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Creating a methodology to assess climate change adaptation capacity of residential infrastructure.

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Abstract: Extreme weather catastrophes have been rising in the past years, as well as the global population that lives in cities. Therefore, we must prepare for the future through systems that help us measure the level of preparedness our infrastructures have to withstand threats related to climate change. A methodology was implemented to design a climate change adaptation evaluation framework for residential infrastructure, which consists of a versatile and straightforward Excel-based tool. The tool shows promising indicators of being a useful instrument to understand climate change-related threats that may affect a dwelling according to location, typology and, inputs such as construction, context and other factors. Areas for improvement are mainly related to input data and its preciseness, the correct interpretation of input selection and the representation of risk in percentage form, which could be questionable.

Keywords: Climate change, Adaptation, Metric, Methodology, Infrastructure.

1. Background

Over the past 40 years there has been a sustained increment of climate change related environmental threats, leading to a 210% increase of catastrophic events globally (Munich Re, 2017). It is therefore crucial to consider how this intensification of extreme weather events will affect our cities and the places we inhabit, directly altering our welfare. The intensification of weather events such as extreme heat waves, urban flooding and wildfires, will have a direct impact on the built environment, in terms of exposure to overheating and potential flooding or burning of buildings and infrastructure, among other consequences.

Climate change mitigation can be simply described as the implementation of activities that reduce GHG emissions to the atmosphere (IPCC 2020), therefore reducing the potential effects of climate change. On the other hand, climate change adaptation encompasses the alteration or transformation of systems or processes in order to better withstand current or future climate change related impacts (UNFCC 2020). Climate adaptation is vital in attempting to deal with the climate change problem, as its implementation can be extremely necessary in terms of protecting our livelihood.

2. Creating a tool to assess climate adaptation

The research question that arises is; how can we measure the climate adaptation capacity of residential built environment projects in order to assess and estimate the ability of infrastructure to withstand climate change consequences?

The objective of the research is to create a methodology that allows understanding how a built environment project, specifically a residential structure, is prepared to face climate change consequences.

There have been several efforts to generate these systems, ranging from government initiatives in the United States such as the Resiliency Council (USRC, 2020) and the HAZUS platform (FEMA 2020), to private-led rating systems (RELI, 2020) and several others. These platforms mainly attempt to that assess the dangers to which certain regions are exposed in terms of natural disasters.

Similarly, the 'ThinkHazard' platform (THINKHAZARD, 2020) consists of a database of cities which indicates the risk level to which they are exposed to such threats. The tool informs specific levels of danger, along with relevant information for each threat. Hence, in the design of the adaptation tool, it was considered useful to incorporate the database of the 'ThinkHazard' methodology. However, the tool should also allow the assessment of risks at the built environment level. Similarly, to the 'ThinkHazard' and depending on the specific city to be analysed, the adaptability tool adopted a risk level associated with different natural disaster. The tool considered a numerical scale ranging from '0' to '4'. While level '0' expresses the absence of risk, level '4' expresses the highest risk possible.

2.1 Threats

The tool considered the natural disasters or threats that are not linked to climate change (i.e. earthquakes). Likewise, those natural disasters that do not imply a considerable or measurable consequence to housing infrastructure (i.e. drought) are also disregarded.

2.2 Infrastructure characteristics

The tool took into consideration the specific characteristics of the dwelling and created a new numerical scale. This allowed having a point-based scale, where the maximum available points would constitute the highest possible risk for a specific threat. Therefore, the different input data for the evaluated dwelling will result in a greater or lesser amount of points, depending on the risk level associated with that particular threat. Finally, this scale can be translated into a percentage, where the worst possible scenario (i.e. where the greatest possible danger conditions are met according to the selected inputs) would lead to the highest risk.

The tool was subdivided into three the different stages (Figure 1):

- *Stage 1:* In this stage, based on the 'ThinkHazard', the user selects the location for the project, and urban risk levels are collected from a database operating in the background of the tool.
- *Stage 2*: Once the location has been selected, the user proceeds to the second stage, which consists of defining the type of housing to be evaluated. From this point on, the numerical risk values delivered on Stage 1 is amplified, maintained or reduced, according to the dwelling type chosen and the threat being evaluated.
- *Stage 3:* In this stage, the user provides specific inputs on the housing characteristics, which in turn affect the numerical values obtained in Stage 2.

