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SELECT. FC: METHODOLOGY, CALIBRATION, APP AND DATABASE TO ASSESS AND SELECT FRAGILITY CURVES FOR SEISMIS RISK STUDIES

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Abstract.

Fragility curves (FCs) are crucial for evaluating structural performance against seismic risks, depicting the probability of damage at varying hazard levels. Using appropriate FCs is essential to ensure accurate damage and loss calculations for specific construction types. This study introduces "Select.FC", a methodology featuring a multidimensional index to assess and select the most suitable FCs from existing literature. The index evaluates various variables, assigning scores to each, and ranks FCs from A to F based on their suitability, simplifying result interpretation and enhancing reliability.

The evaluation dimensions include technical suitability, local system compatibility, and similarity between candidate and target building types, encompassing 15 variables. Technical suitability is inherent to the FC and the most time-consuming, assessing variables inherent to FCs, while the other two dimensions depend on specific construction features. The methodology's scores were calibrated using the Fuzzy Analytic Hierarchy Process applied to expert survey results, involving 30 international professionals.

Additionally, herein is made public a free online application, "Select.FC", with a database of over 50 evaluated FCs which implements the said methodology. The App permits the evaluation of all the FCs included in the database for the specific typology of the area under study and obtaining of the class of adequacy. A QR code for accessing to the App is provided. Future work will expand the FC database with more pre-assessed technical suitability dimensions and allows users to input and classify their own FCs.

INTRODUCTION

Seismic risk, determined by the combination of hazard, exposure and vulnerability, is the measurement of the damage expected in a given interval of time, based on factor as the seismicity and the resistance of constructions, among others. Seismic risk studies allow for a probabilistic evaluation of the consequences that these ground movements could have on the structure or set of structures considered. Therefore, when conducting seismic risk studies, experts have to deal with with a multitude of uncertainties, especially in the methods used to assess the factor involved. For instance, one critical aspect is the choice of fragility curves that represent the vulnerability of each typology of buildings exposed.

Fragility curves (FCs) are the graphical representation of the probability of reaching or exceeding a limit damage state given a level of ground shaking and constitute the most extended decision-making tool to establish the relationship between hazard and damages. The employment of adequate FCs is key to evaluate the performance of constructions against seismic risks accurately since selecting an inappropriate FC for a given construction typology can significantly affect the accuracy of damage and loss calculations. Moreover, the selection of an accurate FC can aid to understand the risks associated with the specific types of structures.

Nonetheless, despite this fact, many of the FCs commonly used in seismic risk studies for highly vulnerable areas were designed for regions with higher GDP and more research investment, hence different construction techniques and materials quality compared to the areas being studied [1]. For said reason, having a methodological approach for evaluating and selecting FC for seismic risk studies and a practical manner to employ it like a web application is crucial.

In this line, this contribution presents the *Select.FC* integral approach that renders as easy as possible to researchers the selection of the most appropriate FC for a region. This work integrates and unites:

- a proposal for giving ranges and rankings to assess the suitability of a particular curve for a given area by means of a multidimensional index [1] named *Select.FC*;
- the calibration and validation the scores assigned to the variables involved in the methodology through an expert survey analyzed employing the fuzzy set method;
- a web application (App) also called *Select.FC*, which includes a comprehensive database of FCs with the technical variables already assed.

1 SELECT.FC METHODOLOGY

1.1 Select.FC: a methodology to assess and select fragility curves

The methodology for assessing and selecting seismic FCs involves the following steps [1]. Initially, it is crucial to identify and characterize the types of buildings under study. Following this, a comprehensive search of available scientific literature is undertaken, including research projects, journal articles, theses, conference papers, and other relevant sources. This search is focused on sources related to the characterization of buildings pertinent to the specific area being analyzed.

Next, a rating index is developed from a set of proposed variables aimed at evaluating key aspects of the identified FCs for the building types being studied. Figure 1 outlines the conceptual framework, dimensions, and variables of this index, indicating the maximum scores for each aspect in brackets. Using this index, a classification is created to determine the suitability of the FCs for each identified building type.

The Final Index, which has a maximum score of 100 points, is calculated based on a multi-dimensional index known as the Global Index. This Global Index is adjusted by a reduction coefficient that reflects how well the curve fits a particular building type within the studied region, referred to as the Building Class Similarity dimension. The similarity between the building types of the candidate functions and that of the region under study is determined by considering the quantity and nature of their attributes.

