IDENTIFICATION OF ADAPTIVE STRATEGIES IN VERNACULAR ARCHITECTURE FACING FLOOD RISK

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ABSTRACT
Floods are a common phenomenon that cause environmental disasters with a great affectation on society. For centuries, humankind has tried to adapt the natural environment to protect humans from destructive weather effects using architecture as a human shelter. Vernacular architecture is known for mixing traditional solutions with indigenous engineering to solve local problems in a trial-and-error process of continuous improvement. Therefore, it is possible to find some solutions as mentioned in isolated papers describing how a population faces the risk of floods. In this context, it is necessary to make a study that considers bringing together as many possible strategies where floods are a pattern for building designs that encourage people to seek solutions in their dwellings. This paper presents different architectural adaptation strategies to face flood risks in traditional constructions located in flood prone zones. These solutions were gathered from 55 studies on vernacular architecture from 23 countries. Twenty-seven different adaptive strategies were found. Then, these strategies were classified based on the methods to protect dwellings from flooding, as described by the Federal Emergency Management Agency and an unsupervised machine learning algorithm. Results show that people tend to apply more than one solution at each instance. Using clustering analysis, nine ways were found to combine these methods and seven alternatives to mix adaptive solutions. These results could be useful for designing new dwellings in flood prone areas.
Keywords: vernacular architecture, dwelling, adaptive strategies, flood-risk.

1 INTRODUCTION

The purpose of this article is to present different strategies of architectural adaptation applied in traditional architecture in areas exposed to flooding. This analysis was the result of combining two currently known facts. The first was flooding phenomena. This is the most common disaster related to hydrometeorological phenomena [1] and, in the context of global warming, its effects are expected to become more frequent and more intense. On the other hand, there is architecture, a fact that has been identified as one of human developments to solve – though partially sometimes – the problem of living protected from the elements. Based on these two facts, the following question arose: what is the role of architecture in flood disasters?

In the context of studies to cope with flood risks, it has been found that vulnerability reduction is relatively effective [2], i.e., the reduction of the predisposition or propensity to be negatively affected [3]. In this sense, there are different approaches. Commonly, these involve making a series of analyses and assessments of risk elements [4]–[6]. One of the approaches to reduce vulnerability accepted by the research community, is to reduce (a) exposure to the risk itself; and (b) the susceptibility to impacts [7]. Another approach from risk science adds that vulnerability is also considered a combination of four capabilities: (a) the capability to react to an exposure threshold; (b) the capability to cope with risks; (c) the capability to recover; and (d) the capability to adapt [8], [9].

As regards architecture, specialized literature shows that it has a role in (a) the variation of susceptibility or extent to which a system or society is damaged; and (b) it is part of adaptation mechanisms to the flood disaster [8]. In architecture, coping, recovery, and adaptation capacities can be found reflected through strategic designs and construction

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solutions. Indicators of these capabilities include retrofitting and creating new adjusted infrastructure, both classified as adaptation mechanisms [10]. To this, we can add the maintenance and rehabilitation of buildings, reflecting the knowledge of reaction to degradation agents. Now, do floods influence the way architecture is done?

Floods can become an element to be considered for the design and the way to adapt constructions. This is possible to infer from the adaptation strategies when studying popular architecture – whether vernacular, indigenous, or traditional. This architectural category is representative of local construction traditions, since it is the product of the set of cultural values created by society [11] and the result of the interaction of ecological, economic, material, political, and social factors [12]. Upon careful examination, it can be seen that it contains a set of solutions to local problems – local construction technology – achieved by implementing local material resources and the knowledge acquired by local inhabitants [13], developed over time through a trial-error process.

Solutions from popular architecture for seismic retrofitting have been widely documented. Among these we can mention construction systems such as *Pombalino*, in Portugal [14] and *Casa Barracata* in Italy, which have been two local responses to seismic disasters [15], [16]. There is a study by Michiels [17] on a series of traditional building techniques taken from the vernacular heritage for the *seismic retrofitting* of earthen buildings, which can be transformed into intervention alternatives for foundations, walls, and roofs [17]. Other solutions have been widely included in conference abstracts [18].

