Seismic Risk Assessment for Masonry Buildings based on Discriminant Analysis of a Virtual Database

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SUMMARY:
Reliable damage and loss assessment due to an earthquake is a problem of paramount importance for the NatCat (Natural Catastrophes) insurance and reinsurance market. The improvement of exposure data quality requires a parallel advancement in the modelling methodology capable of taking advantage of the detailed information and, consequently, providing an adequate risk assessment. Sophisticated numerical tools, which are widely used to design buildings under complex load situation and to assess the structural behaviour in great detail (like FEM), have evolved to a level where they may be used with confidence in seismic risk assessment analyses. This paper presents a generic tool for creating detailed 3D Finite Element models of a large number of realistic masonry buildings, as part of a typical building stock. The tool generates any kind of edifice automatically and can be used to estimate the expected amount of losses in a certain area of a country after an earthquake

Keywords: Insurance risk assessment, virtual damage database, simulated building stock, SBP-Tool

1. INTRODUCTION

The insurance and reinsurance market offers an important solution for the society to promptly recover after natural catastrophes. The earthquakes that in the last two years stroke Chile (Maule, Mw 8.8, February 6, 2010), New Zealand (Darfield, Mw 7.0, September 3, 2010 and Lyttelton, Mw 6.1, February 21, 2011) and Japan (Honshu, Mw 9.0, March 11, 2011) proved, once more, the strategic importance of this kind of industry and renewed the crucial question of how to develop a resilient concept for society.

Any further advancement in that respect is strictly related to the capabilities of creating reliable models to predict the natural risk. This process implies a better understanding of the hazard, of the vulnerability and of the exposure that are involved.

Even if important on-going projects, like the Global Earthquake Model (GEM), are aiming at sharing and improving our knowledge, the “state-of-the-art” of the empirical data-set regarding earthquake’s economic losses available present a severe no uniformity. The worldwide information available is extremely different from both the quality and the geographical points of view.

Since earthquakes are rare events, the situation will not likely change significantly in the foreseeable future, therefore it is necessary to further investigate the development of innovative concepts based on consolidated numerical techniques.

2. OVERVIEW

2.1. Overview of seismic vulnerability assessment

A good overview of the development of seismic vulnerability assessment methodologies over the past 30 years is given in Calvi (2006). On one hand, there are the empirical methods, like *Damage Probability Matrices (DPMs)* Whitman (1973), the *Vulnerability Index Method* Benedetti (1984), the *Continuous Vulnerability Curves* Spence (1992) and the *screening Methods* JBDPA (1990). On the other hand, Calvi describes also six different analytical methods, like the *Analytically-Derived Vulnerability Curves and DPMs* Singhal (1996), *Hybrid Methods* Kappos (1995), *Collapse Mechanism-Based Methods* Bernardini (1990) to cite some of them.

2.2. Overview of loss estimation

The large majority of earthquake loss estimation studies are concerned with regional loss estimation in which the main objective is to obtain estimates of economic loss over a large number of structures. One of the earliest studies in loss estimation was performed by Freeman (1932) who provided rough estimates of probable average earthquake loss ratios for various types of buildings in order to develop a rational basis for estimating earthquake losses for the insurance industry. Until the earlies 1970s most regional earthquake loss estimation studies were confined within the insurance industry. Steinbrugge (1982) summarised some of the early earthquake loss estimation studies conducted by insurance companies in order to establish earthquake insurance premiums. As part of his study, a methodology was proposed that used different types of constructions as an input and estimated damage to the property in terms of percentage of the replacement cost. He used reference graphs that linked the ground motion intensity on the losses from collapse and the non-collapse cases to the total loss.

In the analytical fragility assessment of Park (2008), a two-storey unreinforced masonry (URM) building was created to represent a typical essential facility, i.e. a firehouse, in the central and southern US region. In the interest of achieving a simpler model for dynamic analysis, Park reduced the complex 3D model into several models that are based only on a two dimensional behavior. It was also assumed that the earthquake excitation was parallel to a wall. For the modeling of “*In-Plane Walls*” Park utilized a very simple composite nonlinear spring model, while for “*Out-of-Plane Walls*” a single nonlinear spring with bi-linear hysteresis behavior was used.

Park’s study works with the idea to simplify a 3D model into a 2D spring model and, therefore, this approach is not useful for estimating realistically the damage area of a structure.

