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DEVELOPMENT OF A DATABASE FOR INDICATORS OF RESILIENT SYSTEMS

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Abstract

Resilience assessment is a complex and challenging process. It is interrelated to variety of aspects such as social, economic, ecological, etc. The objective of this research is to develop an indicator database to evaluate the resilience of any system. In literature, much research focused on determining resilience indicators; nevertheless, there are still no criteria to select a proper set of indicators for a specific system. Furthermore, sustainability and resilience are two correlated quantities and some of the indicators might be useful in quantifying both of them. This paper illustrates the correspondence of these two intertwined concepts. It focuses on determining whether resilience and sustainability are interconnected.

Different frameworks for computing resilience are available in the literature (e.g., BRICS, PEOPLES, DRR, CCR, CDRI). None of them, however, describes a clear procedure for selecting the necessary indicators for a specific system. For this reason, a software tool was developed where all indicators associated with resilience are listed and analyzed. Indicators are grouped according to different scales (e.g., spatial and temporal scale, hazard type, measurement method, etc.). The developed tool helps decision makers to choose the proper set of indicators. It also gives an overview on the status of the system and brings suggestions to develop this status. Finally, a case study has been analyzed to examine the software tool.

Keywords: Resilience; sustainability; indicators.

1. Introduction

Recent studies suggested that resilience could replace sustainability in the future in terms cities development [1, 2]. Nevertheless, these two concepts are not independent each other. The correlation between them is rather complex. For instance, it is possible to have a sustainable city that consumes resources and energy efficiently, that optimizes waste management and has a good economy, but at the same time it does not operate well in cases of shocks and major turbulence. It is also possible to have a resilient city that is not sustainable in terms of energy consumption, social equity, economic efficiency, etc. Such cities are not even resilient, but rather resistant, as they resist the hazardous situations. As an example, on September 2004, more than one century of Deforestation and soil erosion provoked landslide and flood in Gonaives (a commune in northern Haiti). The absence of a mitigation plan has left the people with no shelters. This catastrophic event showed how an unsustainable way of development might increase the vulnerability of communities.

The purpose of this study is to clarify the correspondence of sustainability and resilience in order to have a balanced development. To reach this goal, different assessment methods were investigated. The absence of a holistic method for resilience led us to come up with a new tool for resilience evaluation. In addition, there is no single or widely accepted method to the measurement issue as the landscape of resilience indicators is confusing and increasingly hard to navigate [3]. The expectation of this study is to facilitate the process of resilience evaluation and decision-making with the help of different strategies, including a new categorization method that defines and evaluate indicators in a simple way.

2. Clarifying the correlation between sustainability and resilience

In order to understand the intertwinement of resilience and sustainability, it is necessary to clarify their definitions first. According to Merriam-Webster, *resilience* is the ability to become strong, healthy or successful again, after something bad happens. This is different from *resistance*, which is the ability to prevent something from having an effect. In the report of the World Commission on Environment and Development: “Our Common Future” 1987, *Sustainable development* is a development that meets the needs of the present without compromising the ability of future generations to meet their own needs [4]. Sustainable development includes three main pillars; *environmental protection*, which is strongly correlated with global warming and other impacts to ecosystem; *social equality*, which focuses on the social well-being of people and the growing gap between incomes of rich and poor; *economic development*, which generates economic growth without hurting the environment.

The correlation of sustainability and resilience is studied for each of the three pillars. Almost all of the **environmental impacts** of human activities including global warming can cause hazards, or at least increase their intensity. Global warming has two primary aspects: a rise in the temperature and a rise in the sea level. The outcomes are: increase in the risk of drought, increase in the intensity of storms, and having more intense mid-latitude storms, etc. There are also some other impacts of human interventions which amplify the damage. Deforestation can be an example of these interventions. The approach of sustainable development is to minimize the number or the intensity of hazards while resilience minimizes their effect. On the other hand, sustainability always encourages communities to build green buildings and facilities that generate energy using renewable resources, such as solar energy. They are eco-friendly as they decrease the non-renewable resource consumption; thus, they lower the environmental impacts which can be catastrophic. They are also more resilient since, in the case of hazard, these resources compensate a large amount of loss which comes from the infrastructural damage. This is why improving the resilience of building units, as the smallest spatial scale, is essential. Starting from the building scale, we may be able to improve the resilience of larger systems.

