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Traditional and scientific knowledge for a sustainable vulnerability reduction of rural housing in Haiti

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ABSTRACT: On January 12, 2010, a M 7.0 earthquake strikes Haiti, affecting hundreds of thousands of victims and disrupting three million lives. Observations made after the disaster revealed that, in both urban and rural areas, occupants of traditional buildings were exposed to limited risk, thanks to the moderate vulnerability of these structures to seismic stress.

In areas affected by recurrent natural hazards, vernacular architectures often reveal a great deal of ingenuity regarding the use of available resources and the development of technical devices, reducing the vulnerability of built structures. However, the relevance and potential of these solutions remain marginally recognized by scientific community and organizations involved in post-disaster reconstruction.

In the framework of the ReparH research project, funded by the French National Research Agency, a collaboration was established between researchers from the field of architecture (CRAterre-ENSAG) and engineering (3SR- UJF), together with the Haitian organization GADRU, to reflect on supporting the development of reconstruction and vulnerability reduction strategies, based on local construction methods and resources.

This paper serves to present current research works in the context of two PhD theses addressing the issue of housing in risk prone areas, from a methodological and technical point of view. The first part deals with a method for the analysis of construction practices through the identification of the characteristics of existing buildings, local know-how and factors influencing the built environment of a community. The second part relates to the development of a scientific study, resulting from exchanges between field and academic work, dealing with a building system used for reconstruction, based on locally available materials such as earth, stone and wood.

1 ANALYSIS OF LOCAL BUILDING PRACTICES

The development of a qualitative method for the analysis of construction practices in a specific geographic area aims to address the existing need, applicable to field work and to scientific research, to implement investigation approaches that integrate the analysis of built structures, lifestyles and resources present *in situ*.

As part of a PhD in architecture developed within the CRAterre-ENSAG laboratory, this work is based on an iterative approach of design, experimentation, verification and adaptation, made possible mainly through practical applications in the field, achieved in the framework of programs of housing improvement in Haiti and risk reduction and disaster preparedness in Bangladesh.

The content of this analysis involves four main subjects, relative to the factors influencing the living space and the living environment of a given community. The natural and built environments imply the physical, climatic, geological and morphological analysis of the territory. Buildings, in terms of their architectural characteristics, are designed as a response to the needs,

desires and activities of their dwellers, but also represent the materialized result of combined technologies and materials. Knowledge and know-how compose the experience and comprehension developed by a group of people in shaping their habitat and in dealing with challenges that it presents. The tangible and intangible resources available include materials, the means and capacities to implement and develop a built environment as well as the ability to prepare and respond to crises.

The methodology is based on a participatory-driven approach, actively involving local populations and stakeholders in the collection, reworking and validation of information, as well as on a flexibility of investigative processes and supports to allow the necessary adaptation to each specific context. Its implementation is structured into different phases, alternating group meetings, individual interviews, the detailed analysis of constructions and direct observations, leading to the acquisition and verification of information by integrating data from multiple sources. Group meetings are aimed at the general public and at local authorities and representatives of local organizations, as well as, in the form of *focus groups*, at those involved in activities related to construction, such as artisans, self-builders and people in charge of specific tasks. The analysis of existing architectures allows identifying specific architectural and building characteristics of dwellings and the lifestyles of their dwellers. Individual interviews provide an opportunity to understand the factors influencing design, implementation and evolution processes of the built environment, as well as the common practices and specific measures linked to vulnerability reduction and risk preparedness. This information is complemented with direct observations carried out by the surveyors. Graphic supports are used to facilitate discussions with the persons interviewed, and later to present the survey results to local populations.

All these methods and tools were compiled based on a literature review including materials developed for humanitarian interventions (Abarquez, & Murshed 2004; IFRC 2007 et 2011), pre and post disaster evaluations (Cuny 1982 ; Debray 2008; UN-HABITAT 2010) as well analysis procedures for buildings, derived from the fields of heritage preservation (Ferrigni et al. 2005; Hicyilmaz, Bothara & Stephenson 2011) and engineering (Baggio et al. 2007; Hughes & Lubkowski).

2.1 Applications in Haiti

Between 2010 and 2012, an analysis of local building practices was conducted, in collaboration with Haitian associations, involving several field research trips, in the West and Southeast departments of Haiti. A special focus was given to the rural areas of Cap Rouge (Jacmel), Grande Rivière (Carrefour) and Clémansso (Kenskoff), all affected by the 2010 earthquake.

