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A NEW DECISION MAKING METHOD TO SELECT PRIORITY INTERVENTIONS AFTER EXTREME EVENTS

Glen Dervishaj[1], **Gian Paolo Cimellaro**[1], **Anil Agrawal**[2]

[1] Department of Structural, Building and Geotechnical Engineering, Politecnico di Torino,
address
glen.dervishaj@outlook.com , gianpaolo.cimellaro@polito.it

[2] Department of Civil Engineering, The City College of New York
address
agrawal@ccny.cuny.edu

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Abstract. *This study proposes the implementation of decision making tools in quantifying and ranking resilience initiatives. The objective of this study was to build a flexible model capable of assessing and ranking any resilience dimension, like initiatives, projects and indices. The model used is in the study is called Simple Multi-Attribute Technique (SMART), the simplest form of Multi-Attribute Utility Theory. SMART offers a simplified and easy to use approach. The benefit of the SMART model lies on how simple the scoring criteria of alternatives and weights of these criteria are established. They can be defined by the decision maker by building a hierarchy and then assign scores to each of them. Otherwise, a set of formulas exist to compare or help the decision maker asses these weights based on the same hierarchy (importance) he previously built. Three criteria were used in the SMART model: Time (the amount of months required or planned to complete a project), Cost (budget for each intervention) and Phase (if the project is either completed or still in planning, design or construction). After evaluating these projects with the SMART model, a comparison was made by assessing the same projects through their functionality curve, which is described by the drop in functionality (the cost of projects was used to describe this value) and the time required to complete a specific project. The study highlights the difference between these two seemingly similar models and their different results to then add a third component of calculation, the Social Impact of these projects. This dimension was added because it was recognized that the output of the previous models only took into consideration their performance, and not their impact in the quality of the urban space they are surrounded by. The case study for this approach was New York City and its ongoing recovery projects post Hurricane Sandy. The projects are part of four main Initiatives: Infrastructure, Buildings, Coastal Defense and Neighborhoods.*

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1 INTRODUCTION

Many studies have found that resilience was first used in the field of ecological studies, and it was introduced by Holling in 1973 **[1]**. The definition given by Holling is the following: "Resilience determines the persistence of relationships within a system and is a measure of the ability of these systems to absorb change of state variable, driving variables, and parameters, and still persist". In other words, ecological resilience is defined as a "characteristic of ecosystems to maintain themselves in the face of disturbance" as said by Adger **[2]**. One aspect of resilience is the speed of recovery from a disturbance, which is different from what we perceive as a "response" that generally describes the direct reaction to impacts **[3]**.

Following what has been stated by Folke **[4]**, resilience of social systems is closely connected to ecological resilience, significantly in cases of communities where the livelihoods of the individuals rely greatly on natural resources. The capability of social systems to adapt and to develop is extremely reliant on the support capability of the encompassing network. Reducing this capability might cause an increase in vulnerability within the social organization. Similarly, the performance of an ecosystem is closely related to the actions of the interlinked social systems, resulting in high and dynamic reciprocity between the two. At the center of these disturbances lies human activity which can have great repercussion in both ecological and social system resilience.

An increased number of Natural and man-made disasters and their respective damage has resulted in the introduction and emerging topic of Resilience. A new dimension that is being attributed now to regions inhabited by humans, specifically dense ones. Cities welcome more than 50% of the current global population and by 2050 that number is expected to increase to 70%. As the population increases, more people will live in large cities. Many people will live in the growing number of cities with over 10 million inhabitants, known as megacities. These large conglomerations suffer an immense number of losses during a catastrophic event.

The most important asset of cities is us, the people living in them. A high concentration of people means bigger cities, complicated infrastructure and infinite number of buildings and public spaces. How is this all related to the risk cities face from disasters? Simply because we can look at cities or areas the same way as we look at our own self. A person being prepared for an unexpected event is the same as a system being prepared for one. There are 4 main drivers that make a person/city resilient:

1. Knowledge/ Awareness (misinformation can cause a great deal of harm in cases of emergency)
2. Training / Experience
3. Resources / Redundancy (how to use these resources and how to manage them appropriately)
4. Plan of Action / Mitigation

These four drivers were chosen based on the generalization between low risk and impact event and the high risk and impact ones. Then we can have a short example on how these drivers are related to each other, the human behavior and the risks we face every day as similar little disturbances like cutting a finger to having an accident or getting an illness. In case we cut a finger, we can just clean the wound, sterilize it and put a bandage. In the next scenario, depending on what kind of accident and impact it has, there would be different measures to take. One might not have suffered an injury or the situation might be critical. In the latter, the help of exterior agents is needed. This is the case for most natural disasters ranging from none to some warning before the impact and with varying damage.

What does this mean for urban resilience? The examples help understand the main factor of these events: their magnitude. Based on the level of impact, different measures can be taken, and the "*treatment*" for the area differs in time.