Social sustainability measures equity as the fair access to livelihood, education, resources, and level of participation in the political and cultural life of the community. In both sustainable development and resilience concepts, the social equity and participation play a key role. More equity - as a sustainable approach - leads to less vulnerability and improves resilience. As an example, after hurricane Katrina hit New Orleans in 2005, being alive or dead, having a habitable house or being homeless was determined on the basis of how high from the sea level people were living. The level of the housing units above the sea - in New Orleans - became a characteristic of class stratification [5]. On the other hand, place attachment - which is the emotional bond between person and place – is one of the important indicators of resilience. It makes the habitants of a community tend to manifest their sense of community and to bond with other members of the same group by providing social and cultural services. Socially sustainable communities can provide place attachment more since they improve participation of residents. For example, cohousing is a type of intentional community composed of private homes supplemented by shared facilities. Cohousing has been always considered as a good example of a sustainable way of life. It has different ecological, economic and social benefits including improvement of place attachment and participation. It's easy to imagine how these factors can help the community act in a more cooperative way. So sustainability - by improving community competence and place attachment- helps resilience, and the effect is sensible in case of hazardous situations.

The third pillar of sustainable development as stated above is **economic** sustainability. Economic sustainability is the ability of an economy to support a defined level of economic production indefinitely in a manner that sustains natural resources and provides social welfare. An increase in production does not necessarily lead to an increase in welfare. Index of Sustainable Economic Welfare (ISEW) is an economic indicator intended to replace the Gross Domestic Product (GDP) which is the main macroeconomic indicator of System of National Accounts (SNA). On the other hand economic resilience is the ability to bounce back from economic shocks and to reduce the vulnerability of economies to crises and strengthening their capacity to absorb and overcome severe shocks while supporting strong growth. "A community needs to have access to resources to grow and react to changes" [6]. The difference between resilient and non-resilient economy is that the resilient economy addresses local needs on often locally based sources of employment, skills, and finances." Indicators of economic resilience determine poverty rate, income distribution, economic gaps, life expectancy, diversity etc. Both sustainable and resilient economy need to provide a defined level of production considering the social welfare and the income distribution. In addition, sustainable economy tries to control the environmental impacts of this production level and improves resilience by lowering hazards intensity. For example, after superstorm Sandy hit New York City and the New Jersey coastline, there was much discussion about large technical infrastructure solutions for dealing with expected future storm and coastal flooding. One suggestion was closeable sea gates at the narrow section of the entrance to New York harbor [7]. But these gates could lock the city into long-term maintenance costs that also had serious environmental side effects. This is how a risk reduction plan can amplify the problem if both resilience and sustainability are not considered simultaneously.

Besides, in these three pillars, both resilience and sustainability are strongly dependent on durability of the project. Durability is an important indicator of sustainability. Improving durability means less energy and resource consumption. The longer the structure lasts, the less resources are required to build replacements. Furthermore, the more resilient buildings and structures are, the less maintenance is needed, and thus the cost of it is reduced. Durability is also integrated with the first sustainability pillar. If the life of a building increases, no matter what the building is made of, the environmental impact of its construction -which contains the largest amount of impact over building life cycle- is reduced.

In order to explain the correlation between *durability* and *resilience*, let's consider the two projects shown in Fig. 1. Project 2 is more durable than project 1. After an extreme event, Project 2 reaches the desired level of functionality sooner than project 1, because less resources and time are required to go back to the initial conditions; thus, requires less maintenance, and recovers quicker. Therefore, durability has a positive effect on resilience.