Essential characteristics considered in this assessment include the lateral load-resisting system, number of stories, ductility, year of construction, and compliance with seismic regulations, as these are significant in terms of the seismic vulnerability of the building typology being analyzed. The fragility curve must correspond to a building type made of the same material as the one under investigation.

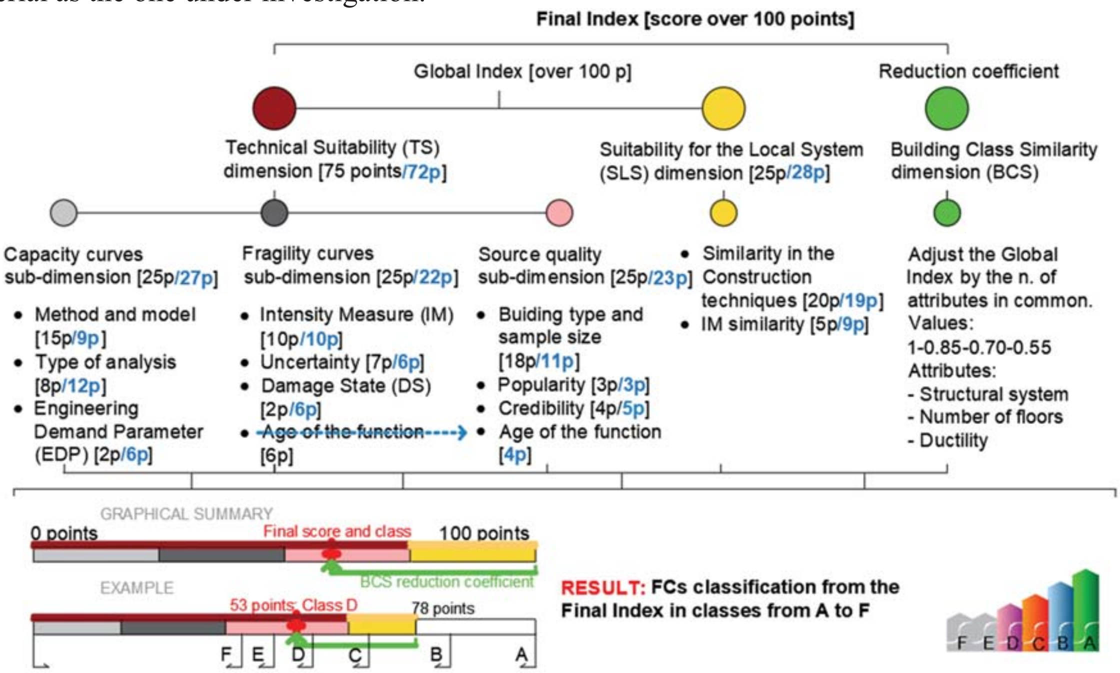

Figure 1: dimensions and variables of the index proposed to evaluate FCs. Source: adapted from [1]. Scores given in the original proposal included in [1] in black. Scores resulting from the calibration herein after described in blue.

The Global Index consists of two main dimensions: the *Technical Suitability* of the Fragility Curve (FC) and the *Suitability for the Local System*. The *Technical Suitability* dimension is further divided into three sub-dimensions: *Capacity, Fragility*, and *Quality*. Each of these dimensions and sub-dimensions includes various variables that allow for a comprehensive evaluation of the FCs. These variables were selected based on previous studies in the field [2], [3] and [4].

The *Capacity* sub-dimension includes variables related to the *Method and Model* used, the *Type of Analysis* performed, and the *Engineering Demand Parameter* (EDP) considered in constructing the curve. The *Fragility* sub-dimension pertains to characteristics directly related to the FCs being evaluated, such as the *Intensity Measure* (IM) used, , the source of *Uncertainty* associated with FCs that are treated, and the *Damage State thresholds* considered. The *Quality* sub-dimension assesses whether the capacity and fragility curves are derived from existing structures or building prototypes and considers the *Sample Size* of buildings used; and variables related to the *Authenticity* and *Credibility* of the study, taking into account the type of publication in which the FC is proposed (e.g., scientific article, doctoral thesis, conference paper). Additionally, it includes the *Popularity* of the FCs, measured by the number of citations in Google Scholar of the study proposing the curve and the *Publication Year* of the study that proposes the curve.