It is important to understand the risk, exposure, sensitivity and vulnerability of a country in order to be prepared. In the worst case scenario of a catastrophic event taking place, the damage would be extraordinarily big for areas that have no mitigation plans and are not aware of the risk they face. That is why it is of great importance to implement policies and laws regarding disaster mitigation. This will increase awareness and knowledge will be shared between experts and communities to be informed and educated on how to behave during these events. This will also increase the work willing to be put on early warning systems, which play an enormous part in saving precious lives before the event occurs. Take New York for example and the Rockaway community. The New York State issued a warning before Superstorm Sandy for areas like the Rockaway to evacuate their homes since they were the most at risk. What happened is that people felt safe in their homes after they had gone through Hurricane Irene without major damages. A warning had been issued for Hurricane Irene as well and it was said to have a great impact (and it had in general, most destructive hurricane in the US) but this community did not suffer losses. That is why they chose not to evacuate and Sandy hit hard. The damage Sandy caused to the transportation system was considerable everywhere but was extremely unforgiving for the Rockaway community and its only connecting bridge to the land. The people living, in what is defined as a Barrier Island, were stuck for several days after the storm. The only way of moving people from the island and exchanging supplies was by starting a ferry service. The Bloomberg administration started the ferry Nov. 12. 2012 less than a month after the superstorm knocked out A line service to the Rockaways. Subway service was not restored until May 2013.

New York serves as an example not only for its stark particularity but also for its immediate response in terms of actions and policies. It is one of the cities that partnered with ARUP and the Rockefeller foundation for implementing resilient measures in their urban fabric. The US are also part of the nations which have agreed upon and implemented the Hyogo Framework for Action, a blueprint for nearly 173 nations worldwide in disaster mitigation and early warning systems.

The research focuses on the resilience and rebuilding initiatives of the city of New York. The study was conducted partly at the Politecnico di Torino, Italy under the supervision of Professor Gian Paolo Cimellaro and in collaboration with The City College of New York, USA with the supervision of Professor Anil Kumar Agrawal.

The study is based on the work done by the New York City government. Extensive research was put into decision making models and resilience evaluating models. Moreover, previous literature sources related to Hurricane Sandy and the emerging topic of resilience were considered.

One objective of the study is to bring attention regarding the impacts of climate change and on the recovery of communities living in the affected area and describe possible and most “profitable” rebuilding strategies from this perspective.

2 LITERATURE REVIEW

A lot of studies have been made on this topic by experts in different fields. An interesting approach is the one taken by the Rockefeller Foundation and ARUP which define “Urban Resilience as the capacity of individuals, communities, institutions, businesses, and systems within a city to survive, adapt, and grow no matter what kinds of chronic stresses and acute shocks they experience” **[5].** Their work extends to a great number of cities around the world who face natural or man-made events.

The UN have also done an immensely good job in the interesting topic of preparedness and hazard mitigation. Their definition for resilience goes as followed: “The ability of a system, community or society exposed to hazards to resist, absorb, accommodate to and recover from the effects of a hazard in a timely and efficient manner, including through the preservation and restoration of its essential basic structures and functions" **[6]**. Found in the UNISDR Terminology in English document. The work done by the UN, specifically the Hyogo Framework for Action plays a key part in an analysis done in this study. It was decided to use the data from the HFA to build a model with which to quantify the progress in resilience of countries around the world. This part will be expanded upon on a separate chapter below.

In summary, Resilience can be defined as "the ability of a system to cope with change" **[7]**. Walker highlights the importance of including a great number of different stakeholders, especially the common and ordinary people, very early in the phases of assessment in order to get a realistic view of the local conditions **[8]**.

Nowadays assessing resilience, at different levels, can be done using a number of different tools. Many methods focus on the capacity to adapt, or bounce back which in itself is a difficult task. In order to learn and adapt, a look back at the history of hardships a community has been through is required. By doing so, we can acquire a better idea on what the response and level of adaptability of that specific community is. It is however apparent that certain problems and difficulties are predominant in different parts of the world simply because communities (areas) are not affected by similar events or problems. This aspect can be analysed and expressed in different methods. One of these is by looking at migration.

Mobility can be considered as a significant sign of the resilience of a community. If this shift is done at a bigger scale, then mobility can mark vulnerability which can then translate to negative effects on both areas. In some rare cases, this phenomenon can be positive or improve resilience only if it is generated by positive pull factors of the receiving area.

As it can be observed, the complexity of resilient systems and mobility highlights the need for increased basic resilience of any place.

A system should be resilient at any times, before the migration in order to withstand change. An important factor at play here is diversity, in terms of economic options and social opportunities since it encourages learning and adaptation.

Diversity, in many aspects, affects the community, its properties as well as its level of resilience. Folke presents another key aspect which is local knowledge and community participation in studying a certain case **[4]**. This can be accomplished simply by taking advantage of the previous experiences of the local communities regarding natural resource management. This will then play a key role in this work as the framework proposed at the city level strongly endorses the participation of various stakeholders. Although the above are related to economic and social resilience, quite a few concepts can be applied to any type of **resilience, like awareness, preparedness, resourcefulness, robustness, adaptability** and the ability to learn.

Public institutions on the other hand have the ability to empower an environment and practices that improve resilience. They have a major contribution in developing an equitable distribution of resources among populations, economic growth (coupled with stability), all these factors can possibly have a big impact on augmenting local resilience. Managing the social-ecological systems is if truth be told a very important part in increasing their resilience as long as the various stakeholders within the system are included as well. It is so established that the role of institutions in increasing social resilience is vital, as they incorporate all social systems and control the distribution of asset

An interesting aspect brought up is that short-term management efforts, could lead to a loss in the long-term plan and development of a systems resilience **[4]**. Additionally, they also emphasize that not measuring the impacts on the ecological system, could have a negative outcome and weaken the resilience of the whole system, if it is combined with efforts that do not take the interdependence of both the social and ecological systems adequately into consideration. This is predominantly true in cases where the system is considerably fragile. Another key characteristic to keep in mind when considering the management of these systems, regarding resilience obviously, is focusing more on long-term actions and development.