Nowadays it is possible to take advantage of the numerical simulations of the buildings subjected to earthquake loads using the classical finite element method, which has evolved rapidly in the last few decades.

The new study of Guidotti (2012) outlines how to obtain a description of the spatial variability of the strong-ground motion through large-scale 3D simulations of wave propagation. In this framework Guidotti used the case study of the Mw 7.1 earthquake scenario of Darfield (Canterbury), on 22 February 2011, where 180 people died and around 2,000 were injured in Christchurch, the largest city in the South Island of New Zealand with about 400.000 inhabitants.

The main goal of his study was the 3D seismic wave propagation in the soil. Therefore the soil with the dimension 1 km x 1 km and 50 m deep was modelled with absolute detail: more than 1.000.000 finite elements. Afterwards, Guidotti integrated the numerical model with the approximately 150 buildings that compose the Caterbury Central Business District (CBD). These buildings were modelled in a simple way; a real building was described as a “rigid body” (Fig. 2.1.). However simplifying a multiple-degree of freedom (MDOF) model of a building into a single degree of freedom

(SDOF) model is not sufficiently accurate to get an idea of the real response of a building. Also the damage area at a building due to an earthquake cannot be estimated with these kinds of simple models.

This is the point where the expert knowledge of seismologists and earthquake engineers should come together and where a highly motivated interdisciplinary team should be created in order to produce reliable 3D models of the soil system in combination with reliable 3D models for the vulnerability.

Obviously, Guidotti has shown that it is possible to describe a very complex soil system through large-scale 3D simulations. This part was modelled in high detail but to get a better understanding of the vulnerability of buildings, like the damage area, the building should be modelled realistically and not only as a “rigid body”. In this case, the goal it is to substitute the “rigid body” models by detailed 3D-FE models. Mühlhausen (2011a) has shown how to estimate the damage area for these types of numerical FE-models.

As a conclusion, it could be said that the reliability information about the expected peak ground velocity and realistic simulated portfolios with real 3D building models should be the basis to improve regional loss estimations.

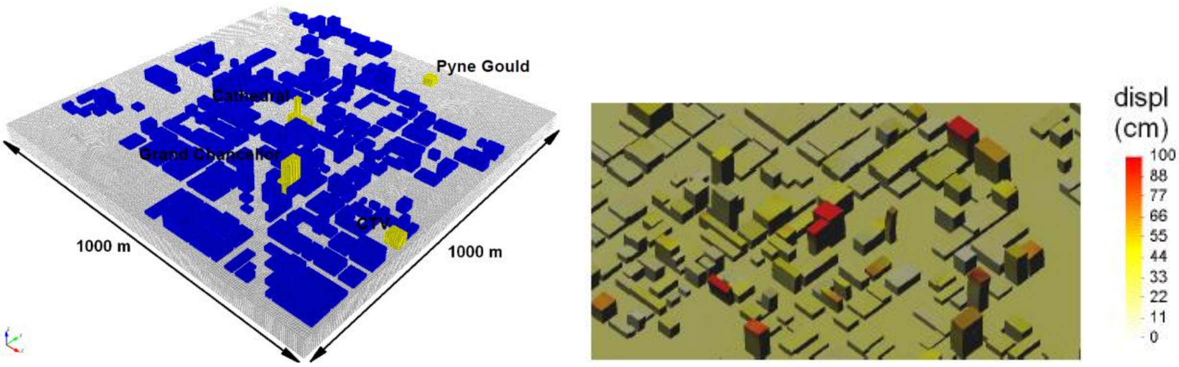

Figure 2.1. Left: 3D-model of the soil and the buildings in Christchurch CBD, Guidotti (2012)
Right: Snapshots of the simulated displacement of the buildings of the Christchurch CBD, Guidotti (2012)

The present work provides a preliminary contribution in the field of loss estimation and especially this paper explains how to create virtual portfolios, which consist of 3D Finite Element models, by using a specifically developed tool to implement this approach in an automatic way. In this way, the numerically simulated portfolios will be used for a more realistic assessment of the regional earthquake damage to masonry buildings by using the concept study of Mühlhausen (2010), (2011a) and (2011b). A short overview of the concept is given in Fig. 2.2. The reader may find more detailed information concerning the concept in the given literature.

