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## Recommender Thermometer for Measuring the Preparedness for Flood Resilience Management

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### Abstract

A range of various thermometers and similar scales are employed in different human and resilience management activities: Distress Thermometer, Panic Thermometer, Fear Thermometer, fire danger rating, hurricane scales, earthquake scales (Richter Magnitude Scale, Mercalli Scale), Anxiety Thermometer, Help Thermometer, Problem Thermometer, Emotion Thermometer, Depression Thermometer, the Torino scale (assessing asteroid/comet impact prediction), Excessive Heat Watch, etc. Extensive financing of the preparedness for flood resilience management with overheated full-scale resilience management might be compared to someone ill running a fever of 41°C. As the financial crisis hits and resilience management financing cools down it reminds a sick person whose body temperature is too low. The degree indicated by the Recommender Thermometer for Measuring the Preparedness for Flood Resilience Management with a scale between  $T_{\min}=34,0^{\circ}$  and  $T_{\max}=42,0^{\circ}$  shows either cool or overheated preparedness for flood resilience management. The formalized presentation of this research shows how changes in the micro, meso and macro environment of resilience management and the extent to which the goals pursued by various interested parties are met cause corresponding changes in the “temperature” of the preparedness for resilience management. Global innovative aspects of the Recommender Thermometer developed by the authors of this paper are, primarily, its capacity to measure the “temperature” of the preparedness for flood resilience management automatically, to compile multiple alternative recommendations (preparedness for floods, including preparing your home for floods, taking precautions against a threat of floods, retrofitting for flood-prone areas, checking your house insurance; preparedness for bushfires, preparedness for cyclones, preparedness for severe storms, preparedness for heat waves, etc.) customised for a specific user, to perform multiple criteria analysis of the recommendations, and to select the ten most rational ones for that user. Across the world, no other system offers these functions yet. The Recommender Thermometer was developed and fine-tuned in the course of the Android (Academic Network for Disaster Resilience to Optimise educational Development) project.

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*Keywords:* flood, resilience management, preparedness, recommender thermometer, quantitative and qualitative criteria, multiple criteria decision making

## 1. Introduction

Various thermometers and similar scales are used in different human and disaster management activities: Depression Thermometer, Anxiety Thermometer, Help Thermometer, Emotion Thermometer (Mitchell et al. 2012), Anger Thermometer (Goldstein et al. 2013), Panic Thermometer (Complete Resource... 2014), Problem Thermometer (Michigan State University 2014), Mood Thermometer (Gil et al. 2005), Fear Thermometer (Heyne 2002), Distress Thermometer (Patel et al. 2011), Feeling Thermometer (Swanbrow 2001), Hurricane scale, Richter Magnitude Scale, Fire Danger Rating, the Torino scale (assessing asteroid and comet impact hazard predictions). Also different neural networks (Liu et al. 2014, Kong-A-Siou et al. 2013), early warning (Van Veen 2014, Krzhizhanovskaya et al. 2011, Alfieri et al. 2012, Borga et al. 2014, Hissel et al. 2014), fuzzy (Kou et al. 2014), expert (Kou et al. 2014, Karnib et al. 2002) and decision support (Hubbard et al. 2014, Krzhizhanovskaya et al. 2013) systems are used for flood resilience management. Some examples of these worldwide systems will be briefly described below.

Krzhizhanovskaya et al. (2013) present a *decision support system* for flood early warning and disaster management. It includes the models for data-driven meteorological predictions, for simulation of atmospheric pressure, wind, long sea waves and seiches; a module for optimization of flood barrier gates operation; models for stability assessment of levees and embankments, for simulation of city inundation dynamics and citizens evacuation scenarios. All the models are wrapped as software services in the CLAVIRE platform for urgent computing, which provides workflow management and resource orchestration (Krzhizhanovskaya et al. 2013).

The FP7 Theseus research project (2009–2013) aims to develop and assess innovative technologies and methodologies for coastal protection against erosion, flooding and environmental damages. While protection structures may help to reduce the level of hazard and the expected degree of loss, some danger of technical failures or human errors will always remain. For extreme events, the implementation of non-structural measures as early warning systems and disaster management practices is required to ensure the protection of population. A methodology for helping the local authorities to prepare an action plan in case of coastal flooding was developed and tested on the estuary of Gironde in France. The methodology builds over the return of experience from past events and tries to clearly identify all the stages of an evacuation and the thinking process that can lead to a robust evacuation plan. It relies on a conceptual framework – SADT – which helps to understand how data should be processed from its collection to its use in the plan. The risk scenarios were calculated for current and future conditions of the XXIst century, taking into account the effects of climate change (Hissel et al. 2014).