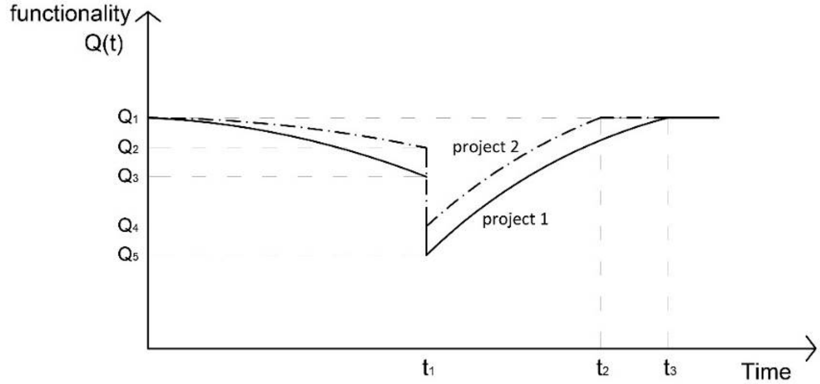

Fig. 1 – Durability vs. Resilience

Sustainability and *resilience* in some dimensions such as the environmental point of view they have the same trend in reducing the destructive impact of global warming for example. It is important to assess and evaluate any project from both points of view to have a sustainable and resilient community. Rating and Evaluation determine where you are on the road to sustainability and resilience, and identify new opportunities and assessment methods to the organizational practices. Assessments should be holistic, harmonious, habit-forming, helpful, hassle-free, hopeful, and humane [8]. There are different ways to assess and develop sustainability and resilience including indicator-based approach. The reason why an indicator-based approach is selected is that indicators help decision-makers assess progress towards the intended goals and objectives.

In sustainability, different credit weighting tools are adopted by the most popular rating systems around the world. Most of them are developed for the assessment of buildings as nationally and globally, buildings contribute significantly to energy consumption, as well as to other environmental impacts, such as air emissions and solid waste generation. For example, 38% of US primary energy consumption is related to building operations and 65% of all 1997 Municipal Solid Wastes [9]. In this case, green procurement in construction section plays a key role in sustainable development. Leadership in Energy and Environmental Design (LEED) is an example of green building certification programs used worldwide. LEED (Leadership in Energy & Environmental Design) which developed by USGBC (US green building council), attempts to wed elements of two primary methods of communicating environmental attributes that relate to buildings, Eco-labeling and Life Cycle Assessment (LCA). The LEED rating system is not the first green building program, but it is the only program with national scope and the only one that has been adopted by many private organizations (Herman Miller, Ford Motor Co., Natural Resources Defense Council) as well as local (Portland OR, Seattle WA, San Jose CA) federal (GSA, Department of State) and government bodies in U.S. One of the critical issues in developing a rating system for assessment is the distribution of points and weights across the different areas and indicators [8]. LEED is a credit-based system. The last version of LEED contains 110 credit points which are divided among 7 impact areas: Sustainable Sites (SS), Water Efficiency (WE), Energy and Atmosphere (EA), Materials and Resources (MR), Indoor Environmental Quality (IEQ), Location and transportation, Innovation in design and regional priority (ID) [10].

In resilience, the vagueness of the concept makes it difficult to define, but it becomes even more problematic when trying to measure it. Measuring community resilience is still in the primary stages of development. Different frameworks available in the literature are based on the definition of different sets of resilience indicators, but not in a holistic way. An example of current research is LEED [11], a tool developed by the resilient design institute (RDI) which has been promoted like the Leadership in Energy and Environmental Design for green buildings. There are three credits in the LEED methodology: (i) assessment and planning for resilience, (ii) design for enhanced resilience and (iii) passive Survivability and Functionality during Emergencies. These three credits are designed to ensure that a design team is aware of vulnerability and addresses the most significant risk in the project design, including functionality of the building in the event of long-term interruptions in power or heating fuel.

