is mostly composed of low-rise and mid-rise buildings. Masonry and reinforced concrete are the predominant construction materials (Badoux, 2001). Reinforced or confined masonry do not belong to the construction practice and therefore, in Switzerland, masonry buildings are solely unreinforced. The masonry buildings are subdivided into stone-masonry buildings with flexible floors and brick-masonry buildings with rigid floors. Reinforced concrete buildings are essentially shear-wall buildings with low reinforcement ratios (Greifenhagen and Lestuzzi, 2005). A specific feature in Switzerland is the wide spread construction of thick reinforced concrete basements required for atomic shelters.

Building surveys of Sion and Martigny

Within the framework of a comprehensive research project dealing with the seismic vulnerability assessment at urban scale, the building stock of the cities of Sion and Martigny was surveyed to determine their main structural features (Lestuzzi et al., 2016). The main parameters of the building stock (i.e. construction date, number of stories, load-bearing structure, rigid or flexible floors, in-plan and elevation regularities, roof shape) collected during the survey were stored in databases. The field surveys of Sion and Martigny were completed in 2015.

Building stocks

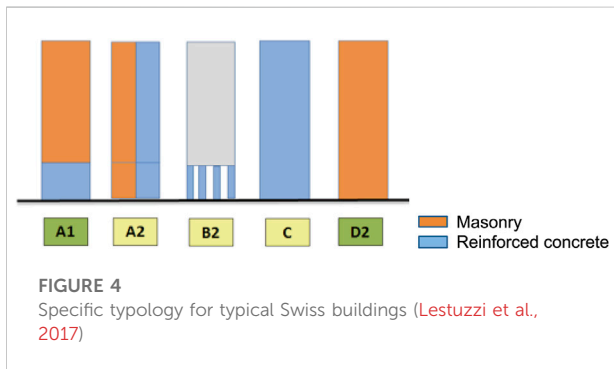
The surveys of Sion and Martigny focused on common residential and administrative buildings. The survey of the city of Sion concerns around 3'200 buildings and the survey of the city of Martigny concerns about 1'600 buildings. Figure 2 shows the distribution for the city of Sion and Figure 3 shows the distribution for the city of Martigny (Lestuzzi et al., 2016).

Distributions of building types are similar for both cities and correspond well to the usual distribution of typical Swiss cities. Unreinforced-masonry (URM) buildings represent more than half of the building stock. The building stock of Martigny constitutes an upper bound, with URM buildings reaching three quarters of the whole stock. The remaining building stock is composed of reinforced-concrete (RC) buildings, essentially RC shear-wall buildings. The distributions of the number of stories are similar for both cities and correspond to the typical Swiss building stock. Low-rise buildings, up to three stories high, represent 70% of the building stock. Taller buildings, seven stories and over, are uncommon and correspond to less than 6% of the building stock.

Building typology

A specific typology valid for typical Swiss buildings with stiff floors was developed within the framework of the research project dealing with the seismic vulnerability assessment of the cities of Sion and Martigny. The specific typology is based on a detailed survey involving the construction drawings collected in the city archives for a limited number of buildings. Five new building types were defined (Diana et al., 2021): A1, A2, B2, C and D2 (Figure 4). Type A1 corresponds to unreinforced masonry (URM) buildings with a reinforced concrete (RC) basement floor. Type A2 is for buildings with mixed URM-RC along the height. Type B2 is related to buildings with RC pillars in the base floor. Type C is for buildings with RC shear walls and type D2 is for buildings with URM shear walls.

An important part of the building stock of both cities, around 25%, could be characterized by the specific Swiss typology (i.e. 845 buildings for Sion and 391 buildings for Martigny). The related distributions are plotted in Figure 5. The distribution is different for both cities. For Sion types C and A2 are dominant instead type D2 is largely predominant for Martigny (Diana et al., 2021).