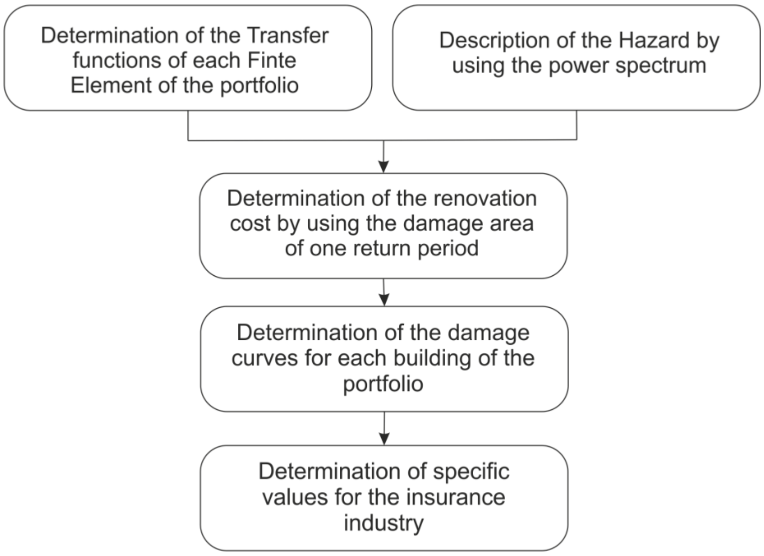

Figure 2.2. Overview of the used concept

The concept uses a similar approach as the one that has been developed for rapid seismic assessment of reinforced concrete buildings in Turkey Sucuoglu (2007). In it the potential damage of a building due to the action of an earthquake is determined by using a classification of visually assessable building features, such as the number of floors or the presence of a soft storey.

The requisites of when designing the new concept are:

- The concept must be easy to understand,
- The concept must be reliable,
- The concept must be cheap,
- The concept must be flexible to accommodate new building types,
- The concept must be applicable after a short introduction to the operator.

3. THE NUMERICAL SIMULATED PORTFOLIOS WITH THE “SBP-TOOL”

To improve the loss estimation it is useful to deal with numerical simulated portfolios. A specific tool, the **S**imulated **B**uilding **P**ortfolio-Tool (SBP), creates a specific number of virtual 3D-FE buildings in an automatic fashion. The cooperation between the University of Kassel and the Munich Re has resulted in the development of a first generic C-Code that can produce hundreds or thousands of virtual masonry buildings. The so produced virtual buildings are a useful way to describe portfolios not only regionally, but also in the whole world. On one hand a portfolio can represent a small village with just 20 buildings, while on the other hand, a portfolio of thousands of buildings can represent a whole city or a special region of a city, for example, the city centre.

By using the SBP-Tool, the following input parameters are needed in order to generate a portfolio:

- Number of buildings*
- Dimension of the ground plan**
- Dimension of the rooms**
- Dimension of the windows and the doors**
- Regular or irregular location of the building***
- Dimension and location of the balcony
- Number of inner walls in the two horizontal directions**
- Number of storeys**
- Number and size of windows**

– Balcony***
– Soft storey***
– Thickness and stiffness of the walls
– Visual condition of the building

* Each building will be generated with different input parameters
** The parameter will be generated automatically between a defined range, a mean or a expected value and a variance.
*** The parameter will be automatically selected between true (exist) and false (do not exist)

When, for a portfolio with 100 buildings, the mean value of "*Number of storeys*" is equal to 4, a distribution function for this parameter will be generated for the buildings in that particular portfolio. For a better understanding, in Fig. 3.1., the distribution function is shown with the number of storeys and the associated number of buildings in the defined range.