Since achieving resilience is so complex, future plans should aim to increase resilience of the entire system and not only of individual components. One of the biggest challenges and important factor is uncertainty. The effect that humans will have, climate change and other unpredictable factors, pose a big problem in predicting what will happen **[8]**. It should be noted that the social resilience of a system is not equal to its individual components. Increasing resilience does not mean that vulnerability decreases, at least not for all stakeholders.

3 APPLYING DECISION MAKING METHOD CONCENPTS IN RESILIENCE

This chapter describes the methodological approach of this work. It details the specific technique used and concludes with a comparison of the results.

The city of New York took immediate action following Hurricane Sandys landfall. A great number of initiatives and strategies were devised in order to mitigate and rebuild from the storms rubble. The aim of this study is to propose a simple methodology that would help understand the advancement of this process. This study will be helpful for stakeholders, decision makers, and communities alike.

The decision maker's aim is to improve the services associated with the preferences and habits of the users. Therefore, the need for a tool that can describe which action would benefit more a certain region is required. In this study, the tool that has been chosen to accomplish this feat is the SMART model. The reason for using this model lies in a few reasons. Firstly, it was an objective of the study to find a way of processing, describing and evaluating projects in a weighted and reasonable manner. During the literature review and state of the art on resilience, quite a lot of assessment methodologies were found by different authors. There is actually a very long list of techniques. Considering the difficult and lengthy process of assessing resilience, as well as the fact that most of these techniques are not flexible to various situations, it was decided to find, adapt or build an easy to use and understand methodology. Its aim is to be able to evaluate and describe a number of parameters, projects or any form of resilience indicators. A research on decision making methods with the above intentions in mind led to consider the multi criteria methods. Afterwards, the SMART technique was chosen as the most appropriate and interesting method to try and put into use in the context of resilience.

The SMART technique presented itself as precisely an easy to use, adaptable and flexible method, capable of evaluating different criteria, in this case various projects, in which weights could also be attributed to the measuring criteria. Some background on these tools and on how the SMART model was used for the purpose of this study is given below.

The tools and techniques are used for selecting or proposing the "best" or more convenient choice. Decision making tools are used and find applications in many different fields. A topic which could benefit from the aforementioned tools is Resilience.

Baker et al., provide some context on some aspects of decision making that include goals, criteria, requirement and problem definition **[9]**. In order to reduce the possible disagreement of the above elements it is suggested that the first steps of decision making should be deciding who the decision makers and stakeholders are. A step by step overview regarding a general decision making process is: 1) Define the issue, 2) Determine requirements, 3) Establish objectives, 4) Identify the possibilities, 5) Define the evaluating criteria, 6) Choose a decision making tool, 7) Assess the alternatives based on the established criteria, 8) Check that the chosen alternative is actually a solution to the issue established at first.

It is vital to form distinction between the cases whether or not we've one or multiple criteria (Fülöp 2005) **[10]**. In some cases, there might be one criterion, either kilometers per hour, cost, color, time or whatever the criteria of that case is set to be. Then the choice is easily done by choosing the highest value for that criterion.

When it so happens that we have a determined number of criteria and the number of alternatives is theoretically infinite then the decision is made with what is called multiple criteria optimization.

In summary: “Decision making is the study of identifying and choosing alternatives based on the values and preferences of the decision maker. Making a decision implies that there are alternative choices to be considered, and in such a case we want not only to identify as many of these alternatives as possible but to choose the one that best fits with our goals, objectives, desires, values, and so on.” **[11]**.

A problem of multi-attribute decision making has two main elements, the criteria and alternatives that have been chosen to be scored. As we will see below and also in the SMART model further, a common feature of these methods is the so called *decision table*. On the rows of the table there can be found the criteria and on the columns the score of for each alternative is listed. Scores represent the performance of that alternative in a given criterion.

Firstly, weights are assigned to each criterion based on their importance. There are different methods to develop these weights, some easier than others. More importantly weight distribution is a key aspect of these methods as it has a big influence on the results. These weights can be calculated with formulas or they can be agreed upon between the decision makers, the decision makers and stakeholders or as part of the personal sensibility.

Then the final scores for each alternative is calculated as a product of the performance of each alternative on the criterions and their associated weights. Usually, higher ranking value means a better performance of the alternative, so the alternative with the highest ranking value is the best of the alternatives which is also the one that should be picked at the end unless further considerations are made.

These methods have the ability to partly or entirely rank alternatives. In one case, the best and preferred alternative can be chosen. In other cases, it can be opted to choose from a list of the best performing alternatives.