For implementation of a regional Tsunami Early warning system (EWS) in Sumatra island in Indonesia, a set of detailed and accurate tsunami propagation and flooding models using Delft3D were developed. The purpose of the models was not only to reproduce the 2004 Indian Ocean tsunami, but also to determine tsunami flood hazard maps with different return periods. The model outputs have then been used to build a tsunami flooding database covering 1250 hypothetical sources for different earthquake parameters. The model simulations produced detailed information of near-shore tsunami wave height, tsunami inundation length and run-up. Smart storage of computational results, in a geo-referenced database, allows quick access to the requisite information. The result is a system capable of issuing a warning within few minutes after a detection of an earthquake (Van Veen 2014).

Flash floods and debris flows develop at space and time scales that conventional observation systems for rainfall, streamflow and sediment discharge are not able to monitor. Consequently, the atmospheric, hydrological and geomorphic controls on these hydrogeomorphic processes are poorly understood, leading to highly uncertain

warning and risk management. On the other hand, remote sensing of precipitation and numerical weather predictions have become the basis of several flood forecasting systems, enabling increasingly accurate detection of hazardous events (Borga et al. 2014). The objective of Borga et al. (2014) research paper is to provide a review on current European and international research on early warning systems for flash floods and debris flows. Borga et al. (2014) suggest three areas in which advancements in science will have immediate and important practical consequence, namely development of rainfall estimation and nowcasting schemes suited to the specific space-time scales, consolidating physical, engineering and social datasets of flash floods and debris-flows, integration of methods for multiple-hydrogeomorphic hazard warning.

The methodology for the preparation of evacuation plans was applied on a pilot city of Theseus, Bordeaux on the estuary of Gironde (France), and the software used to calculate evacuation times was tried out on Cesenatico near the Adriatic coast (Italy). This comparison verified the replicability of methodological guidelines in two different European contexts. The cultural and organizational differences and the different number of people involved underlined strong questions to be addressed when applying them. In order to assess the efficiency of an evacuation strategy and to compute the number of people successfully evacuated over time, a macroscopic model (not representing each individual vehicle but only flows of vehicles in congestion points) for the simulation of traffic congestion was used. This model will be integrated in the Theseus decision support system for helping coastal managers to select their strategy for risk mitigation (Hissel et al. 2014).

Hubbard et al. (2014) developed a spatiotemporal framework for identifying building vulnerabilities and content evacuations during riverine flooding events. Hubbard et al. (2014) investigate the spatiotemporal properties required to trigger building contents evacuations in the floodplain during a flood event. The spatial properties for building risks are based on topography, flood inundation, building location, building elevation, and road access to determine five categories of vulnerability, *vulnerable basement*, *flooded basement*, *vulnerable first-floor*, *flooded first-floor*, and *road access*. Using this framework, a model designed to track the spatiotemporal patterns of building evacuations is presented. The model is based upon real-time flood forecast predictions that are linked with building properties to create a model that captures the spatiotemporal ordering of building vulnerabilities and building content evacuations. Applicable to different communities at risk from flooding, the evacuation model is applied to a historical flood for a university campus, demonstrating how the defined elements are used to derive a pattern of vulnerability and evacuation for a campus threatened by severe flooding (Hubbard et al. 2014).

As it is the case with many karst aquifers, the *Lez* basin (southern France) is heterogeneous and thus difficult to model. Due to its supply of fresh water and its ability to reduce flooding however, more in-depth knowledge of basin behavior has proven critical. In addressing this challenging issue, an original methodology based on neural networks is presented herein so as to better understand the hydrodynamic behavior of such systems (Kong-A-Siou et al. 2013).

Most of the existing disaster assessment models are based on single method, such as expert system, or one of the multi-criteria decision making (MCDM) methods (Kou et al. 2014). Kou et al. (2014) propose an efficient disaster assessment expert system, which integrates fuzzy logic, survey questionnaire, Delphi method and MCDM methods. Two simulation experiments on typhoon and earthquake are introduced to validate the integrated expert system. The experimental results show that the proposed expert system is not only efficient, fast and accurate, but also robust through self-adaptive study and has strong adaptability to different environments (Kou et al. 2014).