In the case of floods, this disaster is known to have become a guideline for design and architectural adaptation. The use of piles has been documented as adaptive strategies in stilt constructions located in coastal areas [19]–[21]. But unlike the studies related to seismic disasters – such as the one presented by Michiels [17] – in the case of floods, although a number of investigations has been conducted reporting some adaptive strategies for some regions of the world, these reports do not contribute to generating global alternative solutions. It is unknown if existing solutions exist and if there are patterns that can be drawn. This relationship between architecture and floods poses the following research questions: What other adaptive strategies can be taken from popular architecture? Will there be patterns among adaptive strategies based on their properties?

To adopt traditional adaptive strategies, a literature review of 35 documentary sources has been completed. Different cases were recorded and characterized based on their architectural and construction properties. Each representative case was recorded as a probabilistic observation. Hierarchical cluster and K-Means analyzes were performed to determine association patterns. The main findings are presented in the results section.

Finding solutions to reduce the effects of floods is relevant because it is one of the environmental disasters with the greatest economic and social losses [22]. They are also the cause of more than 200,000 deaths and adverse effects affecting about 3 billion people in the world every year [23].

2 METHOD

To adopt from popular architecture adaptive strategies in floods, more than 100 documentary sources were first reviewed – including articles and conferences – identified under the keywords "vernacular architecture flood risk" and "vernacular architecture flood disaster". These documents were filtered to documents on traditional flood adaptation techniques that resulted in 35 sources. 55 types of housing were taken from these documents from 40 different communities, in 23 countries.

There were three eligibility criteria for the selection of objects of study in this research: (a) traditional dwellings; (b) located in areas exposed to flood disasters; and (c) that presented at least one type of adaptation strategy to this category of disaster. Each one of the strategies described in the literature was contrasted with illustrations – photos or plans – found in source documents.

The variables for this analysis consist of a set of adaptation strategies which were taken directly from a literature review. These, in turn, were organized based on the adaptive methods proposed by FEMA [24], which have also been used in guides for *retrofitting* and architecture studies in floods [25]–[27]. Adaptive methods are the following: (a) to make buildings; (b) dry methods; (c) floodproof wet methods; (d) relocation; (e) levees or retaining walls; and (f) rebuilding. In addition, an extra category was created adding other methods found, named as (g) formal design, with the possible inclusion of strategies related to the shape and composition of buildings (Fig. 1).

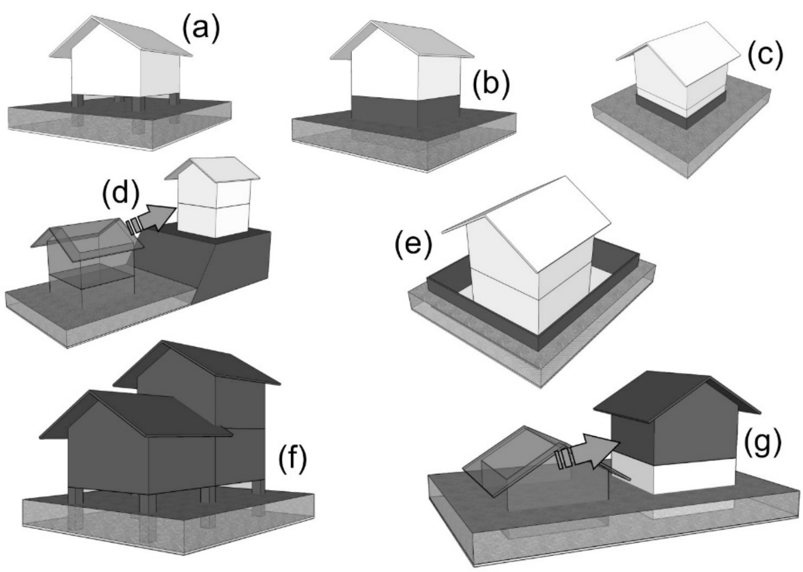

Figure 1: Categories of adaptive methods.