However, neither LEED nor other frameworks for resilience introduces a rating system that makes the comparison between different projects possible.

3. Proposal of resilience assessment method

None of the resilience frameworks (e.g. BRICS, PEOPLES, DRR, CCR, CDRI) [12, 13, 14] describe a process to select the resilience indicators of a specific system. The proposed method which has been implemented in a software tool allows selecting the proper indicators for a given system, provides a scoring method for each of them and in the end combine them by providing a resilience index which can be used by decision makers to select the proper indicators (Fig. 2). This tool ensures the resilience assessment process and increases the result accuracy.

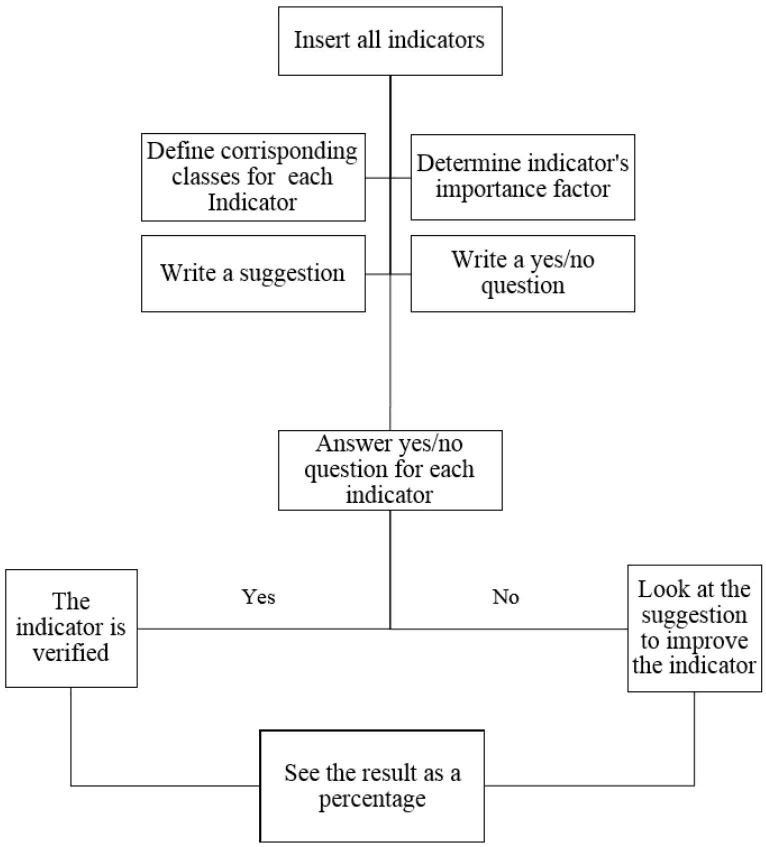

Fig. 2 – Flowchart of the software process

3.1 Resilience Indicators

Different frameworks propose different indicators, which overlap each other. After an extensive comparison between different frameworks, a complete list of resilience metrics which is based on the work of Mileti (1999) [15] , Burby et al. (2000) [16],Heinz Center (2002) [17], Vale e Campanella (2005) [18] , Ronan and Johnson (2005) [19], Berke & Campanella (2006) [20] ,Godchalk (2003 & 2007) [21, 22], Murphy (2007) [23], Sylves (2007) [24], Norris et al. (2000 & 2008) [25],Morrow (2008) [26] ,Colten et al.(2008) [27], Tierney (2009) [28],Renschler et al. (2010) [29] ,Cutter et al. (2008 & 2014)[30,3] , and Burton et al. (2015) [31] has been inserted in the software . All the indicators can be found in the book “Urban resilience for emergency response and recovery, Fundamental concepts and applications” [32] in six categories. As an example, the indicators of community capital category are presented in table 1.

