Timber Structures and Architectures in Seism Prone Areas Included in the UNESCO World Heritage List

(Progress Report)

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A study carried out by the authors about the timber architectures and load bearing structures in the UNESCO World Heritage List evidenced, even if a very small number of ancient timber structures are inscribed, a widespread presence of this constructions in the world as well as a large number of typologies.

This study showed that in many Countries and in several cases, timber structures and wooden architectures are not the object of conservation and appropriate repair and are suffering from neglect and alteration. This situation, which has been evidenced from the study of the files on the monuments inscribed in the UNESCO World Heritage List, should give rise to much concern for the possible effects of structural failure, especially for the buildings which are in seism prone areas. It must be added that, except for some recently inscribed specimens, the List is mainly based on old traditional concepts related to aesthetic and historic values only and little attention is paid to the load bearing structure; but we ought to remember the importance of the efficiency of the structural mechanism, which is the main responsible for the survival of the architectural heritage.

In the seism prone areas, all over the time, man experimented a large number of structural systems to prevent injuries from earthquake and, according to experience, tried to improve the building techniques. The wooden structures, because of the lightness (related to the strength) of the material and the ductility of the connections, proved to be more efficient than other systems; this is one of the reason for their diffusion all over the world.

We can tell about very simple anti-seismic constructions, like the pre-Hispanic huts and houses in Joya de Cerén, San Salvador (c. 600), or about the reconstruction of San Francisco de Lima, Peru after 1657 adopting the traditional native techniques (reeds and mud). The Portuguese Gaiola, a structural system conceived for the reconstruction of the city of Lisbon destroyed by the terrible earthquake occurred in the year 1755, as well as the Casa Baraccata of Vivenzio in Italy (after 1788), are interesting example of made-on-purpose planning of seism-resistant systems.

The paper deals with the main systems documented in the UNESCO World Heritage List.

1. The "*Wooden World Heritage*" and the "World Heritage List in Danger" in relation to the seismic risk

With the analysis of the World Heritage Dossiers kept in the UNESCO-ICOMOS Documentation Centre in Paris, we can draw up a list of the "Wooden World Heritage". At present this does not include every timber structure or wooden architecture which is in every site inscribed on the World Heritage List, but the list of every site where the presence of timber in the structures is documented.

AFRICA

BENIN:	**1985** Royal Palaces of Abomey
ETHIOPIA:	**1978** Rock-Hewn Churches, Lalibela
	1979 Fasil Ghebbi, Gondar Region
GAMBIA:	**2003** James Island and Related Sites
MADAGASCAR:	**2001** Royal Hill of Ambohimanga
MALI:	**1988** Old Towns of Djenné
	1988 Timbuctù
	1989 Cliff of Bandiagara (Land of the Dogons)
	2004 Tomb of Askia
MOZAMBIQUE:	**1991** Island of Mozambique
NIGERIA:	**1991** Sukur Cultural Landscape
TOGO:	**2004** Koutammakou, la terra dei Batamarriba
UGANDA:	**1994** Tombs of Buganda Kings at Kasubi

ARAB STATES

ALGERIA:	**1992** Kasbah of Algiers
EGYPT:	**1979** Islamic Cairo
	2002 Saint Catherine Area
MAURITANIA:	**1996** Ancient *Ksour* of Ouadane, Chinguetti, Tichitt and Oualata
MOROCCO:	**1985** Medina of Marrakesh
	1997 Medina of Tétouan
	2001 Medina of Essaouira
	2004 Portuguese city of Mazagan
OMAN:	**1988** Archaeological Sites of Bat, Al-Khutm and Al-Ayn
SYRIAN ARAB REPUBLIC:	**1986** Ancient City of Aleppo
TUNISIA:	**1979** Medina of Tunisi
	1988 Kairouan
YEMEN:	**1992** Old Walled City of Shibam
	1993 Historic Town of Zabid