## 2. Recommender Thermometer for Measuring the Preparedness for Flood Resilience Management

Based on the analysis of above thermometers and similar scales, neural networks (Liu et al. 2014, Kong-A-Siou et al. 2013), early warning (Van Veen 2014, Krzhizhanovskaya et al. 2011, Alfieri et al. 2012, Borga et al. 2014, Hissel et al. 2014), fuzzy (Kou et al. 2014), expert (Kou et al. 2014, Karnib et al. 2002) and decision support (Hubbard et al. 2014, Krzhizhanovskaya et al. 2013) systems, as well as on the long experience of the article's authors (Kaklauskas et al. 1999, 2011) and in order to determine most efficient tips and resilience alternatives to flood adaptation in the built environment area a Recommender Thermometer for Measuring the Preparedness for Flood Resilience Management consisting of a database, database management system, model-base, model-base management system and user interface was developed (see Figure 1).

The following tables make Recommender Thermometer database:

- Initial data tables. These contain general facts about the preparedness for flood resilience management of built environment considered and the information of its deterioration and obsolescence. The reasons of refurbishing and their significance as well as the money intended to be spent on it are also given.
- Tables assessing preparedness for flood resilience management of built environment solutions. They contain quantitative and conceptual information about alternative solutions.
- Table of questionnaire (see Figure 1). Each of the question leads to recommendation.
- Tables of alternative recommendations.
- Tables of alternative built environment refurbishment solutions. A number of options (Homeostasis, Omnivory, High flux, Flatness, Buffering, Redundancy (Wardekker et al. 2010)) that could be considered within a resilience approach to flood adaptation in the built environment area have been developed and successfully used in advanced industrial economies.
- Tables of multivariant design of built environment refurbishment solutions. They provide quantitative and conceptual information on the interconnection of the elements of preparedness for flood resilience management of built environment to be regenerated, their compatibility and possible combinations as well as data on complex multivariant design of a of built environment.
- Tables of multivariant design of recommendations.

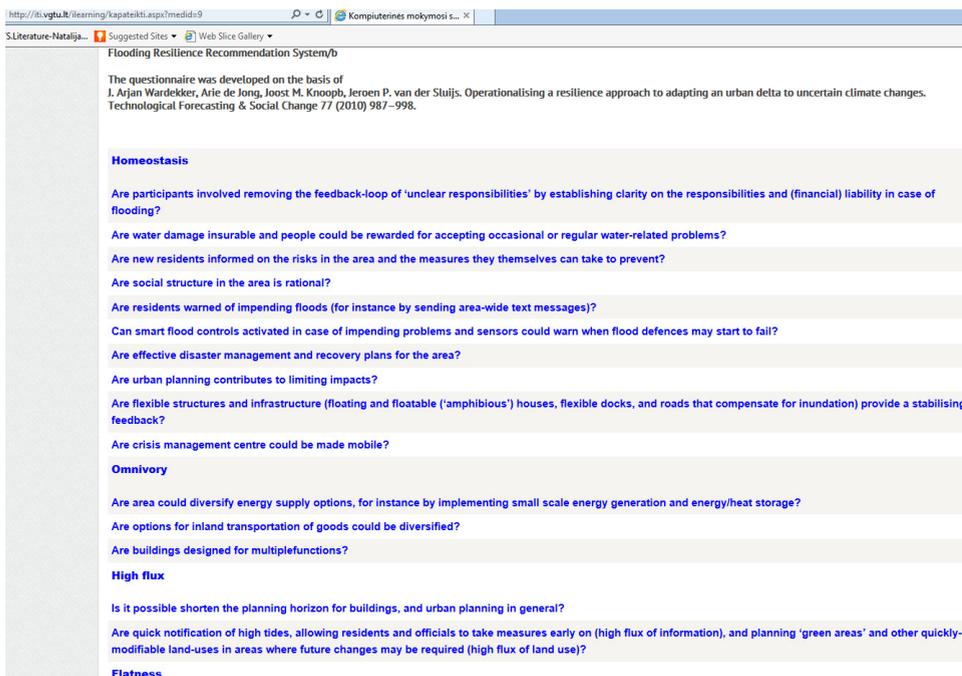


Figure 1. Fragment of questionnaire for measuring the preparedness for flood resilience management

The Model-base consists of the following models:

- a model for the criteria weight establishment,
- a model for multivariant design of alternative recommendations and built environment refurbishment solutions,
- a model for multiple criteria analysis and setting the priorities,
- a model for determination of alternative utility degree,
- a model for determination of the “temperature” of the preparedness for resilience management (Thermometer model),
- a model for providing recommendations and rational built environment refurbishment solutions.