The items listed below are a portion of the collected information, allowing to capture some of the features of local houses and some existing measures taken to reduce their vulnerability to the natural hazards affecting the area (Cuny 1982; Douline & Bellin 2010; Moles 2010).

1.1.1 Building typologies

Across the studied areas, wooden frame housing units are the most common. Their design is based on a regular grid of wooden poles making the main structure of the building, infill techniques vary depending on the materials available locally.

Clissage is the most ancient technique. It consists of horizontal braided palm timber strips, forming panels that are inserted between the vertical elements of the wooden frame. Sometimes left exposed, these panels are usually covered on both sides with an earthen mortar or with a mixture of earth and lime. This technique allows to create lightweight structures, posing little threat to occupants as the braiding helps to avoid the possible collapse of large blocks (Cuny 1982). During the earthquake of 2010, damages to such constructions were very limited (Audefroy 2011; Douline & Bellin 2010) and concerned mostly the plasters, that either cracked or were pulled apart from their support. Recently, the shortage of wood and the association of such techniques with an image of poverty have led to their gradual abandonment, with a consequent loss of associated skills. However, due to its rapid implementation and the recognition of its good behavior during earthquakes, *clissage* has spontaneously been reused by local populations for the construction of emergency shelters and the repair of houses, based on ancient know-how.

Tiwoch is another technique that characterizes most rural dwellings present in surveyed areas, and it is very commonly applied in the construction of new buildings. It involves a supporting structure composed of wooden poles, with an infill of stone masonry and a mud, earth and lime or cement mortar.

Timber boards nailed to the poles define a third technique known as *palmiste*, once widespread but becoming inaccessible today due to the scarcity and high cost of wood. Aside from increasing the ease of implementation and extension of the structure, the boards serve as bracing elements, improving the general uniformity and rigidity of the structure.

1.1.2 Building practices reducing housing vulnerability

Many vernacular buildings incorporate devices to improve their structural behavior against the impact of natural hazards. Analysis conducted after the earthquake of 2010 revealed that, while presenting localized damage, oftentimes a consequence of previous structural deterioration, traditional buildings generated few casualties. Damages mostly affected the secondary structures of such buildings, while the main structure and most expensive portions were preserved, making them easily repairable, both financially and technically.

Indeed, builders often modified and improved constructions, developing solutions to reduce the vulnerability of structures. However, while the implementation of one of these solutions did not often improve sufficiently the behavior of the construction, it is interesting to note that several devices are generally incorporated into the same structure and that, together, they truly improve the behavior of buildings facing recurring events, such as hurricanes, but also less frequent disasters, such as earthquakes (Mora et al. 2010).

In vernacular houses, the low height of the building helps to enhance wind resistance and, as their center of gravity is lowered, this also increases the resistance to earthquakes. Regarding wood structures, horizontal bracing at the four corners of the wall plate consolidate the structure (Fig.1a), while at the level of the roof, diagonal braces between the ridge beam and the king posts ensure the stability of the roof structure (Fig.1b). Mortise and tenon joints allow slight deformations of the building, while maintaining structural integrity.

In addition to the technical characteristics of wood frame partitioning, the gradual reduction on the thickness of walls and use of lighter materials on the upper portions help protect occupants in the event of a partial collapse of the walls (Fig.1c).



Figure 1. Grande Rivière : (a) bracing of the frame, (b) bracing of the roof structure, (c) gradual reduction of the thickness of the wall.

To increase resistance to strong winds, several devices of vernacular architectures correspond to some principles advocated by hurricane engineering as practiced today. A four pitches roof with slopes of about 30 degrees as well as the small roof overhangs reduces wind impact on the construction.

The uncoupling between the roof structure of the main house and the one of the veranda reflects the principle of structural disconnection between primary and secondary structures; the gallery plays the role of a fuse element as, even if torn out, it will not compromise the main roof structure (Fig.2a).

In addition, some architectural elements serve a purpose beyond aesthetics and function as they also assume a structural function; aside from providing a space for safekeeping, closed granaries bring greater resistance to roof and this is especially the case for roofs with two slopes. Similarly, the enclosures of veranda made of crossed timber planks, secure the struc-

tures, and even if the lower masonry wall collapses, they maintain a relative consistency and a full collapse is thus prevented (Figure 2b). The decorative friezes adorning the gables help deflect the wind flow and thus minimize depressions likely to tear off roofs (Barré et al. 2011).