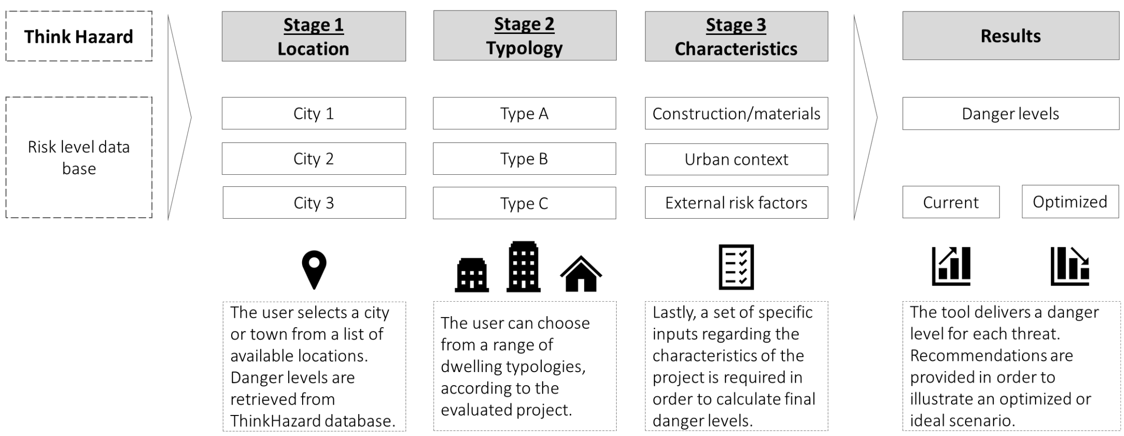


Figure 1. Tool methodology stages

Finally, the tool calculates a new and final risk numerical value for each analysed threat. This numerical value is translated into a hazard percentage that is graphically represented for each threat through bar charts. At the same time, the tool calculates an optimized hypothetical case, showing the potential reduction in risk levels, in the case that the project implemented certain optimization measures. The numerical values of Stage 2 and 3 accomplish the purpose of representing the context and the particular conditions of the project, which may increase or decrease specific risks. As an example, a detached house that is located in a city with a high risk of urban flooding, but is located in the highest grounds of the city and has pre-emptive measures to face a potential flood, should score a lower risk level than the one initially described at the urban level. The correction factors used in the different stages of the tool design are detailed in Table 1.

Stage 1 **Location**		**Risk increase/decrease**	**Stage 2** **Typology**	**Stage 3** **Characteristics**	**Results**
			Multiplying factor		
(Whole number ranging from 1 to 4)	+ Risk	**Increase: High**	N/A	x **3.0**	
Very Low = **1**	+ Risk	**Increase: Medium**	x **2.0**	x **2.0**	
Low = **2**	+ Risk	**Increase: Low**	x **1.5**	x **1.5**	Final numeric value corresponds to final product of multiplying factors.
Medium = **3**		**No effect**	x **1.0**	x **1.0**	
High = **4**	- Risk	**Decrease**	x **0.5**	x **0.5**	
ThinkHazard risk levels	- Risk	**Non existent**	N/A	x **0.0**	

Table 1. Tool multiplying factors

The first stage represents 'ThinkHazard' risk values. In stages 2 and 3 the numerical values are corrected depending on the selected inputs. If an input represents a risk increase for a particular threat, a multiplying factor greater than '1.0' is applied, increasing the numerical value from the previous stage. The multiplying factors may also be used to reduce and can also be multiplied by '0.0', to eliminate the consideration of that input in the final risk score (i.e. if evaluating extreme heat in an intermediate flat and providing input on the characteristics of the roof, the user has the option of selecting an alternative that multiplies the value by '0.0').

The tool calculates the highest possible risk level, comparing it with the numerical value obtained by the evaluated project. The evaluated project is then measured against this maximum possible score. Finally, the tool calculates an optimized scenario where the project meets the lowest possible numerical risk values. This is calculated by simply modifying the specific characteristics of the home that could be modified in order to reduce the risk level of each threat.