Based on the above models, a Recommender Thermometer can make until million recommendations and built

environment refurbishment alternative versions, performing their multiple criteria analysis, determining utility degree and selecting most beneficial variant without human interference.

Some of the above-listed modules (a model for the criteria weight establishment, a model for multivariant design, a model for multiple criteria analysis and setting the priorities, a model for determination of alternative utility degree) have been programmed using corresponding methods developed by the authors of this work (Kaklauskas et al. 19992011): a method of complex determination of criteria weights considering their quantitative and qualitative characteristics; method of multiple criteria complex, proportional project evaluation; method of defining the utility and market value of an alternative and method of a multiple criteria, multivariant design of a project life cycle. These methods determine the priority, significance ( $Q_j$ ) and utility degree ( $N_j$ ) of the compared options. Utility degree ( $N_j$ ) values are then added to the equations below to determine the “temperature” of the preparedness for flood resilience of built environment ( $T_j$ ):

If investments to flood resilience of built environment are too high, then:

$$T_j = 36.6^\circ + ((100\% - N_j) : 200 \cdot 36.6^\circ). \quad j = \overline{1, n}; \quad (1)$$

where  $T_j$  is the “temperature” of preparedness for flood resilience of built environment in the  $j$ -<sup>th</sup> alternative.  $N_j$  – the value of the preparedness for flood resilience of built environment utility degree in the  $j$ -<sup>th</sup> alternative and  $n$  - the number of alternatives compared.

If investments to flood resilience of built environment are too low, then:

$$T_j = 36.6^\circ - ((100\% - N_j) : 200 \cdot 36.6^\circ). \quad j = \overline{1, n}. \quad (2)$$

### 3. Case Study: Flood resilience management in Lithuanian built environment

The example considered is flood resilience management in Lithuanian built environment. Five alternatives of preparedness for flood resilience management of built environment (Homeostasis, Omnivory, High flux, Flatness, Buffering, Redundancy (see Table 1 and <http://iti.vgtu.lt/imitacijosmain/daugkrit.aspx?sistemid=409>) have been analysed.

Floods are a risk in over 5% of Lithuania’s territory, or 351,000 ha, including 193,000 ha of agricultural lands, 97,000 of forests, and 28,000 ha of urban territories. A 2011 preliminary estimation of the flood risks in the Republic of Lithuania by the Environmental Protection Agency (EPA) showed that between 1961 and 2010 Lithuania suffered flood damage worth about LTL 153,875,000. More than 70% of the damage fell on Rusnė and other coastal areas in Pamarjys.

Rusnė is the only Lithuania’s town on an island, in the southwest of Šilutė District. A modern bridge over the Atmata connects the town to the mainland and the road then leads to Šilutė. The other bank of the Skirvytė is in Kaliningrad Oblast, Russian Federation. A modern bridge was constructed over the Atmata, but there are times when even the bridge cannot save the locals from spring floods, which usually cover over 40,000 ha of meadows with water. The residents of Rusnė are protected from floods by levees. The island has a system of polders with 20 water-pumping stations. The land at the lake of Dumblys is 1.3 m below the sea level.

Extreme floods are mostly characteristic of the areas in the lower reaches and delta of the Nemunas. The floods result from higher discharge in the Nemunas caused by snowmelt; because of ice jams the extent of submerged riverside land may often increase. Ice jams may prolong floods for extensive periods (by slowing down the receding stage). Such floods very often reach the level of a disaster.

Floods resulting from snowmelt and ice jams account for about 70–75% of cases; about 15% are caused by heavy rains. The risk of floods may increase because of ice jams frequent in the Nemunas delta. Another 15% of cases may be attributed to other reasons such as the rising sea level in the Baltic Sea, accidents in hydrotechnical facilities and so on. Spring and winter are the typical flood seasons in Lithuania; they cover about 60% and 35% of cases respectively.