Table 1 – List of Community capital indicators inserted in the software

Community Capital Indicators	**Resilience metric**	**Data Source**
Place attachment	Net international migration	Morrow 2008
	% population born in a state that still reside in that state	Vale e Campanella 2005
Political engagement	% Voting participating in presidential election	Morrow 2008
Social capital-religious organizations	Population affiliated with a religious organization per 10,000 persons	Morrow 2008 Murphy 2007
	Religious organizations per 1,000 population	
Social capital-civic organizations	Civic organizations per 10,000 persons	Morrow 2008 Murphy 2007
Social capital-disaster volunteerism	Red cross volunteers per 10,000 persons	Cutter et al. 2014.
Citizen disaster preparedness and response skills	Red cross training workshop participants per 10,000 persons	Cutter et al. 2014.
Social capital	Social advocacy organizations per 10,000 population	Murphy 2007
	Arts, entertainment, and recreation centers per 10,000 population	Burton 2015.
	Civic organizations per 10,000 population	Morrow 2008 Murphy 2007
Creative class	% workforce employed in professional occupations	Norris et al. 2008
	Professional, scientific, and technical services per 1,000 population	
	Research and development firms per 1,000 population	
	Business and professional organizations per 1,000 population	
Cultural resources	National Historic Registry sites per square mile	Burton 2015.

3.2 Classification of Indicators

Since resilience indicators are difficult to be analyzed, there are several ways to classify them. During them classification process, different methods (e.g., spatial scale, temporal scales, hazard type, etc.) can be considered. The majority of the indicators are time and spatial dependent and are difficult to be transferred from one scale to another. Therefore it is important to distinguish between indicators which are specific to the case study considered and the ones that can be generalized and extended to different hazards, communities etc. [33]. The first comprehensive work on classification of resilience metrics was performed in the European project emBRACE, which proposed thirteen categories [34]: Inherent or adaptive , Outcome or process, Domain, Relation with the phenomenon ,Composite indicators, Scale of applications, Level of measurements , Resources & Capacities, Actions and Learnings, Generalization, Relation to resilience, General importance, Pre/Post-hazard event phase and Qualitative or quantitative. However, the classification proposed in emBRACE presents some limitations, because some of these categories overlap each other and they are not integrated in a useful manner, but they have the advantage of listing a series of characteristics for the indicators.

After reviewing the state of the art on classification methods, a new classification method is proposed. Through this classification, it is possible to assess resilience quantification properly and select the optimal resilience strategy. In this method, resilience metrics were classified according to seven categories (or classification methods); Hazard Type, Temporal scale, Spatial scale, Building type, Level of Development, Domain and Measurement method. Seven proposed classification methods are shown in the columns of Table 2, while in the rows, different classes are identified. In the following paragraphs we describe the different classification methods in detail.

Table 2 – Proposed classification method

Hazard Type	**Temporal scale**	**Spatial Scale**	**Building type**	**Level of Development**	**Domains**	**Measurement Method**
Natural (e.g. Flood, Earthquake, Tsunami, Fire, Tornado, Hurricane etc.)	Pre-Phase (Preparedness)	Building	Critical facility (e.g. Hospital, City-hall etc.)	Developed countries	Social/ Cultural	Quantitative
Manmade (e.g. Terrorism, Wars, Criminality, Power outage etc.)	Short Term (Emergency Response)	Building Block (Neighbo rhood)	Residential building	Under-developed countries	Economic	Qualitative
	Long Term (Reconstruction phase)	City/ State	No Building type	Not in country scale	Ecological/ Environmental	
		Region			Governmental /Welfare/ institutional	
		Country			Physical/ infrastructural	

Hazard type is necessary to be considered for the indicators' classification. For example, community resilience index (CRI) uses process and outcome indicators in 43 coastal communities in Indonesia. Also, since every community face specific natural hazards according to its geographic location, it is essential to cope with them and not with all of the hazards.