3.1 SMART model

This section introduces the Simple multi-attribute rating technique (SMART), developed by Edwards **[1]**. The objective is to help decision makers understand the advancement and benefits of certain initiatives, strategies or activities in the field of Urban Resilience. The model allows various stakeholders to take into consideration which policy or action is most appropriate in each case, as well as providing information on the budget, timeframe and state of operations. Assigning weights to each criteria is also achieved through an easy process that reflects the relative importance of each criteria. A hierarchy of importance is established by the decision maker. Generally, 10 points are assigned to the least important criterion. Afterwards, the next criterion is assigned more points and this operation is repeated for each criterion. The final weights are obtained by dividing the total by the sum of the points and normalize it to one.

The SMART model is part of the Multi-Attribute Utility Theory (MAUT). It describes the simplest form of the MAUT technique. The model is used when evaluating the performance of various attributes by assigning multiple criteria. The values associated to the criteria can be both qualitative and quantitative. Once the objectives and criteria have been identified then it is required to give weights to each criteria. The utility U_j (final score) of the alternatives is computed as the total sum of the criteria (dimension) score multiplied with the weight of the same criteria. The values for each dimension can usually be expressed in a linear function by setting minimum and maximum rules. Edwards supposedly proposed a ten step technique. An overview of these steps has been already given by These steps are very similar to the steps of a general decision making tool with the presence of weights as the main difference and the way the scores are assigned. Adopted by Olson **[12]** these ten steps are: 1) Identify the decision-maker(s), 2) Identify the issue of issues, 3) Identify the alternatives, 4) Identify the criteria, 5) Assign values for each criterion, 6) Determine the weight of each of the criteria, 7) Calculate a weighted average of the values assigned to each alternative, 8) Make a provisional decision, 9) Perform sensitivity analysis 10) Decide. Depending on the desired result, the alternative with the highest final (utility) U_j score should be selected.

SMART is the simplest form of the MAUT methods. There are a few ways of giving ratings to alternatives in SMART, considering the ordinary scale of a given criteria. In SMART rating criteria scales are converted to a general inner scale. This is done for the sole purpose of differentiating between the alternative rating and the criteria weighting. This is primarily done by using a Value Function. As a simple and quick rating method, SMART uses the easiest and most common of a value function: The additive model which is applied using a linear. Usually ratings are set going from 0 to 100 and then normalizing where appropriate or desired **[13]**.

3.2 Applying the SMART model to the resilience projects in New York City

In the case of New York and the advancement of the strategies for resilience, the goal is to put into perspective and show the relation between different initiatives, as well as ranking them. Using the SMART model gives us the opportunity to get a better understanding of how the city has done so far. Our objective are the initiatives. The measuring criteria identified in the study are: the cost of each project, the timeframe required to complete these projects and finally, the current state operations (phase).

The benefit of the SMART technique is that it possesses great flexibility. For example, the weights of each criterion are easily determined by the decision maker and can also be easily changed in further stages based on the sensibility of other users, may that be a government, a mayor or another person interested in the particular development of his area. After assigning weights, the next step is using the data available to evaluate the initiatives and their performance in the present moment.

In order to give values to the initiatives it is required to develop an attribute scoring rule used to set system utility values. To establish the values, some rules or preferences need to be created. For example, it was decided to give scores from 0 to 1. Regarding Cost, the higher the investment, the higher the score achieved. For the criterion Time, the less time it took for a project to be completed, the higher the score achieved, whereas an extended duration of the operations would assign that initiative a lower score. Phase, the last dimension (criterion), was set in a way to describe and ground furthermore the final results.

Specifically, in this case study the data was obtained by the OneNYC Report provided by the state of New York. The dimensions and scoring rules mentioned above were tailored to the data found in this report. However, the bulk of the data was extracted online by the interactive and up to date map at https://maps.nyc.gov/resiliency/. Firstly, an overview of the data was required. Analyzing the minimum, maximum, average and other various patterns found in the data. This step was crucial for setting the rules of the scoring technique.

The resiliency projects started around New York City are established as the alternatives. The next step in building the SMART model is identifying the dimensions by which to evaluate these alternatives. As already mentioned the dimensions (criterions) are: Budget (Cost), Time and State of Operations (Phase). Afterwards, the weight of each of the dimensions should be established. There are a couple variations on how to properly weight our criterions.

However, in this study, it was chosen to rank the dimensions first, and subsequently assign “importance” to them. The hierarchy for evaluating the project is as follows:

$$\text{Time} > \text{Cost} > \text{Phase}$$

This ranking puts the criterion of Time as the most significant. Once this priority ranking is set, the least important criterion is assigned a rating of 10. The other ratings are decided starting from this base value. Cost and Time were assigned a rating of respectively 20 and 35. The weight associated to each of them is each rating divided by the total. This allows the normalization of weights so their sum amounts to 1. After performing the divisions, the weights (W_i) for Time = 0.54, Cost = 0.31 and Phase = 0.15 are obtained.

The next step in completing the model is giving scores for each project. The scoring values were decided by analyzing the data available in order to reflect a fair final score. Rules for all criterions were set. Each different from the other. A simple calculation that normalizes the time each project was completed (or expected to be completed) was chosen for the Time criterion, on the other hand for scoring projects related to their Cost and Phase criterion, it was decided to build scoring tables respectively (Table 1 and Table 2).