New buildings construction for the 2016–2019 period

In Switzerland, construction regulation is specified at the cantonal level. Therefore, building regulation is different from one canton to the other. Since 2004, in the canton of Wallis, the building construction permit is delivered only if an adequate seismic design can be established. The related systematic verification is requested for every building from three stories and over. For low-rise buildings up to two stories, adequate seismic design is mandatory

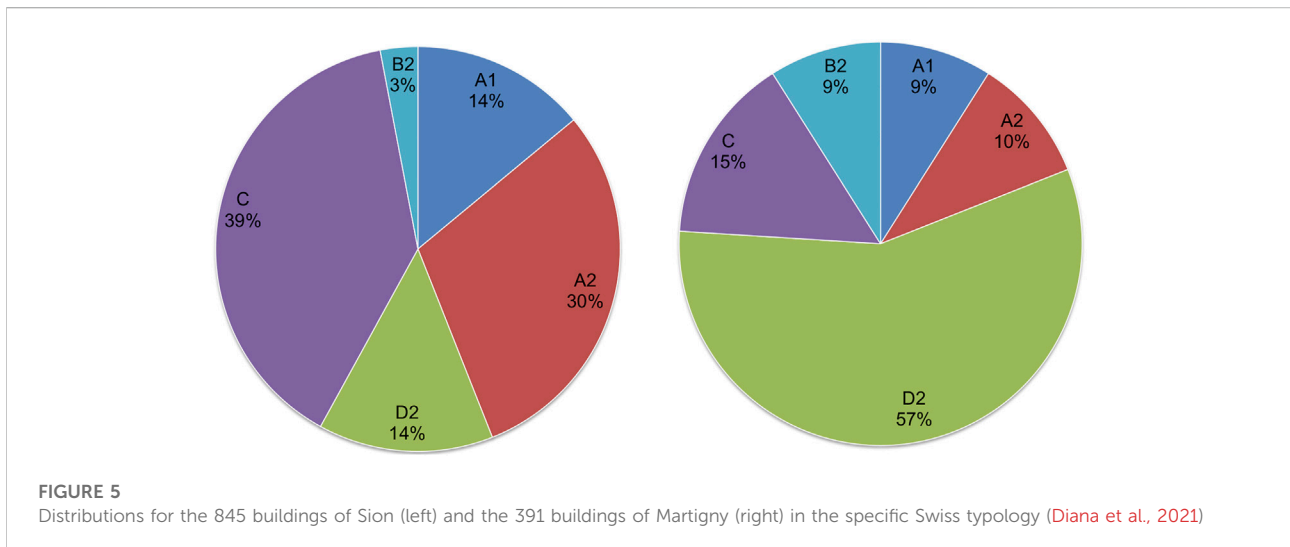


TABLE 2 Building constructions and actual building replacements in Sion.

Sion (3200 buildings)	Total (2016–2019)	Annual rate (%)
New building constructions	116	0.91
Building replacements	16	0.13



FIGURE 6

Sion, low-rise URM building demolished and replaced by a mid-rise RC building.

but without specific checking. This distinction is based on the general consideration that mid-rise and relatively high-rise buildings are more seismically vulnerable than low-rise buildings.

The information concerning new building construction for the 2016–2019 period is available in the cantonal archives of Wallis where the requests for building construction permits are stored. Additionally, the information was checked through a rapid visual survey, to confirm actual construction of the building. In some cases, the project was abandoned after the building construction permit request due, for instance, to an objection procedure. Such an issue may especially arise in case of building replacement.

Building replacements in Sion

The main figures of the recorded building constructions for the city of Sion are summarized in Table 2. During the 2016–2019 period, 116 new building constructions were identified. Considering the total amount of buildings (3'200), the average of 29 new buildings per year corresponds to an annual construction rate of 0.91%. Among the 116 new buildings, only 16 correspond to actual building replacements. The related average number of four building-replacements per year corresponds to an annual replacement rate of about 0.13%.

Selected examples of building replacements in Sion are shown in Figure 6 to Figure 9. Pictures of the demolished buildings could often be extracted from Google Street View.

The recorded items contain different replacement configurations. In most cases an isolated building is replaced by a new isolated building (Figures 6, 7). In one case the new building is inserted into the empty space between the two adjacent buildings resulting in a row of three buildings (Figure 8). In a few cases several neighbouring buildings are replaced by a single larger building (Figure 9).

Building replacements in Martigny

The main figures of the recorded building constructions for the city of Martigny are summarized in Table 3. During the 2016–2019 period, 73 new building constructions were identified for the city of Martigny. Considering the total amount of buildings (1'600), the related average of about 18 new buildings per year corresponds to an annual rate of 1.14%. Among the 73 new buildings, 20 cases correspond to actual building replacements. The related average number of five building replacements per year corresponds to an annual rate of about 0.31%.