Temporal scale was taken into account since resilience can be considered as a dynamic quantity that changes over time. Resilience means the ability to recover from (or to resist being affected by) shocks, insult or disturbance. Recovery is a concept which is time-dependent. The indicators within the Pre-hazard event phase evaluate how much the system is ready to face unpredictable event. Indicators related to this phase mainly address the reduction of risks and vulnerabilities. For example, the existence of a mitigation plan is an indicator of this category. The indicators within the emergency response phase describe the ability and the speed of a system to satisfy the initial needs after an extreme event. Examples of these systems can be the fire, police, and emergency relief services which are vital in the first moments of the turbulence situation. Finally the indicators within the category of the reconstruction phase mainly address capacities to cope after a hazard event and measure the ability and the speed of a system to recover to its initial condition. As an example, home ownership, population income, and poverty are indicators which affect the reconstruction phase level. Also, it is possible that some indicators vary between all the temporal scales, such as population, age, etc.

Spatial scale classification emphasizes the importance of quantifying place-specific indicators. In fact, the resilience indicators may refer to a small unit of analysis (e.g. single building unit), or can be related to a whole city or nation. This classification divides indicators according to five classes that must be defined precisely. At the building unit scale, the resilience-based design considerations must be taken into account. For example, access / evacuation potential in buildings depends on the existence of emergency exit. The neighborhood is a part of a town or city, such as city center, immigrants quarter etc. The region is a part of a country that is different from other parts from different points of view, such as northern region, which can include some cities. The indicators in each category (neighborhood/city/region/country) are subsets of a larger group. The classification has been made just to facilitate resilience quantification in a proper scale.

Within the building scale, **building type** is an important issue. Critical/essential facilities are those that provide services to the community and should be operative after a hazard. They include hospitals, police stations, fire stations, schools etc. Examples of indicators which belong to the first group are the accessibility and the special needs for disabled, which are more necessary to be taken into account for essential facilities than residential buildings. This category is inspired from HAZUS information system [35].

The **Level of development** of countries is important to be considered since some indicators, for example, lifelines such as communication, transportation, etc. are all dependent on the country‘s infrastructures condition, which is different in developed and under-developed countries. So this classification affects the resilience assessment because some indicators might not be applied in underdeveloped countries.

Indicators can be also classified according to their **Domains** or perspectives. For example, there are indicators referring to ecological and social-ecological resilience, psychological resilience, critical infrastructural resilience or organizational and institutional resilience [36]. Domains are defined to clarify the field of study of each indicator. Social resilience is the ability of groups or communities to cope with external stresses and disturbances as a result of social, political, and environmental change [37]. Economic resilience refers to the ability of the economy to cope, recover, and reconstruct and therefore to minimize aggregate consumption losses [38]. For example the economic development indicators including financial services, industry- employment services and industry production. Ecological / Environmental resilience is the capacity of an ecosystem to respond to a perturbation or disturbance by resisting damage and recovering quickly, such as biodiversity, water, and air quality etc. [39]. Governmental / welfare/ institutional services are designed to allow an orderly response, in contrast to the more or less spontaneous individual and neighborhood responses to extreme events [29]. For example legal and security services such as police, Emergency, and fire departments. Physical /infrastructural resilience focuses on a community‘s infrastructures, such as transportation, facilities, health care, etc.

Measurement method has been considered as one of the categories in this method, since whenever a description is made, qualitative or quantitative assessments are necessary because some aspects in life cannot be measured and shall be described without a scale. One condition for quantitative indicators, in contrast to qualitative indicators, is that they have to be fully operationalized. For example, the indicator “percentage of citizens with access to a 4G connection mobile phones” is a fully operationalized quantitative/objective indicator, whereas “trust in politicians” is an example of qualitative/subjective indicator covering individual judgment or perceptions.

4. A software tool for resilience assessment

All indicators were added in the software and the corresponding classes/categories were defined for each (I shown in Fig. 3). In the first step, the project is properly defined by choosing the corresponding classes among each of the categories. The output of this step is a list of indicators, which are associated with the project (II shown in Fig. 4).