It was observed that the longest project planned to date has a duration of nearly nine years. Based on this observation, it was decided that a value of 0 would be given for periods equal or longer than ten years. The available data is provided in four quarters, yearly three-month periods denoted as Q1, Q2, Q3 and Q4. For the purpose of this study, the completion date corresponds to the last month of the quarter. Rebuilding and recovering is considered to have started right after Hurricane Sandy made landfall October 28th, 2012. For example, the project *"World Trade Center Command Repairs"* was completed the first quarter of 2013 (Q1 2013) so the project had a lifespan of roughly 3 months until its completion. Projects finished in the same quarter as the disaster, specifically the last quarter of 2012 are assigned a value of 1. The scores are obtained with the following equation:

$$S_{jt} = 1 - \frac{t_j}{t} \tag{1}$$

Where S_{jt} is the score of the time criterion of each project, t_j is the time the project is completed or is expected to be completed and t is the longest period considered for calculation (in this case ten years).

Score	Investment in millions of USD
0.1	0 - 1
0.2	1 - 5
0.3	5 - 10
0.4	10 - 15
0.5	15 - 20
0.6	20 - 30
0.7	30 - 42
0.8	42 - 55
0.9	55 - 70
1	70+

Table.1 Scoring table used for evaluating the Cost criterion

The next criteria is budget. The scoring method related to cost is approximately the same as the above but with a few variations. For example, an investment is given a score of 1 if the cost is equal or higher than $70 million. The rules for the values were decided based on a couple observations. The average investment per project resulted to be near $15 million, that is why the breaking point between a score of 0.4 and 0.5 is at $15 million. Afterwards, the difference between the score and the amount invested increases slightly until it reaches $70 million. It was also decided to give a score of 1 for projects with investments upwards of $70 million, which are limited in number.

Finally, a simple scoring technique was attributed to the last dimension of Phase (State of Operations). The projects are divided into four categories: currently *Completed*, still in *Con-*

struction, in the *Design* phase and lastly, still in the early *Planning* phase. The scores (S_{ip}) for each are shown in the table below.

Phase	Score
Completed	1
Construction	0.75
Design	0.5
Planning	0.25

Table 2 Scoring table for the State of Operations (Phase)

The rules for scoring each alternative are now established. The next step is filling out the table of all the projects in Manhattan.

After an overview of the data, the scores for each projects were compiled with the method described above. A comprehensive table with the weighted scores of each criterion and the results of the top ten scoring projects can be found below in Table 3. The equation with which the final scores are attained is the following:

$$U_i = \sum W_i S_{ij} \tag{2}$$

Where U_i is the final score of the projects, W_j is the weight of the j criterion and S_{ij} is the score obtained by project i in criterion j.

The last step would be to analyze the result and draw conclusions from the weighted scores. The demanding part of this stage is the critical thinking and brainstorming process so that decision makers take actions accordingly. With these results there is room to rank the projects by their effectiveness. The same method can be used in various case studies, depending on the desired result.

Project N.	Category	Time	Budget	Phase	Score
Project 7	Buildings	0.54	0.21	0.15	0.91
Project 6	Buildings	0.54	0.09	0.15	0.78
Project 9	Buildings	0.51	0.09	0.15	0.76
Project 6	Infrastructure	0.40	0.18	0.15	0.74
Project 3	Infrastructure	0.54	0.03	0.15	0.72
Project 10	Infrastructure	0.54	0.03	0.15	0.72
Project 5	Buildings	0.54	0.03	0.15	0.72
Project 8	Buildings	0.54	0.03	0.15	0.72
Project 12	Buildings	0.54	0.03	0.15	0.72
Project 4	Infrastructure	0.52	0.03	0.15	0.71
Project 2	Coastal Defense	0.52	0.03	0.15	0.71
Project 4	Buildings	0.52	0.03	0.15	0.71
Project 7	Infrastructure	0.51	0.03	0.15	0.69
Project 4	Coastal Defense	0.51	0.03	0.15	0.69

Table 3 Final scores and ranking

It is apparent from the table above that the highest ranking projects are the ones that have already been completed. The completed phase itself doesn't play a big role in the end result as it is only weighed at about 15% of importance in relation to the other three dimensions. Most importantly, the pattern at which the top projects are distributed is related to obviously *Time*. The amount of time it takes for a project to be completed was the most important factor in the calculations and bears a great importance in the final ranking. This can be easily demonstrated by the vast difference projects have in relation to their budget. The amount of money invested differs greatly between the highest ranking projects. Specifically, the recovery of 110 William Street (Project 7) in the Buildings category is ranked number one. The reason behind this is the very quick period of completion as well as a gigantic budget. The project was completed in the last quarter of 2012. The same quarter Hurricane Sandy hit the city of New York. Also, the comprehensive budget of the project was of nearly $37 million. Situated in the Financial District of Manhattan the building is of great importance for the New York City Economic Development Corporation. Currently restored, the building is being rented at the present moment. It is interesting to note that a great number of financial buildings of this district were planned to be upgraded and transformed into residential buildings or hotels. The reason for this change was primarily the flooding risk and problem these types of constructions have. A very similar phenomenon has happened once before in Downtown Manhattan after the 9/11 attack. Regardless, the work detailed in the report for this project was described as *"re-energizing all electrical systems after weekend emergency shutdown"*

Project 7 is directly followed by Projects 6 and 9. Both of these projects have similar properties to their competitor since they were also completed in the last quarter of 2012. The biggest difference between these three projects is their budget. While projects 6 and 9 had investments of $5 million and $6 million dollars respectively, project 7 had the enormous amount of $37 million. There is a clear pattern that is observed in every subsequent project. The results show that the final score and ranking is primarily based on the response time. These results agree with our premise, which valued the necessary time of operations as the top priority. Then, the rankings vary slightly here and there based on the budget.