Figure 2. Grande Rivière : (a) disconnection of the structure of the gallery, (b) bracing of the gallery and decorative frieze (c) Cap Rouge: reduced height and vegetation barrier as protection against strong winds.

The existence and application of strategies for vulnerability reduction, integrated into the environmental management (Fig.2c), the architectures, the practices and the knowledge within a given community stress the importance of systemically taking into account the characteristics of a context, by considering the multifaceted, functional, aesthetic, structural and cultural characteristics of housing structures and their relationship with their environment.

1.2 Considerations

While supporting programs centered on the repair and reconstruction of housing structures, the work started in Haiti allowed to meet two objectives. On the one hand, to collect detailed information on buildings and on vernacular skills that may contribute to improve the technical and methodological solutions offered through ongoing programs. On the other hand, to enable local actors to develop skills so as to independently conduct surveys on existing structures, to be applied as part of future risk reduction activities.

A pilot phase was launched in April of 2012 in collaboration with the Haitian association GADRU, engaged in a reconstruction program supported by the German NGO Misereor. Since July 2012, three other local associations became involved in the survey process, as a way to dispose of specific elements to adapt the processes and contents of projects, current and future, to the characteristics of each site.

This work resulted in the dissemination of the methodology developed as part of the thesis research to local partners, and its appropriation by the latter. Although this process is still ongoing, newly acquired skills have already been used independently by Haitian partners in preparation of the next phases of the reconstruction program.

The interest expressed by the partners in this work and the remarks made following numerous post-disaster interventions (Duyne Barestein 2006, Caimi & Hofmann 2010, Jha et al., 2010) emphasize the need to implement an approach based on the specific aspects, potentials and constraints of each site, to improve the technical and economic accessibility of building proposals and to strengthen the capacities of communities in the management and handling of future crises.

The data resulting from the implementation of this methodology can form the basis of a process of development, validation and implementation of building and operational principles that may contribute to the improvement of technologies known locally and support existing dynamics.

The analysis of existing structures is combined with an anticipation of the impact of future hazards, through the identification of the technical, logistical and organizational resources on which post-disaster interventions could be based, integrating the continuity of the process of construction and evolution of the built environment within a community.

The information gathered is used to undertake a technical study of vernacular architectures, and thus develop research approaches that pave ways to the development and implementation of building activities that help to improve existing housing based on its own specificities.

To understand the characteristics of local housing and the coping strategies of local populations, and, at the same time, to recognize local knowledge and expertise, could become a real starting point toward the reduction of vulnerability in the long term.

2 EXPERIMENTAL STUDY OF A TYPE OF STRUCTURE IMPLEMENTED IN A CONTEXT OF POST-EARTHQUAKE RECONSTRUCTION

In Haiti, traditional buildings have long demonstrated their effectiveness against natural disasters. But yet they remain unrecognized by stakeholders in the construction field, mainly due to the lack of available scientific data. This observation is the starting point of the collaboration between researchers (architects) from the CRAterre-ENSAG laboratory, who acknowledge the value of such architectures, and researchers from the 3SR-UJF laboratory (engineers) who are capable of leading a study on the latter. In fact, the architects already collaborate with several NGOs, leading a number of construction and rehabilitation projects in rural and peri-urban areas around Haiti. The foundation of these programs is based on the idea of bringing a sustainable contribution to local populations, based on the development of local building cultures.

The first idea was to use as much as possible relevant local resources and know-how. To this end, the observation and study of traditional architectures and the interaction with local populations are essential to understand what materials are available on site, construction techniques, the methods of production and construction management and construction costs. In rural areas, a visual inspection allows to make the following observations: local populations often have a very modest income and the construction techniques used are linked to the specific geographical areas where they developed (wood frame filled with stonework bound by an earth-based mortar, timber frame panels filled with mud, stone masonry).

Road infrastructures are very limited, making the transportation of materials a complicated task. As a result, the use of steel frames and reinforced concrete is expensive. Haitians use locally available materials for construction: stones, earth and, to a lesser extent, wood. When not available, the transportation of wood is still relatively easy to manage.