ASIA AND PACIFIC

AFGHANISTAN:	**2002** Minaret and Archaeological Remains of Jam
AUSTRALIA:	**1981** Willandra Lakes Region
	2004 Royal Exhibition Building and Cariton Gardens
CHINA:	**1987** Mogao Caves
	1987 Mount Taishan
	1987-2004 Imperial Palaces of the Ming and Qing Dynasties in Beijing and Shenyang
	1994-2000-2001 Historic Ensemble of the Potala Palace, Lhasa
	1994 Mountain Report and its Outlying Temples, Chengde
	1996 Lushan National Prak
	1997 Ancient City of Ping Yao
	1997 Old Town of Lijiang
	1997-2000 Classical Gardens of Suzhou
	1999 Mount Wuyi
	2000 Ancient Villages in Southern Anhui-Xidi and Hongcun
	2000 Mount Qingcheng and the Dujiangyan Irrigation System
	2000-2003-2004 Imperial Tombs of the Ming e Qing Dynasties
INDIA:	**2003** Rock Shelters of Bhimbetka
	2004 Chhatrapati Shivaji Terminus
JAPAN:	**1993** Buddhist Monuments in the Horyu-ji Area
	1993 Himeji-jo
	1994 Historic Monuments in the Ancient Kyoto (Kyoto, Uji and Otsu Cities)
	1995 Historic Villages of Shirakawa-go and Gokayama
	1996 Itsukushima Shinto Shrine
	1998 Historic Monuments of Ancient Nara
	1999 Shrines and Temples of Nikko
	2004 Sacred Sites and Pilgrimage Routes in the Kii Mountain Range
KAZAKHSTAN:	**2003** Mausoleum of Khoja Ahmed Yasawi
MONGOLIA:	**2004** Orkhon Valley Cultural Landscape
REPUBLIC OF KOREA:	**1995** Haeinsa Temple Janggyeong Panteon, the Depositories for the *Tripitaka Koreana* Woodblocks
	1995 Jongmyo Shrine
	1997 Changdeokgung Palace Complex
	1997 Hwaseong Fortress
UZBEKISTAN:	**1990** Itchan Kala
	1993 Historic Centre of Bukhara
	2000 istoric Centre of Shakhrisyabz
	2001 Samarkand - Crossroads of Cultures
VIETNAM:	**1999** Hoi An Ancient Town

EUROPE (Progress Report)

FINLAND	**1991** Old Rauma
	1994 Petäjävesi Old Church
FRANCE	**1988** Strasbourg –Grande île
GERMANY	**1993** Maulbronn Monastery Complex
ITALY	**1987** Venice and its Lagoon
LATVIA	**1997** Historic Centre of Riga
LITHUANIA	**1994** Vilnius Historic Centre
NORWAY	**1979** Bryggen
	1979 Urnes Stave Church
	1980 Róros
POLAND	**1978** Wieliczka Salt Mine
	2001 Churches of Peace in Jawor and Swidnica
	2003 Wooden Churches of Southern Little Poland
PORTUGAL	**2001** Historic Centre of Guimarães
ROMANIA	**1999** Wooden Churches Maramureş
RUSSIAN FEDERATION	**1990** Kizhi Pogost
SLOVACK REPUBLIC	**1993** Vikolínek
SPAIN	**1986-2001** Mudejar Architecture of Aragon
TURKEY	**1985** Historic areas of Istanbul

LATIN AMERICA AND CARIBBEAN

ARGENTINA:	**2000** Jesuit Block and Estancias of Córdoba
	2003 Quebrada di Humahuaca
ARGENTINA/ BRAZIL:	**1983–1984** Jesuit Missions of the Guaranis
BOLIVIA:	**1987** City of Potosí
	1990 Jesuit Missions of the Chiquitos

	1991 Historic City of Sucre
BRAZIL:	**1987** Brasilia
	1999 Historic Centre of the Town of Diamantina
CHILE:	**2000** Churches of Chiloé
	2003 Historic Quarter of the Seaport City of Valparaíso
	2005 Humberstone and Santa Laura Saltpeter Works
	2006 Sewell Mining Town
COLOMBIA:	**1984** Port, Fortresses and Group of Monuments, Cartagena
	1995 Historic Centre of Santa Crux de Mompox
CUBA:	**1982** Old Havana and its Fortifications
	1988 Trinidad and the Valley de los Ingenios
	1997 San Pedro de la Roca Castle, Santiago de Cuba
	1999 Viñales Valley
	2000 Archaeological Landscape of the First Coffee Plantations in the South-East of Cuba
EL SALVADOR:	**1993** Joya de Ceren Archaeological Site

GUATEMALA	**1979** Antigua Guatemala
HAITI	**1982** National Historic Park – Citadel, Sans Souci, Ramiers
MEXICO	**1987** Historic Centre of Mexico City and Xochimilco
	1987 Historic Centre of Puebla
	1991 Historic Centre of Morelia
	1998 Archaeological Zone of Paquimé, Casas Grandes
	2003 Franciscan Missions in the Sierra Gorda of Querétaro
	2004 Luis Barragán House and Studio
NICARAGUA:	**2000** Ruins of León Viejo
PANAMA	**1980** Fortifications on the Caribbean Side of Panama: Portobelo-San Lorenzo
	1997 Archaeological site of Panamá Viejo and Historic District of Panamá
PERÙ:	**1983** City of Cuzco
	1983 Historic Santuary of Machu Picchu
	1986 Chan Chan Archaeological Zone
	2000 Historical Centre of the City of Arequipa