Based on the calculated criteria values and weights, a decision making matrix for preparedness for flood resilience management of the town Rusnė (see Table 1 and <http://iti.vgtu.lt/imitacijosmain/daugkrit.aspx?sistemid=409>) was developed. As can be seen from Table 1, each

criterion goes together with its measurement unit and weight. The magnitude of weight indicates how many times one criterion is more significant than the other one in a multiple criteria evaluation of windows refurbishment.

Table 1. Fragment of grouped decision making matrix of flood resilience management in built environment multiple criteria analysis

Quantitive and qualitative information pertinent to alternatives									
Criteria describing the alternatives	*	Measuring units	Weight	Compared alternatives					
				Homeostasis	Omnivory	High flux	Flatness	Buffering	Redundancy
Ground subsidence	-		0.004	3	4	3	5	9	5
Water system	+		0.002	8	7	4	5	6	5
Tidal differences	-		0.005	3	4	5	4	7	6
Water barriers	+		0.021	7	6	4	7	8	9
Local ecology	+		0.013	8	7	7	8	8	8
Economical functions	+		0.012	6	9	7	8	7	5
Public spaces	+		0.017	7	8	5	5	6	7
Inland shipping	+		0.027	7	8	6	7	7	7
Port functions	+		0.023	7	8	6	7	7	7
Residential functions	+		0.008	8	8	8	7	6	7
(Para)medical facilities	+		0.029	9	9	8	9	8	8
Cooling	+		0.021	7	5	8	9	7	8
Energy supply	+		0.032	6	9	9	9	7	9
Drinking water	+		0.033	9	7	4	5	7	7
Disaster management organization	+		0.041	9	9	9	9	9	9
Electricity	+		0.035	6	9	9	9	7	8
Sewage system	+		0.028	9	6	7	6	8	9
Main roads leading in/out of the area	+		0.009	8	7	6	8	8	7
Main water barriers	+		0.024	8	7	6	8	9	7
Maeslantkering storm surge barrier	+		0.011	6	6	8	8	9	7

The following alternatives have been chosen for the calculations: Homeostasis, Omnivory, High flux, Flatness, Buffering, Redundancy. The Flatness and Redundancy could hardly be implemented in our concerned area. In contrast, the alternatives such as Homeostasis, Omnivory, High flux, and Buffering could be used in Lithuania. Those alternatives are composed to the area.

When analyzing the alternative Homeostasis we have noticed that such criteria as Water system, Water barriers, Local ecology, Public spaces, Inland shipping, (Para)medical facilities, Energy supply, Drinking water, Electricity, Sewage system, Main roads leading in/out of the area, Main water barriers, Risk information, Social structure, Evacuation plans, Water damage insurance, Safety policy, Areal system management, Urban planning, Modification of areas, Temperature, Sea level rise, River discharge, Societal and governmental issues, Rapid ice-sheet melting, Extreme storm, Maeslantkering failure plus extreme storm have high significance and only need a minor improvement or none at all. The matrix of the quantitative and qualitative information related to the alternatives with certain low percentages illustrates this clearly (cf. the criteria such as Ground subsidence, Port functions, Flooding-resistant buildings, Top-heavy system prevention, Port malaria incidents).

The results of the multiple criteria evaluation of the six flood resilience management versions are given in Table 2 (also see <http://iti.vgtu.lt/imitacijosmain/daugkrit.aspx?sistemid=409>). From the numeric values it can be seen that the 1st version (Homeostasis) is the best among all the versions that were evaluated. The utility degree of it  $N_1 = 100\%$ . The 5th version (Buffering) according to its priority was recognized as the second best. The utility degree of it  $N_5 = 97,67\%$  (see Table 2).