Each of the types of housing found in the literature, which are representative of a particular region, was considered as an independent observation, or model, for this study. For example, one type was the Tlacotalpan dwelling type, in Veracruz, Mexico, and another type was the RAAN dwelling type, in Nicaragua [28]. Each observation was recorded specifying the source where it was found, the region, the country, the strategies used and the adaptive method to which the strategy belongs – based on FEMA [24]. To record the type of strategy, dichotomous nominal data were used – "Yes" and "No" – which were subsequently transformed into fictitious variables – dummy variables – coded as 0 and 1. This helped to standardize all data.

To determine association patterns, we used two recursive segmentation algorithms: cluster analysis and K-Means – unsupervised machine learning methods [29]. Two such solutions were performed.

The first to ascertain the possible combinations of adaptive methods and the second to identify the clusters based on the 27 adaptive strategies identified. We used a cluster analysis method for the following reasons: (a) it is an exploratory analysis tool to identify two or more groups, based on similarities possible shared among variable data of each observation; (b) the method is applicable to identify patterns of multivariate association that (c) does not require normalized samples; (d) is it not based on assumptions of homoskedasticity or linearity [30].

The hierarchical clustering method first associates two or more observations sharing characteristics, and then a first cluster is created. These common features are identified by the distance between them in a multivariate space. The smaller the distance between the elements, the greater the similarity. This first process is conducted in distinct parts of the multivariate space to obtain small clusters. Then these first clusters are treated as individual elements – just as in the first process. Elements are reassociated based on common characteristics, and the distance in the multivariate space. This process is done recursively until two groups remain only. To create the clusters, the type of method used between the observations was a Euclidean distance and for the cluster a Ward method, which applies the criterion of adding the squares of the distances of the observations to minimize errors. These methods are detailed and exemplified in the literature on multivariate analysis and machine learning [30], [31].

The appropriate illustrative instrument to present the results of this study is the dendrogram, which represents, by means of branches, the connections between observations sharing common characteristics. The K-Means method was used as an auxiliary tool to determine the number of significant groups. This was done by contrasting the result from the (a) elbow method – which determines the number of significant "k" sets (K-means), using the sum of the squares of the distances between each center of each group (WCSS) – and (b) the method of cutting the branch of the dendrogram with the greatest distance – which is usually the most representative.

3 RESULTS

From the documentary sources review [11], [13], [20], [28], [32]–[62], 27 adaptive strategies were found organized into seven methods. Within these seven adaptive methods, four types of ways were found to build houses, five dry methods, three wet methods, four relocation alternatives, four types of barriers, two reconstruction ways, and five formal design strategies (Table 1).

Among the particularly striking particular cases, we can mention the following. Floating constructions, which are part of the building tradition in Thailand [48] and Bangladesh [51]. Rooftop dwellings in Romania and Bulgaria, in areas where there is also considerable rainfall, which have a windowsill design with stone materials or earth above the level of water currents to prevent infiltration [20]. Cases were found where inhabitants have dwellings they inhabit seasonally, as it happens in Somerset, England [20]. In Canada, when the sun rises, the snow melts, reaching the windowsills, and causing floods. Solutions they have found is to build houses on platforms to which they add ramps to prevent melted snow in entrances from entering the houses [56].

In East Anglia, United Kingdom, there are mills connected to a drainage system in the city to drain flood water in the area [19]. Other examples of city-level drainage can be found in settlements on the Nile River in Egypt [38] and in Kathmandu, Nepal [40]. In the town of Zeng Chong, in China, local inhabitants built a flood control system based on embankments adapted to the relief to distribute water at various levels, thus preventing concentration in a single point. This water is also used as a system fire protection [56].

Table 1: Existing adaptive strategies in traditional architecture located in areas exposed to flooding.