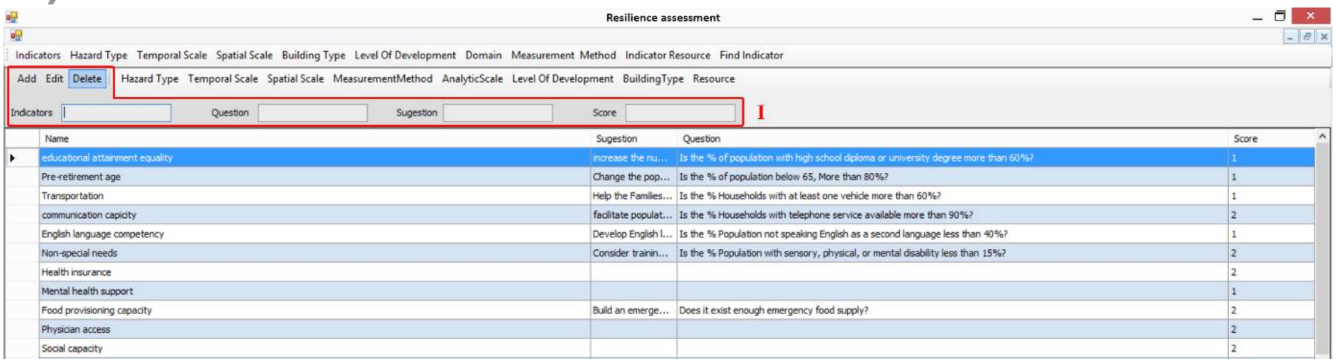

Fig. 3 – Dialog box for defining the indicators and categorizing them.

In the next step, a scoring system is needed in order to assess the resilience status. As the effects of different indicators on resilience are not the same, a coefficient has been allocated to each indicator to consider this difference. An importance factor is assigned to each indicator, ranging from 1 to 2; where 1 indicates low importance referring to secondary indicators, and 2 means high importance which applies to key indicators (III shown in Fig. 4). Key indicators of community resilience can be obtained from different contexts and case studies. Then, according to the provided yes/no questions, each indicator is verified (IV shown in Fig. 4).

The final result is the sum of coefficients of the indicators with positive answers to the questions, divided by the sum of all indicators coefficients. It is calculated as follows:

$$RI = \frac{\sum_{i=1}^{N} I_i \alpha_i}{\sum_{i=1}^{N} I_i} \tag{1}$$

where RI is the Resilience Index, I_i is the importance factor of indicator *i* (2 for high importance indicators and 1 for low importance indicators), a_i represents the answer to the defined question for indicator i (1 if the answer is YES and 0 if NO), N is the total number of indicators.

This result gives an overall view of the state of resilience in percentage and facilitate comparing the state of resilience for different systems (V shown in Fig. 4).

In the last step, the suggestions are presented to the decision-maker in order to develop the resilience of the project without compromising its sustainability (VI shown in Fig. 4).