The *Suitability for the Local System* dimension evaluates the degree to which the FCs are appropriate for the local context based on variables such as the *Similarity in Construction Techniques* and the *Similarity of Intensity Measures* (IMs). This dimension assesses the adequacy of the FCs for the building typologies of the specific zone under study.

1.2 Calibration of the methodology

The multidimensional index proposed by [1] is constructed using scores assigned to each variable, sub-dimension, and dimension according to the criteria set by the research group's experts. However, determining the weights for the different variables in a multidimensional index is a complex and crucial process for developing a composite index, as it requires combining various variables and dimensions into a single indicator. Consequently, in the second phase of the research, validating the assigned weights was considered essential. Hence, once the methodology was established, the scores given to the variables and dimensions were calibrated employing an international survey so as to base the new pounding in a wider expert criterion.

The online survey summarized in Figure 2, available in both Spanish and English, was conducted specifically to gather expert opinions on the weights or relative importance of each variable, sub-dimension, and dimension included in the previously described multidimensional index for rating FCs.

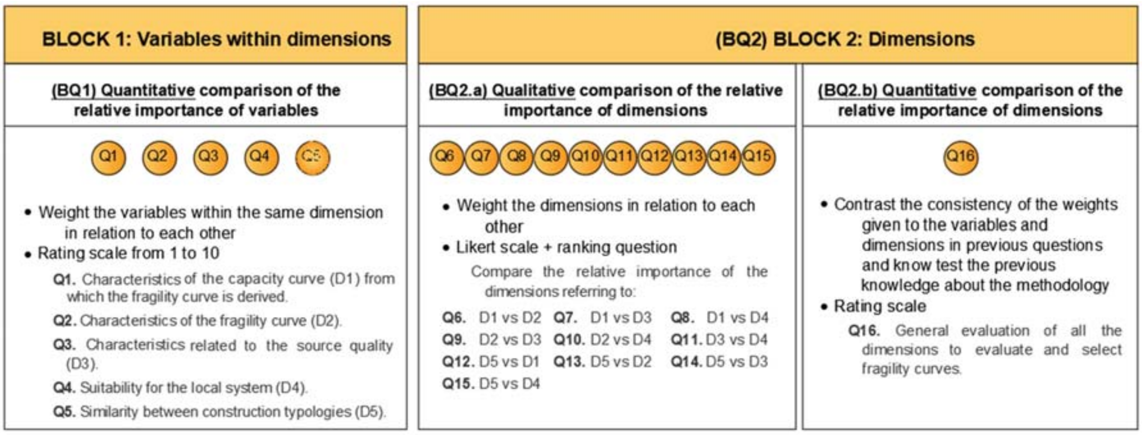

Figure 2: Schema of the survey

The survey has a total of 16 questions (from Q1 to Q16) divided into two blocks (BQ1 and BQ2). The first block (BQ1, from Q1 to Q5) relates the scores of variables pertaining to the same dimension. The objectives, in this case, are to compare the relative importance of the variables included in the same dimension for the selection of a FC and to introduce the variables pertaining to each dimension for the BQ2. The BQ2 presents two sets of questions: the first of these (BQ2a, from Q6 to Q15) qualitatively compares the relative importance of dimensions, thus allowing us to establish the scores given to each dimension, knowing the variables that pertain to each of them. In the second one (BQ2b, Q16), different dimensions are quantitatively compared. In other words, the BQ1 asks the expert to assign a score on a scale of 1 to 10 to each of the twelve variables included in the global index. In the BQ2a, the experts are required to compare successive pairs of different dimensions of the index to collect the relative importance they assign to each one in comparison with the rest; whereas in the BQ2b the experts must assign a score from 0 to 100 to each of the five dimensions. All questions are compulsory.

A total of 30 experts with high level of expertise in the subject matter answered the survey. These experts generally have significant specialization reflected in their research activities and high-quality scientific publications or professional work. They were contacted via email and provided with a cover letter explaining the purpose of the survey and its relation to the study. The responses come from various countries, including Europe, North, Central and South America. Nonetheless, expert responses are inherently subjective, uncertain, and potentially inconsistent [5]. To address these limitations, the fuzzy analytical hierarchy process (FAHP) method was implemented to refine the weighting system derived from the expert survey.