Alternatives	Solutions				
Elevation	Stilt houses	Pedestals of stones, bricks or earth	Platforms of earth, stone or mixture of earth with plant materials	Floating constructions	
Dry floodproofing	Masonry walls of different materials and thicknesses on the first level exposed to the thrust of the water	Walls with stone baseboards	Sill made of stone or earth above the level of the rain flow in terraced houses	Use of exterior waterproofing	Drainage systems
Wet floodproofing	Floodable ground floor	Raised floor or filter wall surfaces	Flood banks		
Relocations	New construction on hills	Seasonal home	Resettlement in another similar place	Construction of emergency house	
Levees and floodwalls	Perimeter walls	Earth levees	Vegetable plantations	Embankments	
Rebuild	Identical rebuild on the same site	Different rebuild on the same site			
Formal design	Orientation in the direction of the main stream	Compact form	Circle shape	Construction with more than one level	Configuration changes

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In the Gifu region, in Japan, we found the Mizuya house: a construction within a house with emergency spaces, located on platforms with heights that are corrected each time an atypical flood takes place. It is projected for future disasters considering a protection error margin in case floods with atypical values occur [43]. Other communities, such as Santa Catarina in Egypt [39], Rathnapura in Sri [42] or Nubian, in Sudan [20], consider the orientation of the house against the main direction of the current. In Vietnam they make configuration changes to improve accesses to houses [40], [49]. In Mexico and India, they build compactly to improve resistance to water pressure [35], [57] and in Nepal, they also build with round shapes [13].

Now, to determine the possible combinations of adaptive methods and applied strategies, we made an analysis of the case characteristics. After conducting the data analysis, from the 55 registered cases, the elbow diagram helped to identify nine significant combinations of methods and seven groups of combinations of adaptive strategies.

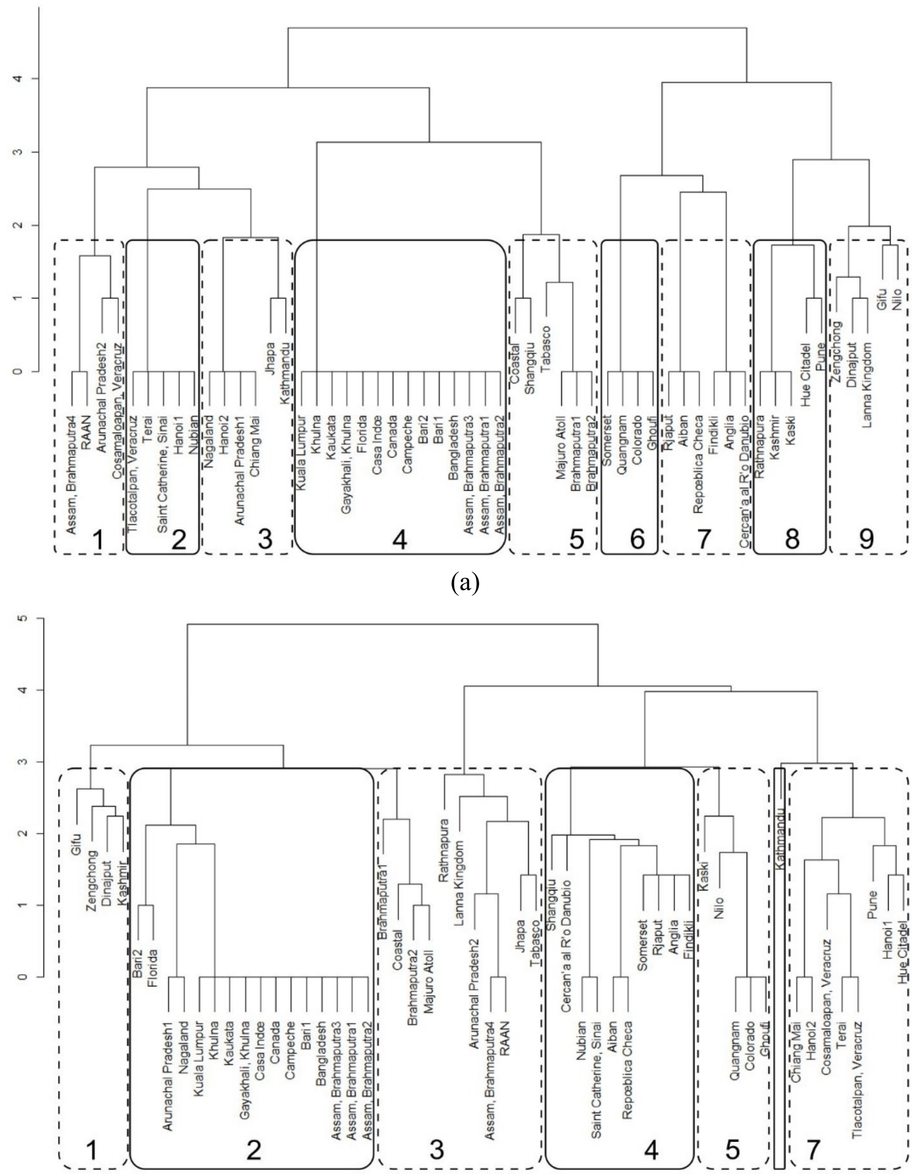
The first dendrogram (Fig. 2(a)) shows that nine clusters can be created – these will be described by a number from one to nine from left to right. These are differentiated by the number of methods applied, which can be: one, two and up to three methods at the same time. Observations that apply only one method are associated in the following clusters: (2) the second, which applies formal design methods, (4) the fourth, which constructs buildings, (6) the sixth, which tends to relocation, and (7) the seventh, which may apply only dry methods or rebuilding only. Observations that apply only two methods at a time are in the first, third, and fifth clusters. What they have in common is that they all create buildings. They differ from each other, because in addition to constructing, (1) the first applies wet methods, (3) the third applies formal design methods, and finally, (5) the fifth applies physical barriers. Observations included in the eighth and ninth clusters tend to apply three methods. Their constant relocation and construction of buildings. These differ in that the eighth (8) applies formal design and the ninth (9) creates physical barriers.