3.3 Comparison with the Functionality Index

This section describes and compares the results from above (Smart Index) through the use of the functionality curve of resilience. It was decided to build the "functionality" curves of resilience for selected projects (specifically only projects that are part of the Infrastructure initiative) considering only two parameters, respectively Time and Cost. The data has been interpreted as Cost being the drop or "damage" sustained by the system at the start of the event (Y axis). On the X axis there is Time, or the period required to finish a project from the time Sandy hit New York. Based on the results from the SMART model it was established a Time of control - T_c which expresses the worst case scenario, the project that is planned to take most time to finish. In this work it was chosen to use only projects of the Infrastructure initiative because this sector is regarded as the most important for the City of New York.

Project 21 is the one expected to finish last after nearly 9 years of work (2021). Alternatively, Project 3 is recorded as the fastest to completion. Same as Project 10, they both finished in the fourth quarter of 2012, right after the storm had hit. Instead, Project 6 was the best performing project as calculated by the SMART model. Results vary but are similar to the SMART technique which proves the efficiency of the methodology. The main difference between the two methods is that when using the decision making tool and its weighting factors, then the projects with the highest score in the most important criteria would float to the top of the list. Also, we can notice that even though two of the criterions are the same in both calculations, the difference in ranks comes from SMARTs weights, which play a big role in the final score.

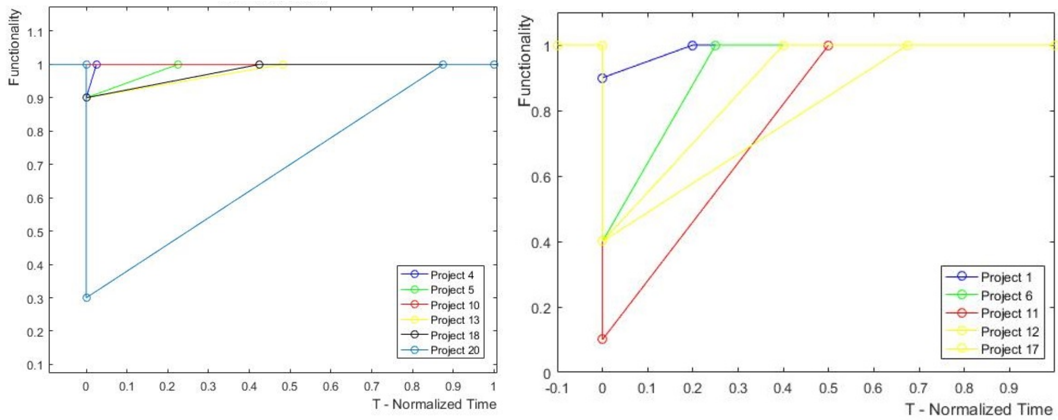

Figure 1: Functionality curves for some projects. Curves for “facilities” (left), citywide infrastructure projects (right).

Curves were calculated for all the remaining infrastructure projects and a new rank was obtained by measuring resilience as the area under the curve. These results are illustrated in the next section alongside the SMART results and the combination with the Social Impact.

3.4 Urban quality of spaces

The value of spaces is always defined by the location, history, peoples cultural background of the place, function, size and purpose. Therefore, the quality assessment of Urban open areas cannot and should not be generalized. A simple example of the concept is found between the difference of noisy and quiet places. Both of them are enjoyable if they are situated in the right context. People expect tranquility and peace from a remote park, so the park needs to be a quiet, private place. It depends what mood it was made for and what the community is looking for. The key part of understanding what the goal must be is to interact with the community. These differences can be observed in most cities when you travel near a university or school, where the services and environment around those areas is much different from other places. Also, a small and well curated private park inside a neighborhood doesn’t have the same impression as a big public park. Landscape Architects certainly play a key role in planning and analyzing urban spaces.

Open spaces like commercial centers have a different distribution and services compared to a space within the city or an office complex. Architects and planners play a big role in giving environments they build the appropriate character. If public spaces are so important to our existence, then it means that humans and/or whole communities receive an even bigger hit when disasters occur. They could be stripped of their homes and at the same time of their favorite place to either work, play or just spend some hours of the day. This consideration was in fact made after the results achieved by the decision making tools. It seemed apparent that none of the methods took into consideration what social impact each of the projects would have on the community. It comes from an easy concept that a resident will “mentally heal” faster and be more resilient if public spaces of importance where restored and improved upon after an event like Hurricane Sandy.

There is a considerable amount of sustainability indicators nowadays. Nonetheless, for the purpose of this study, attention was turned towards qualitative aspects of the urban fabric. That implies that the main focus was finding attributes that attracted people to places. With those attributes, a new Social Impact Index will be introduced. The purpose of this new Index is to create a new rank of the Infrastructure projects. This ranking would now be influenced by attributes that express a community's interest. Contrary to the previous methods where only the performance of the projects themselves was taken into consideration.