Another idea was to reproduce the intelligent building methods identified during surveys, such as the bracing systems for structures, and at the same time improve existing buildings and overcome the main weaknesses of local building systems by improving, for example, ground anchorage systems and the bracing of superstructures. Thus, posts directly anchored in the ground, that tend to rot fairly quickly, are replaced by a system of poles anchored to a wall base and bracing systems are reinforced through the implementation of St Andrew's crosses.

In both cases, analysis of local building practices are a very pertinent means to identify intelligent building systems.

The results of the work described above have enabled the development of several types of model homes, achieving a compromise between costs, the respect of local cultures and seismic resistant performances: 1. timber frame, cross-braced with a stone infill 2. same structure but filled with adobe bricks or wattle and daub 3. tied natural stone masonry.

The thesis work performed at the 3S-R laboratory consisted in the study, from a seismic point of view, of one of such structural types. There is little available literature on the subject (Ali & al. 2012, Ceccotti & al. 2006 et Meireles & al. 2012), which led to the choice of one particular type of structure. The major challenge is to provide scientific evidence of the relevance of earthquake resistant characteristics of these buildings, directly inspired by traditional buildings and building local cultures.

The selected building system chosen for the study was typology 1 as it is the most widely used in reconstruction projects in which CRAterre-ENSAG architects participate. Other alternatives were also studied through an experimental parametric analysis.

In order to analyze the behavior of a wood-frame structure with a Saint Andrew's cross type bracing and a stone infill, the study is based on a multi-scale approach aiming at understanding the behaviors, at different levels, of a housing unit subject to earthquakes (connections, elementary cell unit, the entire house). At every scale, the necessary information was obtained to predict structural behavior at a larger scale. At each level, an experimental study was conducted or will be conducted, to provide comparative data to develop a computer model that will predict the behavior of the housing structure. The scale of the totality of the structure has not yet been studied. A similar approach is applied in Boudaud et al. 2010 and in Folz et al. 2001.

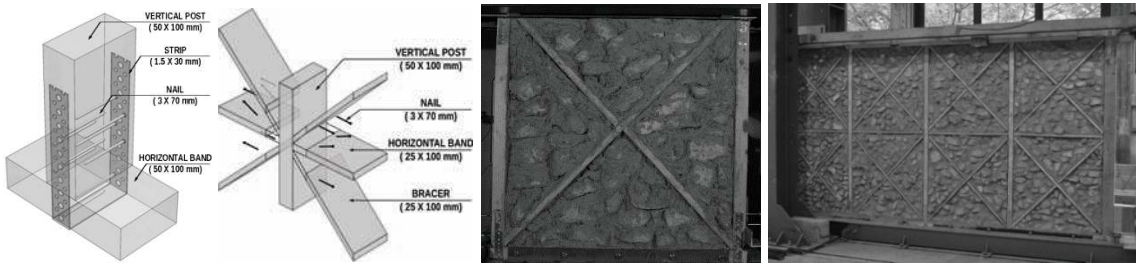


Figure 3. (a) main connection, (b) secondary connection, (c) cell unit, (d) wall.

2.1 At the scale of connections

The assembly studied is a beam-column connection maintained by a perforated and nailed metal strip (see Fig. 3a). It governs the earthquake resistant behavior of the wall. Connections between diagonal and horizontal elements represent secondary connections (see Fig. 3b). They have a limited influence on the earthquake resistant behavior of walls and for this reason they have not been studied.

The post and beam connection was tested in terms of tensile strength and shear through three monotonic tests and one cyclic test. The influence of the number of nails and their type on structures has also been tested.

Results show that the tensile strength of the assembly is proportional to the number of nails employed. However, in terms of shear resistance, beyond 4nails the effectiveness is limited. It was also shown that the ability of nails to deform can greatly influence the quality of a connection and its brittle behavior. An assembly including 16 common nails is deformed until the nails are loosened, whereas a connection including 8 ring shank nails, allowing a resistance equivalent to the previous configuration becomes fragile and breaks through the rupture of the metal strip. In the case of a seismic resistant structure, this type of breakage must be avoided. Therefore, the use of common nails is a better option, in every way, as these are more deformable and much cheaper.

These results allow us to quickly assess the strength of this type of connection and measure its limits. These tests and results are very important for the development of construction in-situ because they provide some very concrete understanding on connections and, being an expensive product, help optimize their use based on the number of nails, their type and the characteristics of metal strips.