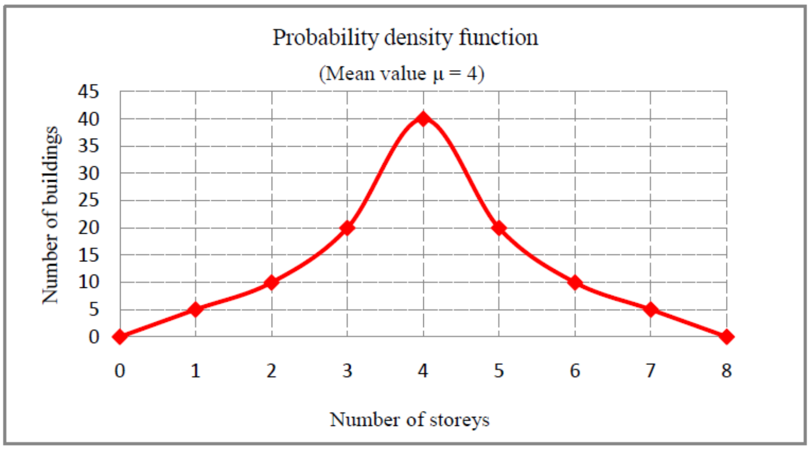

Figure 3.1. Example for a distribution function

During a SBP running process all requirements of the input parameter are checked and SBP will export a data file for each building with the necessary information. The nodes, elements and the degrees of freedom are known now and the data file can be read by a common FE-Software. In this study "SLang – The Structural Language" (developed by the Bauhaus University of Weimar, Germany) is used, SLang (2004).

The SBP-tool generates, for the moment, only shell elements (Fig. 3.2.), but the tool is open, so it would be possible, in a short period of time to input other elements like plate or voluminous elements.

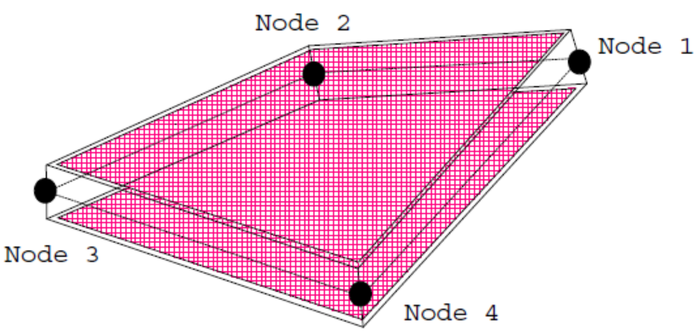

Figure 3.2. Shell4N element used to model the masonry structures in this study, SLang (2004)

For a better understanding, Fig. 3.3. shows how a building can look like.

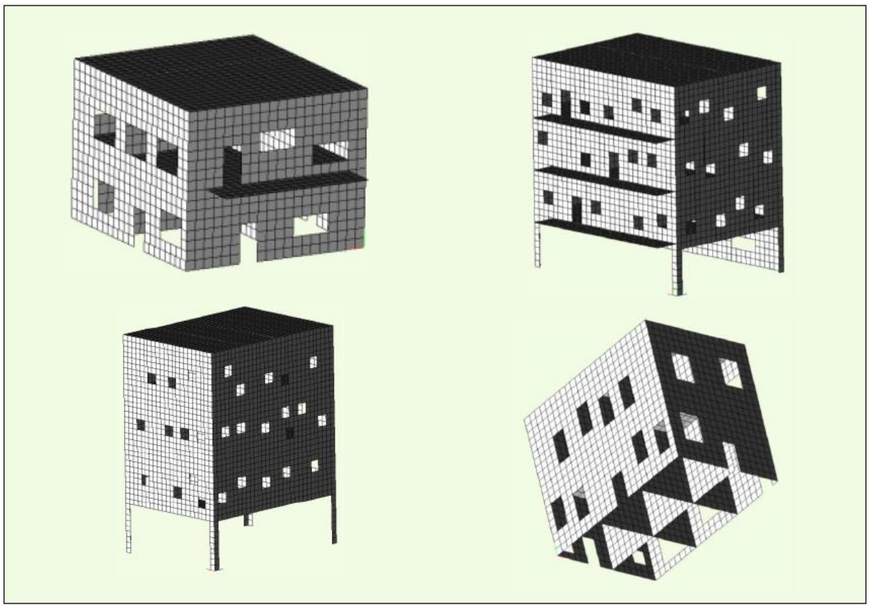

Figure 3.3. Four examples for the buildings
Top left: Typical one family building with a small balcony
Top right: Three storey building with balcony and soft storey
Bottom left: Three storey building with soft storey
Bottom right: View from bottom inside the building with the inner walls

In a generated portfolio (e.g. 100 buildings), each building will be calculated with different hazard parameters. The local soil and the peak ground velocity (PGV) are the two hazard parameters with the largest influence on seismic damage. Accordingly, these two parameters characterise the power spectrum "PS_{Hazard}" of the earthquake loading, Mühlhausen (2011a).