Table 2. Fragment of flood resilience management in built environment multiple criteria analysis results

Precipitation extremes	+	0.025	0.0044 AVG MIN	0.0038 AVG MIN	0.0044 AVG MIN	0.0044 AVG MIN	0.005 AVG MIN	0.0031 AVG MIN
Societal and governmental issues	+	0.012	0.002 AVG MIN	0.0023 AVG MIN	0.002 AVG MIN	0.0023 AVG MIN	0.0015 AVG MIN	0.0018 AVG MIN
Wildcards	-	0.021	0.0041 AVG MIN	0.0026 AVG MIN	0.002 AVG MIN	0.0036 AVG MIN	0.0046 AVG MIN	0.0041 AVG MIN
Rapid ice-sheet melting	+	0.026	0.0048 AVG MIN	0.0041 AVG MIN	0.0034 AVG MIN	0.0048 AVG MIN	0.0048 AVG MIN	0.0041 AVG MIN
Frozen port	+	0.009	0.0016 AVG MIN	0.0018 AVG MIN	0.002 AVG MIN	0.0016 AVG MIN	0.0007 AVG MIN	0.0013 AVG MIN
Port malaria incidents	+	0.026	0.0051 AVG MIN	0.0044 AVG MIN	0.0051 AVG MIN	0.0038 AVG MIN	0.0032 AVG MIN	0.0044 AVG MIN
Enduring heat and drought	+	0.025	0.0042 AVG MIN	0.0048 AVG MIN	0.0042 AVG MIN	0.0042 AVG MIN	0.0036 AVG MIN	0.0042 AVG MIN
Extreme storm	+	0.03	0.0062 AVG MIN	0.0031 AVG MIN	0.0046 AVG MIN	0.0054 AVG MIN	0.0062 AVG MIN	0.0046 AVG MIN
Maeslantkering failure plus extreme storm	+	0.032	0.0063 AVG MIN	0.0049 AVG MIN	0.0056 AVG MIN	0.0056 AVG MIN	0.0063 AVG MIN	0.0035 AVG MIN
The sums of weighted normalized maximizing (projects 'pluses') indices of the alternative			0.1712	0.1555	0.1556	0.1656	0.1683	0.1452
The sums of weighted normalized minimizing (projects 'minuses') indices of the alternative			0.0068	0.0054	0.0044	0.006	0.0087	0.0065
Significance of the alternative			0.1768	0.1625	0.1642	0.1719	0.1727	0.151
Priority of the alternative			1	5	4	3	2	6
Utility degree of the alternative (%)			100%	91.94%	92.9%	97.25%	97.67%	85.44%

\*- The sign "+/-" indicates that a greater (less) criterion value corresponds to a greater significance for a user (stakeholders)

Using the 1st equation and Table 2 (also see <http://iti.vgtu.lt/imitacijosmain/daugkrit.aspx?sistemid=409>), when the investments to flood resilience of built environment are too high, the Recommender Thermometer determines preparedness for flood resilience “temperature”  $T_j$  of the  $j$ -<sup>th</sup> alternative:

$$T_{\text{Homeostasis}} = 36.6^\circ + ((100\% - 100\%) : 200 \cdot 36.6^\circ) = 36,60^\circ,$$

$$T_{\text{Omnivory}} = 36.6^\circ + ((100\% - 91,94\%) : 200 \cdot 36.6^\circ) = 38,07^\circ,$$

$$T_{\text{High flux}} = 36.6^\circ + ((100\% - 92,9\%) : 200 \cdot 36.6^\circ) = 37,90^\circ,$$

$$T_{\text{Buffering}} = 36.6^\circ + ((100\% - 97,67\%) : 200 \cdot 36.6^\circ) = 37,03^\circ.$$

Using the 2nd equation and Table 2, when the investments to flood resilience of built environment are too low, the Recommender Thermometer determines preparedness for flood resilience “temperature”  $T_j$  of the  $j$ -<sup>th</sup> alternative:

$$T_{\text{Flatness}} = 36.6^\circ - ((100\% - 97,25\%) : 200 \cdot 36.6^\circ) = 36,10^\circ,$$

$$T_{\text{Redundancy}} = 36.6^\circ - ((100\% - 85,44\%) : 200 \cdot 36.6^\circ) = 33,94^\circ.$$

#### 4. Conclusions

In order to design and realize efficient **built environment for flood resilience management**, it is necessary to carry out exhaustive investigations of all the solutions that form it. The presented Recommender Thermometer enables one to form millions alternative versions and present tips. The Recommender Thermometer allows one to determine the strongest and weakest points of each **built environment for flood resilience management** and its constituent parts and give recommendations. The authors of the article are currently involved in an augmented reality research. The plans for the next stage of the Recommender Thermometer development involves integrating this system with augmented reality systems, which the authors herein have also developed.

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