The second dendrogram (Fig. 2(b)) can produce seven clusters – these will be described too by a number from one to seven from left to right. The first and second clusters are characterized in that their included models tend to build on a platform. The difference between these two groups is that in the first, other adaptive strategies are also applied to achieve strategies 4–7. The third contains houses that tend to be built on stilts, compactly and also use construction systems that allow filtration in floors. The fifth is represented by the models that tend to relocate to points with a greater height. The seventh cluster is characterized by having houses with more than one floor. The models that tend to use different strategies with no patterns in common are the fourth cluster, with dwellings with two adaptive strategies and the sixth cluster, which is a dwelling applying the greatest possible number of adaptive strategies (seven), both groups without any particular pattern.

4 CONCLUSIONS

In this research, it was possible to identify at least 27 types of adaptive strategies in traditional homes located in areas exposed to floods. It was possible to verify that there are some associating patterns among the 55 observations identified, in 23 countries, and it was possible to establish at least two alternatives to group the types of housing considering probabilistic parameters.

Clustering models were useful to create hierarchical clusters from the characteristics identified in the literature. The results found in this research can be implemented as adaptive solutions to the problem of flooding in different communities, or in new architectural projects – as has happened in Australia [63], [64], Bangladesh [65], Thailand [66] – considering local aspects.



(a)

(b)

Figure 2: Cluster dendrogram. (a) Through adaptive methods against floods; and (b) By type of adaptive strategy applied. Ward D2 clustering method, with Euclidean distances.

But it should be clarified that all these strategies have to be taken with caution. It is known that they have been usable and functional solutions in certain contexts. But it is one thing to have found strategies to be considered as local constructive solutions, a product of the adaptation of societies, and another thing is that said strategies are completely efficient in any context. As expected, there are constant references in the literature to the use of materials and construction systems vulnerable to flooding, such as adobe constructions, mixed bamboo, and earth wall systems [47]. Therefore, not all strategies are universal solutions that can be replicated in any region, that is, not all are efficient architectural approaches.

Due to the above, it remains open for future research: (a) to assess the efficiency of the different strategies in the contexts where they are to be applied, (b) studies on the implications of the configurations, (c) future revisions expanding the number of observations with more cases and more regions, (d) to include in the studies the height permitted for buildings among the dwellings that apply this method – data that could not be obtained in all the cases analyzed – or (e) to replicate the analysis at different scales, to identify adaptive types at the city or regional level.

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