Fuzzy hierarchical analysis

The analytical hierarchy process (AHP) is a method developed to work with complicated systems, including choosing among numerous options [6]. The AHP is based on a hierarchical split of the problem into its parts; the analysis then assists the decision-makers who, through pairwise comparisons, can understand the influence of the considered elements in the hierarchical structure. In this research, the AHP is employed to calibrate the weights of variables, dimensions and sub-dimensions based on expert criteria.

In particular, the Fuzzy AHP method highlights the most prominent variables used in constructing the indices and assigns them the highest weight. By integrating expert responses and the FAHP method, it is possible to improve the objectivity of the weights and reduce the uncertainty when combining expert opinion on a particular variable and turning it into a single value. Said uncertainty may be due several factors, such as, lack of understanding of the task, expert bias, experts' disinterest in the survey, or plain human error. Furthermore, FAHP is the most appropriate one in situations where there is a likelihood of ambiguity and fuzzy results when gathering opinions from experts to create composite indexes [5].

Figure 3 schematizes how the survey responses are treated to enhance expert weights by subjecting them to the FAHP method to calculate fuzzy weights and interval weights. In summary, the responses to BQ1 from the expert survey are used to derive the relative weights of the different variables of each dimension and sub-dimension. Whereas the responses to BQ2a and BQ2b allow us to compute the weights of the dimensions of the multidimensional index. Once the weight of each dimension is established, these dimension and sub-dimensions' weights are used to ensure that the total weight of the variables within each dimension equals the dimension's weight derived from BQ2a and BQ2b.

The scores resulting from the analyses described are summarized in blue in Figure 1.

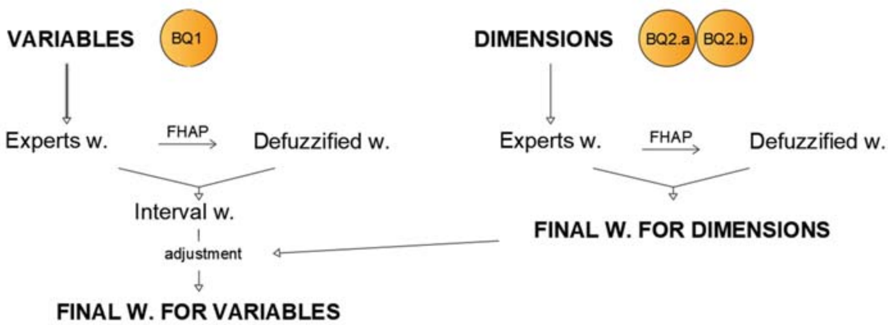

Figure 3: Schema of the analyses implemented to the survey for enhancing the weighting system. W: weight

2 WEB APPLICATION AND DATABASE

The interest in creating a web application implementing the *Select.FC* methodology arises from the difficulties linked to dealing with data bases and scoring a great number of variables inherent to the FCs assessment and selection. The application addresses the aforementioned problems by automating the evaluation process, centralizing and structuring the data, providing a dedicated technological tool, and offering a detailed glossary to facilitate the understanding and application of the methodology. A very relevant advantage that the *Select.FC* methodology offers for its use as a basis for a web application lies in the practicality when evaluating the curves: the most expensive dimension in terms of time spent only has to be evaluated once and its score is valid for all areas and structural systems (see Figure 4 for an example). In other words:

- The technical dimension is independent of the study area, or the type of building analyzed; that is, it depends solely on the method used to prepare the fragility curves. Therefore, once determined for a specific fragility curve, said value is valid for any seismic risk study. Furthermore, this dimension is the one that includes the majority of variables and the most time-consuming.
- The dimension of the local system depends solely on the characteristics of the area under study. Therefore, the value determined for this dimension is valid for any type of building within that area.
- The building class similarity reduction coefficient is the only dimension that must be adjusted for each building type according to its attributes (material, structural system, number of floors and ductility).