2.2 At the scale of the cell unit

By conceiving the wall as an assembly of wooden frames braced with St. Andrew's crosses (see Fig. 3c and 3d) we can experimentally model wall configurations based on a combination of basic cells. Testings made at this intermediate structural scale can be useful to easily compare the influence of several parameters: type of infill, contribution of bracing and other technical details. As described above, several types of structures are implemented directly on site. It is therefore interesting to have the possibility to evaluate the variations in the behavior of the structure according to the building techniques employed. For this purpose, to test the walls at the scale of the cell is ideal, as this allows to test options in a fast and inexpensive way, unlike other types of testing that would take into account the wall as a whole.

Figure 4a compares the envelope curves obtained under cyclic loading for a braced cell unit filled with stone, a cell filled with adobe bricks, and empty cell and an unbraced cell with a stone infill. The curves show that type of infill has little effect on the overall response. Thus, at the level of the cell, as long as the infill is less rigid than the wood frame, it is the wood frame that governs its behavior completely, and so, in the absence of bracing, its resistance decreases much for the same reasons.

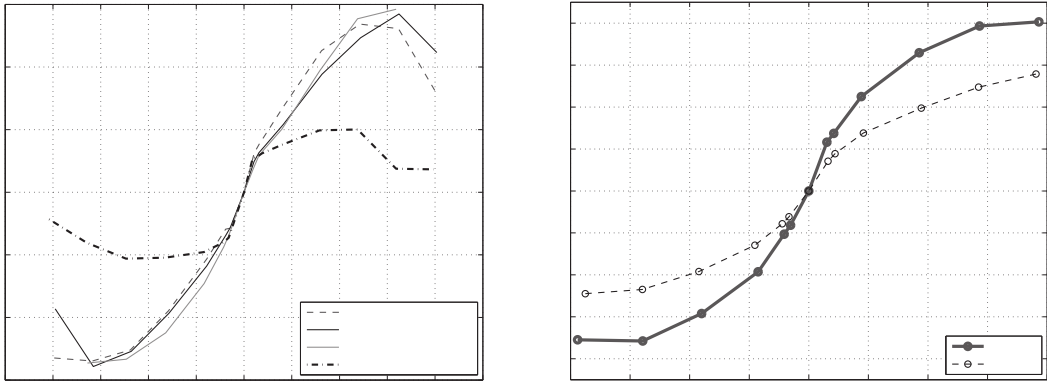


Figure 4. Force-displacement diagram at the scale of: (a) the individual cell (b) the wall

2.3 At the scale of the wall

Figure 4b shows the envelope curves obtained for a wall filled with stones and for an empty wall tested under cyclic loading. This time, contrary to results shown for the cell unit, the infill plays an important role on the global structural behavior. Thanks to the observations made in the previous paragraph, we can understand that the ductile behavior obtained in the absence of infill is explained partly first by the flexibility of secondary connections and second by their freedom of movement. So, without infill, the structure deforms more easily. These results complement the observations made at the cell level by providing additional information on the quasi-static response of this type of structure (cf. Vieux-Champagne & al. 2012).

2.4 Scientific results applicable on the ground

This thesis work, beyond the results reported in this paper, provides considerable support for the development of projects using this type of structure. Currently, due to their low cost and their viability in the context of rural (and peri-urban) Haiti, the use of timber framing techniques is developing at a fast pace, so much so that the Haitian Ministry of Public Works, Transport and Communication (MTPTC) has validated the timber frame and *St Andrew's cross bracing system*.

It will also help to bring answers to a number of technical questions that builders may have.

Finally, it will provide an experimental basis that may serve as a foundation for a study predicting the behavior of structures under seismic loading.

3 CONCLUSIONS

Maintained throughout the research process, the connection between academic and operational settings made it possible, on the one hand, to adapt the development of research work to the actual needs of the rural Haitian context, and on the other hand, to contribute directly to the activities carried out by local stakeholders.

Combining a scientific approach and the realities on the field, this multidisciplinary collaboration between architects and engineers takes advantage of the complementary skills of partners to identify strategies for improving the resilience of local populations, based on local knowledge, dynamics and resources.

This approach allows, first, to enlarge the criteria considered in terms of research, anchoring results to real constraints and potentials, and second, to explore and experiment with methodological approaches and technical proposals that can be accessed and owned by local populations, helping to build up their capacity to respond to the challenges posed by the environment they inhabit.

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