3. Results

3.1 Tool outcome

The result consists of an Excel tool composed of four tabs that represent each of the described stages. This format allows the tool to be versatile and accessible for the use of people who have access to a standard computer. The visualization and interface of the tool is shown below, starting with Figure 2 which represents the first stage, Figure 3 showing the dwelling typologies, Figure 4 the dwelling characteristics and Figure 5 the results tab.

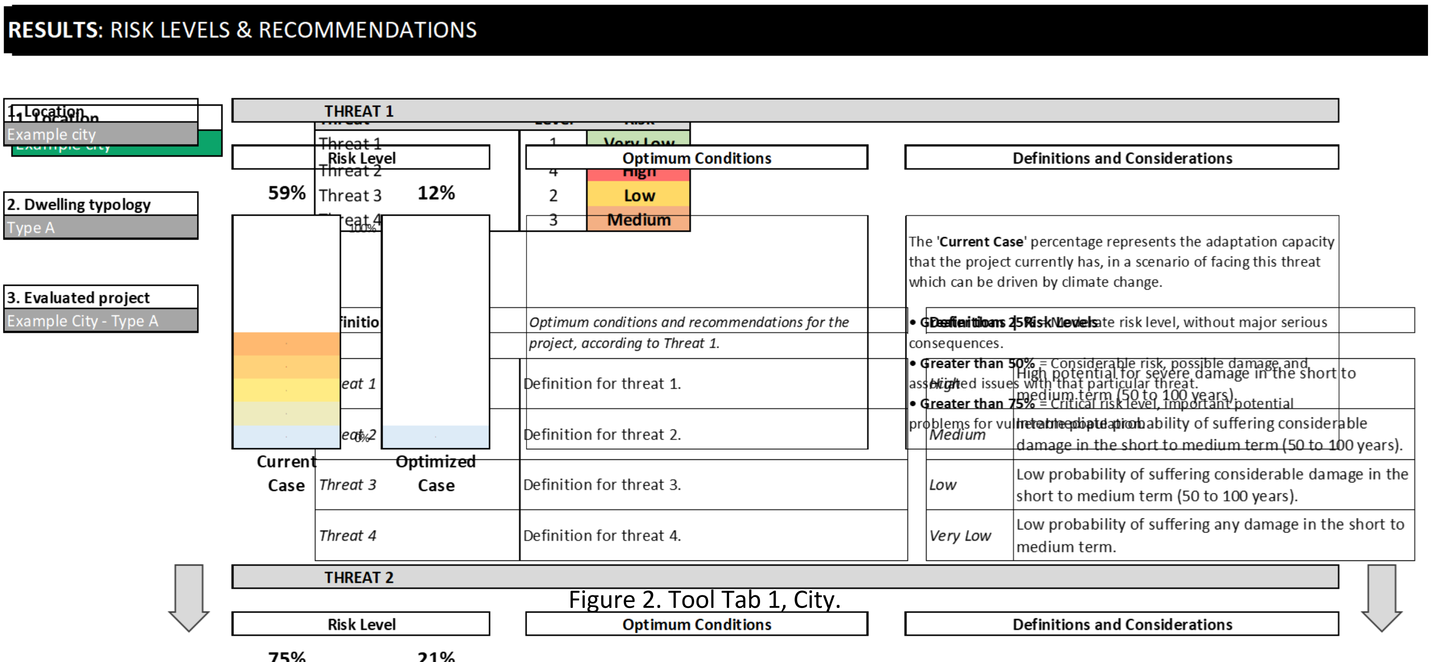
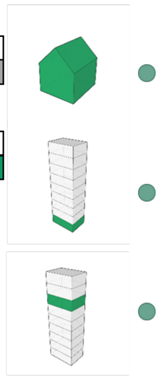


Figure 2. Tool Tab 1, City.

DWELLING: EFFECTS & CONSEQUENCES

1. Location
Example city

2. Dwelling typology
Type A



Evaluated project	Threat	Risk	Potential effect on dwelling
Example City - Type A	Threat 1	2	Potential effect according to Threat 1.
	Threat 2	8	Potential effect according to Threat 2.
	Threat 3	2	Potential effect according to Threat 3.
	Threat 4	1.5	Potential effect according to Threat 4.

Figure 3. Tool Tab 2, Dwelling.