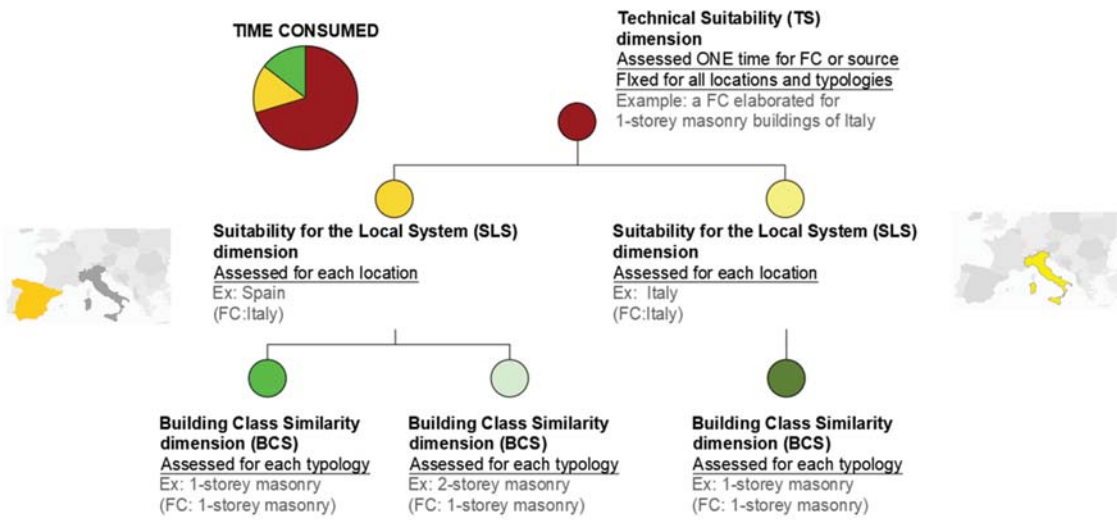

Figure 4: Schema of the practicality of the methodology for implementing it in an App. Source: PhD defense [7]

The created App is able to classify curves automatically according to the results of the evaluations, following the methodology established by *Select.FC* to guarantee accuracy and eliminate human errors in categorization. Furthermore, it allows the download of an Excel file with detailed technical information and specific scores for each variable, facilitating subsequent analysis and presentation of results in a structured manner. Up until June 2024, the App includes a database created with a Structured Query Language, QLS 2019, which comprises more than 50 FCs with the technical dimension assessed.

Figure 5 illustrates the Graphical Interface of the App, developed in [8], which contains filters to search for fragility curves in the database. These filters include two that are compulsory, *Materials* and *Height Range*, and four that are optional, *Structural System, Ductility, Country of origin and Intensity Measurement*. Once the filtering has been carried out, all the FCs that correspond to the indicated conditions and their characteristics corresponding to the technical dimension will be displayed. The said features have already been evaluated. Next, to facilitate starting the evaluation process of the two remaining dimensions, *Suitability to the local system* and *Building Class Similarity*, three additional fields appear.: (i) *Similarity between Construction Techniques, (ii) Similarity between Intensity Measurements* and (iii) *Building Class Similarity*. Once the options that best fit the study have been selected, the App provides an Excel file with all the curve data and the scores and classes obtained from the evaluation (see figure 6). A QR code for accessing to the *Select.FC* web App is included in Figure 7.