An interesting study related to an urban quality like walkability was used for supporting this new index. The study tries to implement a scoring sheet of various qualities connected to walkability.

New York City is one of the most populous cities in the world with a population of more than 8 million people in its five boroughs (as of 2014, recorded by city-data.com). Not only, but an extremely large amount of tourists visits the city every day. This makes it difficult to actually measure which places should be prioritized either in finishing first or which projects would have the most impact.

The study on walkability was particularly interesting because it makes possible evaluating places by their intrinsic property and not by the actual flow of people. An area with high walkability attracts a higher number of people. Improvements on these places would affect a great number of people in a more meaningful way.

The five attributes that will be used to assess walkability and be combined into forming the Social Index (SI) are adopted from Ewing **[14]**:

- Imageability: Imageability is the quality of a place that makes it distinct, recognizable, and memorable. A place has high imageability when specific physical elements and their arrangement capture attention, evoke feelings, and create a lasting impression.
- Enclosure: Enclosure refers to the degree to which streets and other public spaces are visually defined by buildings, walls, trees, and other elements. Spaces where the height of vertical elements is proportionally related to the width of the space between them have a room-like quality.
- Human scale: Human scale refers to the size, texture, and articulation of physical elements that match the size and proportions of humans and, equally important, correspond to the speed at which humans walk. Building details, pavement texture, street trees, and street furniture are all physical elements contributing to human scale.
- Transparency: Transparency refers to the degree to which people can see or perceive what lies beyond the edge of a street or other public space and, more specifically, the degree to which people can see or perceive human activity beyond the edge of a street or other public space. Physical elements that influence transparency include walls, windows, doors, fences, landscaping, and openings into midblock spaces.
- Complexity: Complexity refers to the visual richness of a place. The complexity of a place depends on the variety of the physical environment, specifically the numbers and kinds of buildings, architectural diversity and ornamentation, landscape elements, street furniture, signage, and human activity.

Based on the above assumptions a measurement of all five properties was conducted. The scoring criteria is divided by levels. It was decided to have the following levels: Maximum, (highest attainable score in that particular quality) assigned a value of 1, High, assigned a value of 0.75, Medium, assigned a value of 0.5, Low, assigned a value of to 0.25.

Imageability is estimated by taking into consideration a few aspects of the area. In general, places with no character have no imageability. On the other hand, places with high imageability are recognizable and memorable. This can be achieved with the presence of architecture that suggests importance, presence of historical buildings and landmarks. This quality of urban spaces is not limited to these rigid forms, in fact, places with distinct views that make it memorable are also considered. Lastly, the main component of imageability is the answer to the question: "is the place unique?"

Enclosure can be seen as how well defined a space is and it is altered by different building heights and levels. Continuous edges provide enclosure. A busy street with old trees with large canopies can make otherwise low enclosed places more enclosed. These elements contribute to the room-like feeling of the space.

Human Scale is the presence of people and activity, presence of street furniture, protection from traffic, focus on street level. Cafes on both sides of sidewalk increase human scale as well as the presence of stores and activities that invite you in.

Transparency is the sense of what's going on inside the buildings that surround you. This is influenced if buildings are so far back from street edge that you cannot have a clear view. Like Human Scale, continuous exposure to uses that are clear and accessible also plays a role.

Complexity is hard to measure but there are a few indicators of a complex space. For example, a block with one building is less complex than a block made of several buildings. Having many people on the street/plaza add to complexity. Overly controlled design makes a place less complex; you lose complexity with predictability. Like previous qualities, complexity is higher in places where human activity with various uses is higher.

I – Imageability, E – Enclosure, HS - Human Scale, T – Transparency, C – Complexity

	I	E	HS	T	C	Total	Normalized
Project 1	0.50	0.50	0.50	0.50	0.50	2.50	0.50
Project 2	0.50	0.25	0.25	0.25	0.25	1.50	0.30
Project 3	0.75	0.25	0.25	0.25	0.25	1.75	0.35
Project 4	1.00	0.75	0.50	0.25	0.75	3.25	0.65
Project 5	0.25	0.25	0.25	0.25	0.25	1.25	0.25
Project 6	0.50	0.50	0.50	0.50	0.50	2.50	0.50
Project 7	0.50	0.75	0.25	0.25	0.50	2.25	0.45
Project 8	0.50	0.25	0.25	0.25	0.25	1.50	0.30
Project 10	0.25	0.50	0.50	0.25	0.50	2.00	0.40
Project 11	0.25	0.25	0.25	0.25	0.25	1.25	0.25
Project 12	0.25	0.50	0.25	0.25	0.50	1.75	0.35
Project 13	0.25	0.75	0.50	0.50	0.50	2.50	0.50
Project 15	0.50	0.50	0.50	0.50	0.50	2.50	0.50
Project 16	0.25	0.25	0.25	0.25	0.25	1.25	0.25
Project 17	0.50	0.50	0.25	0.25	0.50	2.00	0.40
Project 18	0.50	0.50	0.25	0.25	0.50	2.00	0.40
Project 19	0.50	0.50	0.75	0.50	0.50	2.75	0.55
Project 20	0.25	0.25	0.25	0.25	0.25	1.25	0.25
Project 21	0.25	0.25	0.25	0.25	0.25	1.25	0.25

Table 4 Summary of values attributed to each urban quality per project

Both the combinations of the SMART and Functionality Index with the new index proved to give yet again a new insight on the results. Obviously, the highest ranking project in the latest table is an area with an enormous amount of people walking by every day. The difference in ranks and the final results proves that it is very hard to express resilience as a whole with only one technique. That is why during this study, a comparison with the Functionality curves was needed and at the end a combination with the social impact (importance) of projects.