Fig. 3.4. presents a generated portfolio consisting of 11 typical buildings for villages, rural areas or residential buildings in cities. The maximum number of storeys is 3 for that portfolio, the dimension for length and width are between 8 and 12 m and the storey high is between 3,5 and 5 m. Some of the buildings are generated with balconies at one wall side. The number of windows is set up to 20 for each wall, so it is possible that a wall has no windows. The location of the windows for this portfolio is set to irregular, which means that the windows can start in different levels on a floor. Inner walls are also defined with a minimum of 3 and a maximum of 6 m. For this kind of portfolio the soft storey variable is set to false.

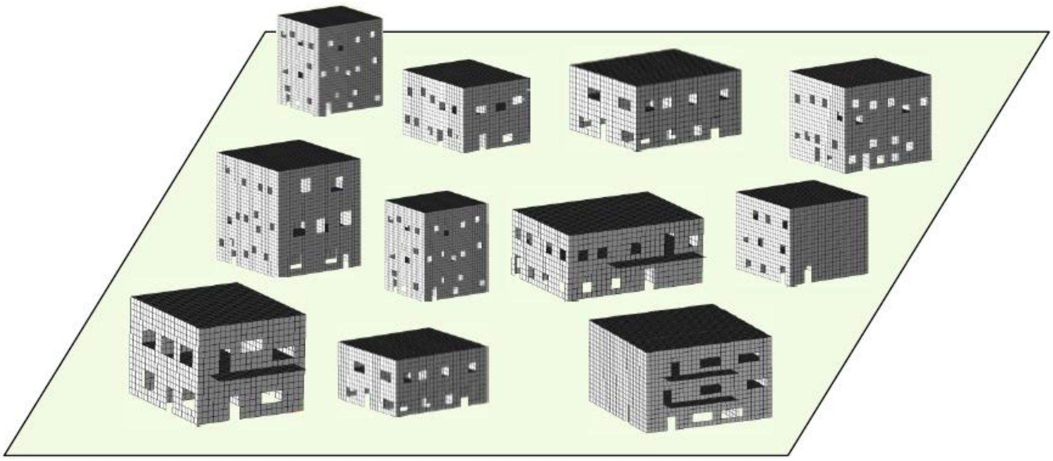

Figure 3.4. Portfolio 1: "Village like" type, generated with the SBP-Tool

In the second portfolio (Fig. 3.5.) typical buildings for the city or multi-family houses are generated. For the buildings in the city centre, the soft storeys can be arranged as well. All other parameters are comparable with the portfolio in Fig. 3.4.

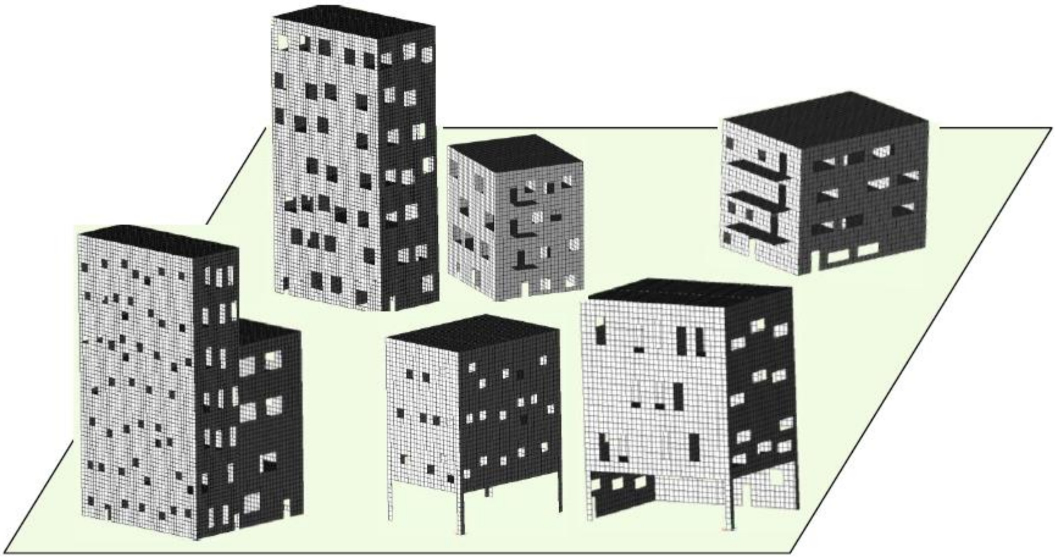

Figure 3.5. Portfolio 2: “City like” type, generated with the SBP-Tool

4. DISCRIMINANT ANALYSIS

Discriminant analysis is a used method in statistics to find a linear combination of risk factors which characterizes of separates two of more classes of objects. A practical example for the application of the discriminant analyisis is the risk of a heart attack by a human. Therefore, some of the identified risk factors are be smoking, being under stress, male over 45 years etc. but the influence of the risk factors will be on different size.