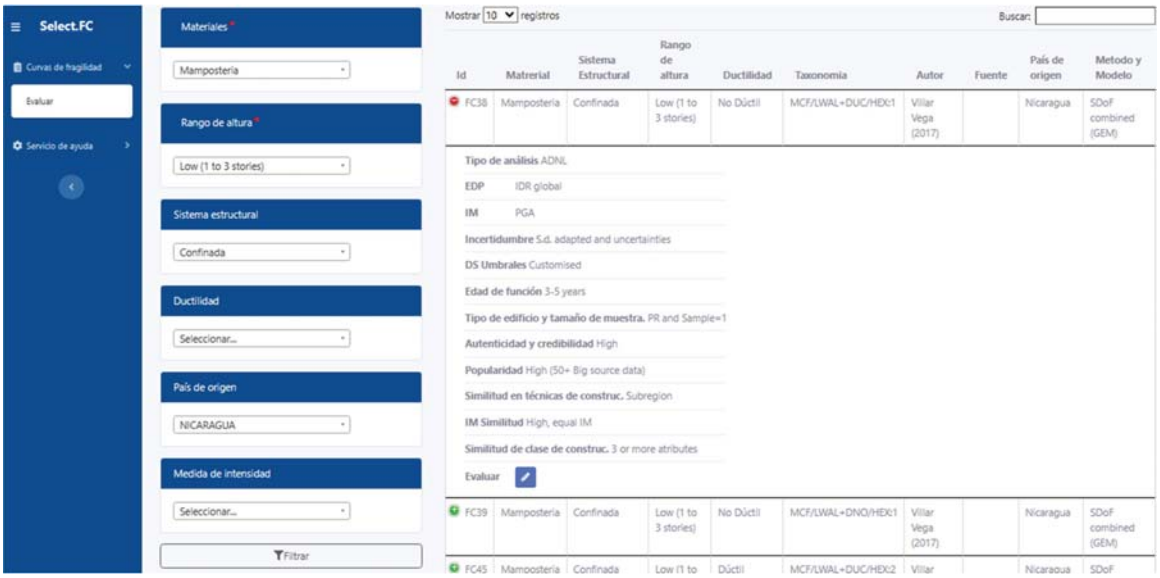

Figure 5: Graphical interface of the App. Source: [8]

ID	Tipología evaluada	Autor	Descripción según taxonomía GEM	Building class similarity	Similarity in Construction techniques	IM similarity	Method and model	[...]	CAPACITY	FRAGILITY	QUALITY	TECHNICAL	LOCAL SYSTEM	GLOBAL INDEX	FINAL INDEX	CLASS
CF1	Mampostería integral 1 piso (ductil)	E. Calderón (2018) based on Hidalgo (2017)	MCR+CBH/LWAL+DUC/HEX:1/IRRE/FN	1.00	20	5	12	[...]	22	24	22	68	25	93.0	**93.0**	**A**
CF2	Mampostería integral 1 piso (ductil)	Calderón and Silva (2019)	MR/LWAL+DUC/HEX:1 and MCF/LWAL+DUC/HEX:1	0.85	20	5	6	[...]	16	17	23	56	25	81.0	**68.9**	**B**
CF3	Mampostería integral 1 piso (ductil)	Calderón and Silva (2019)	MR/LWAL+DUC/HEX:2 and MCF/LWAL+DUC/HEX:2	0.70	20	5	6	[...]	16	17	23	56	25	81.0	**56.7**	**C**
CF4	Mampostería integral 1 piso (ductil)	Calderón and Silva (2019)	MR/LWAL+DNO/HEX:1 and MCF/LWAL+DNO/HEX:1	0.70	20	5	6	[...]	16	17	23	56	25	81.0	**56.7**	**C**
CF5	Mampostería integral 1 piso (ductil)	Villar Vega (2017)	MCF/LWAL+DUC/HEX:1	0.85	10	5	3	[...]	13	20	21	54	15	69.0	**58.7**	**C**
CF6	Mampostería integral 1 piso (ductil)	Villar Vega (2017)	MCF/LWAL+DNO/HEX:1	0.70	10	5	3	[...]	13	20	21	54	15	69.0	**48.3**	**D**
DATA				**VARIABLES**					**RESULTS**						**CLASS**	

Figure 6: Example of the data proportionated by the Excel file. Source: [8]

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Figure 7: QR code for accessing to the *Select.FC* web App

3 CONCLUSIONS AND FUTURE LINES OF RESEARCH

This work has presented a recent methodology for assessing and selecting fragility curves. The *Select.FC* method proportionates a multidimensional index that allows the scoring and ranking in classes from A to F of the FC depending on its level of adequacy to represent the behavior of the typology of the region under study in the face of an earthquake.

Moreover, we have introduced how the scores given to the dimensions, sub-dimensions and variables involved in this methodology have been calibrated: by carrying out a survey to international experts and analyzing the results employing the Fuzzy Analytical Hierarchy Process to reduce the uncertainty inherent to the process of combining expert opinion on a particular variable or set of them and turning it into a single value.

Finally, an easy to use web application that implements the methodology has been made public. The *Select.FC* App provides to the seismic risk experts a database of more than 50 FCs from all over the world with the technical dimension already assessed and a graphical interface that enormously facilitates the evaluation of the rest of the less time-consuming dimensions. Furthermore, the App permits the user to download the results to analyze and custom variables and scores in case it is needed. A QR code for accessing to the App is provided in Figure 7.

To conclude, future lines of research should implement the evaluation of custom fragility curves by functionality that allows users to evaluate their own fragility curves within the application and add it to the data base.

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