Results are divided in three components:

ANALYSIS: DWELLING CHARACTERISTICS

1. Location
Example city

2. Dwelling typology
Type A

3. Evaluated project
Example City - Type A

	Data for evaluated dwelling	
1	*Question related to construction and materials*	*Answer 1*
2	*Question related to construction and materials*	*Answer 2*
3	*Question related to construction and materials*	*Answer 3*
4	*Question related to urban context*	*Answer 4*
5	*Question related to urban context*	*Answer 5*
6	*Question related to urban context*	*Answer 6*
7	*Question related to external risk factors*	*Answer 7*
8	*Question related to external risk factors*	*Answer 8*
9	*Question related to external risk factors*	*Answer 9*

Figure 5. Tool Tab 4, Results.

- *Current case:* Bar chart/percentage value describing the risk level of a particular threat for the project. This risk level is a product of the comparison between the evaluated project inputs against a worst-case scenario where all inputs have the highest possible risk according to the multiplying factors in Table 1.
- *Optimized case:* Bar chart/percentage value describing the reduced risk level for an ideal scenario. The tool gathers the selected inputs and assigns them the lowest possible risk according to the multiplying factors in Table 1. This chart represents a hypothetical version of the evaluated project, where all potential strategies in order to reduce risk are considered. These strategies consist of potential optimizations of the project and do not entail a changing in the location or type of construction. As an example, if the evaluated project is located in a city with extreme heat risk and the dwelling does not count with shading devices, therefore resulting in high overheating risk, the optimized case will consider the implementation of shading devices, without changing the city or dwelling typology.
- *Optimized conditions:* Written section describing the optimized conditions that allow reducing risk levels as seen on the 'Optimized Case' bar chart. These are a list of recommendations that the evaluated project could implement to reduce the risk level.

3.2 Testing the tool: The Chilean case

Chile is a country with great diversity in terms of climate, which allows for a great variety of climate change-related threats. These conditions make de Chilean case a unique example of how climate change can potentially affect a country, its cities and infrastructure.

The tool was therefore tested in the Chilean scenario, by selecting eight case studies that make up a representative sample of the variety of dwellings in different Chilean cities. The testing of the tool in case studies represented an opportunity to critically analyse the results and understand both the positive aspects of the tool and potential aspects to improve. It was found that the tool was simplistic in terms of defining inputs and assigning risks associated with each one of them. Some case studies located near vegetated areas reported high-risk levels of wildfire, regardless of the fact that they were located in areas that rarely see those events. Although the tool attempts to refine the assessment of risk levels using somewhat precise inputs, it seems that greater precision is needed in order to effectively determine whether these inputs really constitute a risk for the evaluated project. In this sense, it seems the evaluation tool is not sophisticated enough to analyse a scenario with highly complex urban, territorial and environmental conditions.

4. Conclusions

The tool succeeds in providing a risk level that is simple to understand by a user who does not have a high level of expertise in climate change or engineering. When representing an optimized scenario, the tool offers improvement recommendations that inform the user of optimizations to implement in the project. While one of the positive aspects of the tool is its ease of use and accessibility, this creates a negative consequence. By having a reduced amount of inputs, each of these pieces of data has a significant impact on the result of the evaluation. Therefore, if the user assigns an input incorrectly, the tool has no correction mechanism and thus the results could be compromised. On this regard, it is fundamental to understand that the results will only be reliable if the inputs are reliable as well.

Another critical aspect to assess is the final product delivered by the tool, which consists of a risk level with a percentage value. Certain doubts may arise as to whether the result should be a percentage, since this suggests a level of probability of occurrence for a specific threat. Strictly speaking, the tool is simply gathering a set of vulnerability conditions to define a maximum risk scenario and then comparing the evaluated project against that scenario. This is to say, that perhaps the deliverable result of the tool should not be expressed as a precise numerical value or percentage, as this may be misleading.

Nonetheless, the value of the tool does not only reside in the numerical values obtained, but also in the comparison of the results against other scenarios. The evaluation indirectly becomes a benchmarking tool, where not only the result is relevant, but also how that result is compared with other cases. Additionally, the versatility of the tool allows for easy modification in order to include new features. In this sense, the evaluation tool does not necessarily represent a final product, but rather the structuring of a working methodology in which improvements can be continuously implemented and therefore, its capacity, enriched.

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