Project N.	SMART Index	Functionality Index	SI	SMART x SI	Fun x SI
Project 4	0.708	0.869	0.65	0.46	0.56
Project 6	0.741	0.795	0.50	0.37	0.40
Project 7	0.694	0.868	0.45	0.31	0.39
Project 1	0.613	0.860	0.50	0.31	0.43
Project 10	0.721	0.870	0.40	0.29	0.35
Project 3	0.721	0.870	0.35	0.25	0.30
Project 19	0.402	0.745	0.55	0.22	0.41
Project 12	0.623	0.750	0.35	0.22	0.26
Project 15	0.429	0.755	0.50	0.21	0.38
Project 13	0.423	0.846	0.50	0.21	0.42
Project 2	0.644	0.850	0.30	0.19	0.26
Project 8	0.613	0.860	0.30	0.18	0.26
Project 17	0.437	0.668	0.40	0.17	0.27
Project 18	0.417	0.849	0.40	0.17	0.34
Project 11	0.662	0.645	0.25	0.17	0.16
Project 5	0.600	0.859	0.25	0.15	0.21
Project 20	0.360	0.566	0.25	0.09	0.14
Project 16	0.326	0.805	0.25	0.08	0.20
Project 21	0.205	0.783	0.25	0.05	0.20

Table 5 Combination of the SMART Index and Functionality Index with the Social Index (Rank by SMART x SI)

4 CONCLUSIONS

The objective of this research was to build and express progress made by different entities regarding resilience. Firstly, the importance and meaning of resilience nowadays in the urban context was established. Afterwards, the study explored a new methodology on how to quantify resilience at different levels.

As per the objective of this research, attention was turned to the level of a single city. The chosen case study was New York City, a thriving economic and cultural conglomerate. The results of the methodology, accompanied by a comparison with another model, proved to be very descriptive of the priorities of stakeholders.

The last part of the work was focused on the development of a framework capable of measuring and ranking the actions that were taken by the City of New York after Hurricane Sandy. The selection and attainability of good data created a problem in the first phase of the framework. After a review of various methodologies, it was decided to use the SMART model, a decision making technique, as the quantifying methodology.

A few considerations should be made about the choice and value of this model. It was mainly chosen for its adaptability, a key component of resilience as well, since it is believed that it can be the foundation for an easy to use tool by everyone. In evaluating resilience and the impact that spaces have, it is of great importance to try and involve a considerable amount of diverse stakeholders. In doing so, a larger amount of information is available which then contributes towards building a more precise model around each different case.

The possibility to add or remove criteria freely, assign scoring criteria based on the objectives of the study, area or sensibility of the decision maker and the capability to develop weights either by formula or by preference of the decision maker, it allows the SMART model to be flexible to a great number of applications. Contrary to what it might be expected, another positive aspect of the model is the fact that it is sometimes more precise and descriptive than MAUT methods which are complicated to use and cannot be applied by everyone. This in turn, is a big plus for an easy to use technique such as the SMART model.

The justification of the SMART model lies on how simple the scoring criteria and weights of these criteria are established. They can be defined by the decision maker by building a hierarchy and then assign scores to each of them. Otherwise, a set of formulas exist to compare or help the decision maker assess these weights based on the same hierarchy (importance) he previously built. Three criteria were used in the SMART model: Time (the amount of months required or planned to complete a project), Cost (budget for each intervention) and Phase (if the project is either completed or still in planning, design or construction).

The last aspect that the study approaches is the importance at the urban, social dimension of the projects. It was noted that in a busy city like New York, different aspects come to play when quantifying the importance of public spaces. This new dimension, Social Impact, was implemented to be combined with the results from SMART and Functionality Index.

This last step proved as difficult to achieve as it is interesting. Measuring the quality of urban spaces was as demanding as measuring resilience. Nonetheless, the process and considerations made in order to assess this dimension proved to be more interesting and/or important than the final rankings as it also brought to light a couple inconsistencies regarding the procedure of work in New York such as the delayed completion of the update and repair of the Hospital.

The study at the end offers an understanding of how long-term resiliency can be measured and optimized through planning and easy to use models of decision making through the participation of various stakeholders. In most developed countries there is a certain level of emergency response that takes place strictly after a disruptive event. In most cases though, rebuilding and adapting is a long process especially after a powerfully impacting event. That is why this kind of approach puts into perspective not only future projects but also preventive measures for existing structures.

The research highlights the difference between these two seemingly similar models and their different results to then add a third component of calculation, the Social Impact of these projects. This dimension was added because it was recognized that the output of the previous models only took into consideration their performance, and not their impact in the quality of the urban space they are surrounded by.

The case study for this approach was New York City and its ongoing recovery projects post Hurricane Sandy. The projects that were used in this work are part of four main Initiatives: Infrastructure, Buildings, Coastal Defense and Neighborhoods.

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