And so in many cases, e.g. vulnerability assessment, statistical analysis based on the observed damage and significant building parameters would provide an acceptable accuracy for regional assessments. Ozcebe (2003), Yakut (2003) and Yucemen (2004) employed with the statistical technique “discriminant analysis” to develop a preliminary evaluation methodology for assessing seismic vulnerability of existing low- to medium rise reinforced concrete buildings in Turkey. The discriminant functions are generated based on the basic damage inducing parameters, namely *“number of stories”, “minimum normalized lateral stiffness index”, “minimum normalized lateral strength index” , “normalized redundancy score”, “soft story index”* and *“overhang ratio”.*

The majority of the building construction in Turkey is not compliant with the actual building codes, thus violating all assumptions of the usual vulnerability assessment procedures. The main goal of the discriminant analysis is to identify the buildings that are highly vulnerable to damage, that is, if the building would survive a strong earthquake. Hence, existing buildings can be classified as safe, intermediate or unsafe by using the discriminant analysis. The developed discriminant analysis was used in this study on the observed building damage database after 1999 in Düzce earthquake, where 484 buildings were evaluated by survey teams.

The present study is also dealing with discriminant analysis but the major difference between the Turkish and the present study is the damage database. The study in Turkey deals with observed real damage while the here presented study will generate a virtual numerical damage database for a local earthquake risk zone. By using the SBP-Tool, a virtual portfolio will be generated automatically and the determination of the damage will be calculated as shown in Mühlhausen (2011a) and (2011b). The estimated damage area at the portfolio would then provide the basis for the discriminant analysis.

Therefore it is possible and necessary to identify the visible risk factors at the buildings. These could be the same like the study in Düzce.

5. CONCLUSION

The SBP-Tool is a generic program written in standard C. Existing algorithms can be edited or improved, while new algorithm can be imported easily. Up to now, the buildings will be generated without stairs inside the buildings for example. Afterwards, it can be useful to generate portfolios with stairs. To accommodate this case, a new routine would have to be developed and integrated into the existing algorithm. The existing SBP routines should not be touched or modified again (Fig. 5.1.). In this way, other researchers can improve or adapt the SBP-Tool to fulfil their needs.

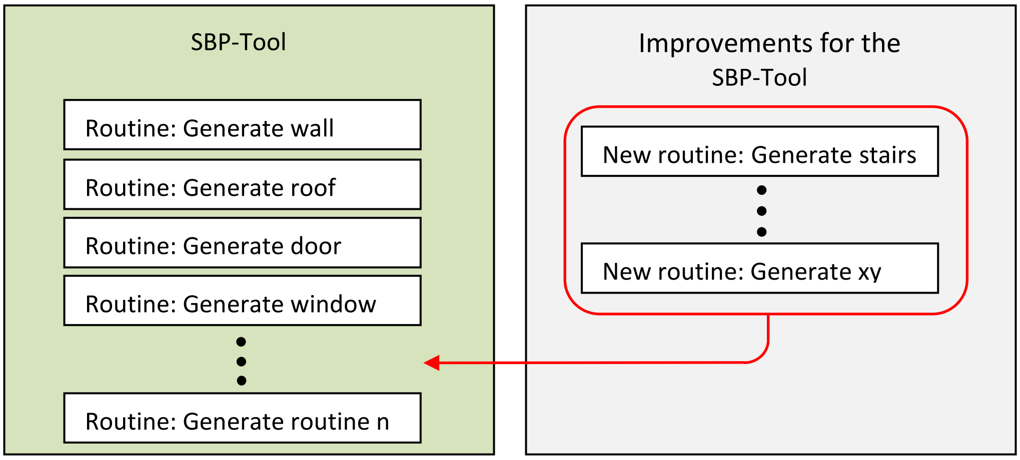

Figure 5.1. Import new routines to the generic SBP-Tool

Finally, this work is on the way to create a first virtual portfolio as a case study, maybe the L'Aquila earthquake scenario (Mw 6,3, April 6, 2009), to demonstrate the whole concept of Mühlhausen (2011a) and (2011b) which included the identification of the risk factors and the discriminant analysis.

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