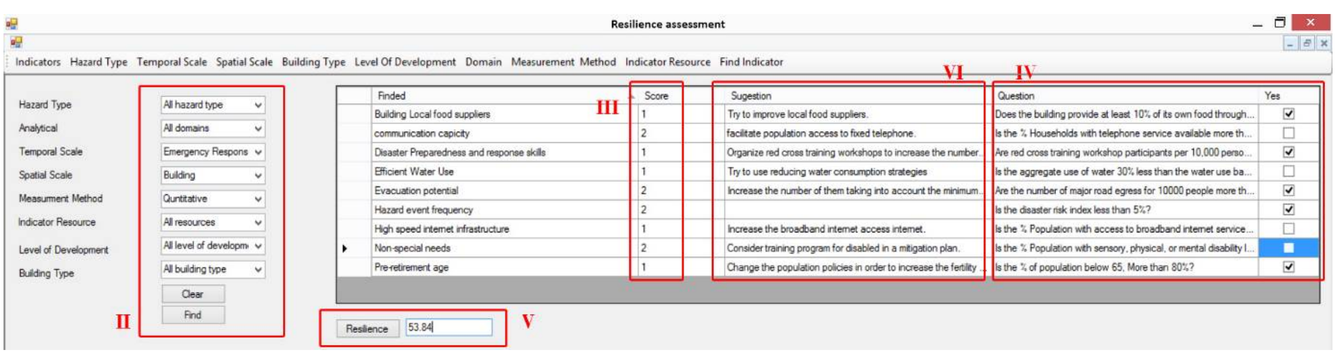

Fig. 4 – Dialog box for defining the project and getting the result.

These suggestions can be useful to enhance the indicators with negative. The suggestions for each indicator could be inspired by previous disaster experiences and case studies. This facilitates the process of resilience improvement. All the given coefficients, questions, and suggestions are defined based on common sense and added or deleted later on.

4.1 Case study; Polytechnic university of Turin, Faculty of architecture (Valentino Castle)

The first step is selecting the relevant classes according to the project. The spatial class in this case study is “building” scale, and as it is an educational center, it belongs to “essential buildings” category. The considered hazard is earthquake and the location of the project is in a developed country. Other classes are not filtered.

Database has been developed using “baseline resilience indicators for communities” and “potential indicators for resilience assessment” presented in emBRACE report [34]. Software output for the case study contains a list of 13 indicators from this database, their importance factor and relevant questions and suggestions (Fig. 5). The answer of yes/no questions prepared for these indicators evaluates resilience of the project, which is equal to 66.66%.

Finded	Score	Question	Yes
Food provisioning capacity	2	Does it exist enough emergency food supply?	☑
Pre-retirement age	1	Is the % of population below 65, More than 80%?	☑
communication capicity	2	Is the % users with telephone service available more than 90%?	☑
Non-special needs	2	Is the % Population with sensory, physical, or mental disability less than 15%?	☑
Disaster Preparedness and re...	1	Are red cross training workshop participants per 10,000 persons more than 5?	☐
Building types	1	Is it a immobile building?	☑
Evacuation potential	2	Are the number of major road egress for 10000 people more than 30?	☐
building stock construction qu...	1	Is the building built after 1997?	☐
High speed internet infrastruct...	1	Is the % Population with access to broadband internet service more than 70%?	☑
Building Local food suppliers	1	Does the building provide at least 10% of its own food through local food suppliers?	☐
Efficient energy use	1	Is the building energy efficiency rating A, B or c?	☐
Efficient Water Use	1	Is the aggregate use of water 30% less than the water use baseline calculated (300 ...	☑
Hazard event frequency	2	Is the disaster risk index less than 5%?	☑

Resilience 66.66

Fig. 5 – Dialog box of software for the case study

5. Concluding remarks

Resilience as a new approach in community development aims to reduce vulnerability and to adapt and recover from extreme events. However, the vagueness of its correlation with sustainability may weaken both concepts. Sustainability and resilience are essential for future cities, while they do not always approach the problem in the same way. Sometimes sustainability and resilience goals, if not examined carefully, can be completely against each other. The paper presents this correlation in different dimensions, including environmental, social, and economic theoretically. To have a deep study of this correlation, both concepts must be evaluated. The lack of a holistic rating system for resilience, led us to propose a method to analyze a project from this points of view (resilience).

An indicator-based approach is used that facilitates the assessment and the decision-making process. As there are many indicators of resilience and they are hard to select, a new categorization has been proposed as first step. In the next two steps, the project is evaluated with the help of a scoring system and proper suggestions are provided based on these scores. The software helps to improve the resilience indicator selection in a specific project by giving these suggestions and showing the effects of each indicator. For example, in the case study provided, if the building energy efficiency would have been developed, the resilience would increase up to 72.22%.

6. Acknowledgements

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