Selected examples of building replacements in Martigny are shown in Figures 10–13. Like in Sion, in most cases an isolated building is replaced by a new isolated building (Figures 10, 11). A case in which two URM buildings were demolished and replaced by a complex of two large high-rise RC buildings is shown in (Figure 12). However, compared to Sion there are several cases of duplicate identical mid-rise and high-rise building constructions in Martigny (Figure 13).



FIGURE 7
Sion, low-rise URM building demolished and replaced by a mid-rise RC building.



FIGURE 8
Sion, low-rise URM building demolished and replaced by a mid-rise RC building inserted between two adjacent buildings.



FIGURE 9
Sion, three URM and RC buildings demolished and replaced by a single large mid-rise RC building with a "U" plan shape.

Assessment and findings

The recorded building constructions for the cities of Sion and Martigny during the 2016–2019 period show that the annual rate of new building constructions reached approximately 1% (see [Tables 2 and 3](#)). This value is slightly larger than the global one

for Switzerland (0.7%, see section 1.2) and should be related to the current dynamic urban development of both cities. However, the actual building replacement annual rate is much lower and ranges from 0.13% for Sion to 0.31% for Martigny ([Tables 2 and 3](#)). The corresponding average value almost matches the global rate for Switzerland (0.23%, see section 1.2). Furthermore,

TABLE 3 Building constructions and actual building replacements in Martigny.

Martigny (1600 buildings)	Total (2016–2019)	Annual rate (%)
New building constructions	73	1.14
Building replacements	20	0.31



FIGURE 10

Martigny, low-rise URM building demolished and replaced by a mid-rise RC building.



FIGURE 11

Martigny, low-rise URM building (in the background) demolished and replaced by a mid-rise RC building.

ongoing studies on other Swiss cities (Visp (Burjánek, et al., 2012), Lausanne, Yverdon-les-Bains) show very similar trends. The building replacement rate shows large variation, due to specific urban development conditions. However, it remains largely under 1% per year.

The actual building replacements in Sion and Martigny mainly concern the demolition of low-rise URM buildings and their substitution by mid-rise RC buildings. This impacts slightly the building stock distributions of the cities. The proportion of RC buildings increased by 3% for Sion and by 4% for Martigny (Figure 14 to be compared with the left plots of

Figures 2, 3). Obviously, the proportion of URM buildings decreased by the same values. Note that all the demolitions are only related to economic issues and not to potential seismic lack.

However, from the seismic vulnerability point of view, the demolished buildings do not belong to the most vulnerable ones (Rosti et al., 2018). Consequently, even if the new buildings are all adequately designed for seismic action, the seismic vulnerability at urban scale is not significantly affected. The distribution of the overall updated building stock of both cities into the predicted damage grades (DG) is listed in Table 4. The lowest damage



FIGURE 12
Martigny, two URM buildings demolished and replaced by a complex of two large high-rise RC buildings connected at their base by shared parking areas.



FIGURE 13
Martigny, two low-rise URM buildings demolished and replaced by a group of three identical mid-rise RC buildings (only two of them are visible on the right picture).

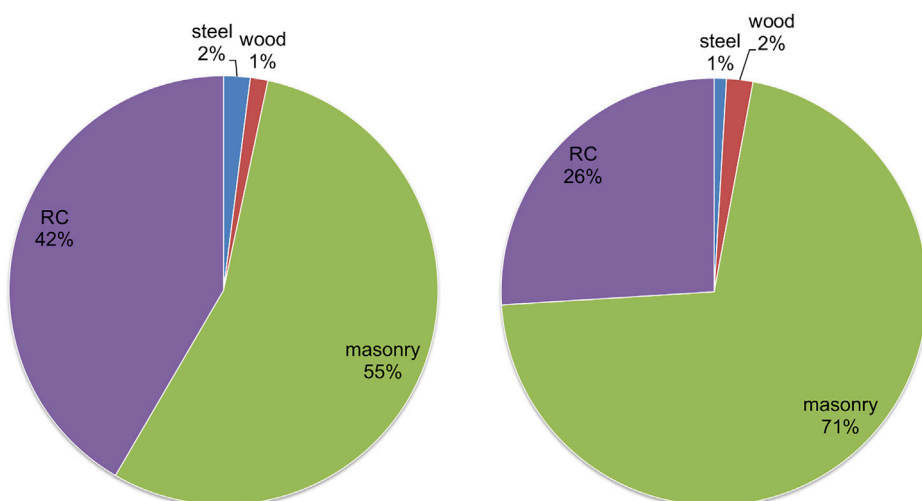


FIGURE 14
Overall updated distributions of building material for Sion (left) and Martigny (right).

TABLE 4 Distributions of the overall building stocks into the damage grades (DG) for both cities. The update of the databases has a marginal impact (bolded values).

DG	Most reliable (2015)		Update (2016–2019)	
	Sion (%)	Martigny (%)	Sion (%)	Martigny (%)
DG1	49	40	50	41
DG2	27	28	26	28
DG3	17	22	17	21
DG4+DG5	7	10	7	10



FIGURE 15

Seismic vulnerability may locally be impacted: decreased when a typical soft-story building is demolished (A) or increased when a seismic separation joint is lacking between adjacent buildings with different story levels (B).

grades are assigned to the new buildings (50% into DG1 and 50% into DG2) because the cantonal construction regulation in Wallis ensures that new buildings fully satisfy the seismic prescriptions according to the latest Swiss standard. The demolished buildings are obviously removed from the data base. However, those buildings correspond to low-rise URM masonry buildings and are therefore essentially related to DG2. Compared to the most reliable results obtained with the original databases (Diana et al., 2021), the update only has a marginal impact on the related percentages. The variations are highlighted in bold in Table 4. The differences do not exceed 1% and are mainly due to the increasing number of buildings and to rounding effects. Compared to the other uncertainties associated to the investigations at the urban scale, such limited variations are not significant and may be neglected.

In a few cases, local obvious vulnerability decreases were recorded. This may occur when buildings affected by typical seismic resistance deficiencies are demolished. Figure 15A shows one case in Sion in which a typical soft-story building was demolished and replaced by a RC building with adequate seismic design. By contrast, seismic vulnerability may also be

occasionally increased. This is principally the case in which a new building is built against an existing one with a different story level and without an adequate seismic separation joint. Figure 15B shows one of those cases in Sion.

Conclusion

The building stock of the cities of Sion and Martigny in Switzerland has been updated since the initial 2015 survey. This survey was performed to assess the seismic vulnerability at the urban scale. The update of the databases for the subsequent 2016–2019 period provided the opportunity to study the building replacements and the related potential seismic vulnerability change. The cases for which an existing building is demolished and replaced by a new one were identified and checked. Those cases do not represent the general practice. The building replacement annual rate ranges from 0.13% for Sion to 0.31% for Martigny and remains largely under 1%. The majority of the new buildings are constructed on free land and do not replace any existing buildings. The potential vulnerable

existing buildings remain in the building stock. Moreover, in case of replacement, low-rise unreinforced masonry buildings are generally replaced by mid-rise reinforced concrete shear walls buildings. This issue slightly impacts the building stock distributions, but the seismic vulnerability is not significantly changed since the demolished buildings do not belong to the most vulnerable ones. It should also be pointed out that all the demolitions were only related to economic issues and not to potential seismic lack.

Nevertheless, local obvious vulnerability decreases were recorded. In a few cases, typical soft-story buildings were demolished and replaced by RC buildings with adequate seismic design. By contrast, seismic vulnerability has also been occasionally increased. This occurs when a new building is built against an existing one with a different story number and without an adequate seismic separation joint.

Consequently, at least for the current Swiss construction framework, the current building replacement rate is too low to lead to a significant decrease of the seismic vulnerability at urban scale. Even for moderate seismic hazard conditions such as in Switzerland, retrofitting of existing buildings remains the adequate strategy for seismic vulnerability mitigation in addition to the systematic appropriate seismic design of new buildings.

Data availability statement

The raw data supporting the conclusions of this article may be obtained by request to the authors.

Author contributions

PL wrote the paper, checked the actual building replacements in Sion and Martigny and performed the related statistical

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analysis. PL achieved the assessment of the seismic vulnerability at the urban scale according to the updated databases.

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Conflict of interest

The author declares that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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