SURINAME:	**2002** Historic Inner City of Paramaribo
URUGUAY:	**1995** Historic Quarter of the City of Colonia del Sacramento
VENEZUELA:	**1993** Coro and its Port
NORTH AMERICA	
CANADA:	**1978** L'Anse aux Meadows National Historic Site
	1981 SGaan Gwaii (Antony Island)
	1985 Historic District of Québec
	1995 Old Town Lunenburg
U.S.A.	**1978** Mesa Verde
	1979 Independence Hall
	1982 Cahokia Mounds State Historic Site
	1983 La Fortaleza and San Juan Historic Site in Puerto Rico
	1987 Chaco Culture National Historic Park
	1992 Pueblo de Taos

Among the sites listed above only 6 are included on the List of World Heritage in Danger in accordance with Article 11 of the Convention of 1972. Among these 6 sites which are highlighted in grey on the list above, no one has been included on the List of World Heritage in Danger because they are at risk of earthquake. Is it a simple coincidence or maybe it is a demonstration that timber structures in many cases perform their duties in a satisfactory way?

2. The Wooden World Heritage in the Zones of Global Seismic Hazard

The purpose of this study is to analyse the value given to the anti-seismic wooden structures in the World Heritage as a mechanism. The first step to achieve this result is the research of the areas in the world with the highest level of seismic risk and the second is the analysis of the World Heritage Dossiers where we have found plenty of documented wooden architectures.

The Global Seismic Hazard Map is the result of a demonstration project: "The Global Seismic Hazard Assessment Program" (GSHAP) of the UN/International Decade of Natural Disaster Reduction conducted in the 1992-1998 period.

"Seismic hazard is defined as the probable level of ground shaking associated with the recurrence of the earthquakes. The assessment of seismic hazard is the first step in the evaluation of seismic risk, obtained by combining the seismic hazard with vulnerability factors (type, value and age of buildings and infrastructures, population density, land use, date and time of the day)."

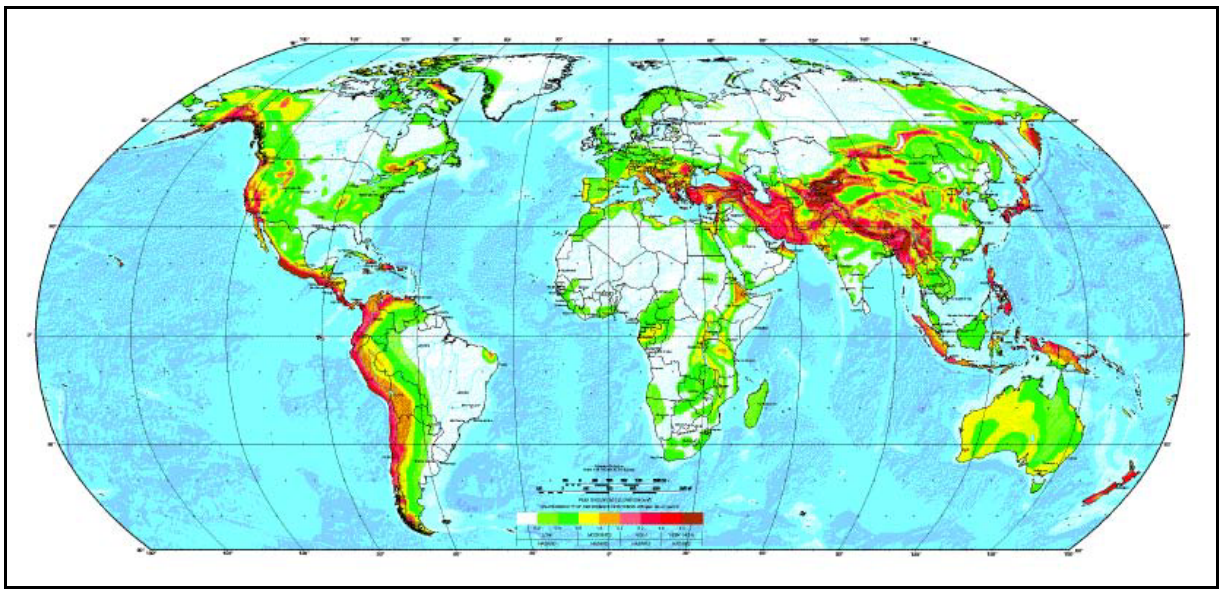


Fig. 1
The Global Seismic Hazard Map
The cooler colours represent lower hazard while the warmer colours represent higher hazard. White and green correspond to low hazard (0-8% g, where g equals the acceleration of gravity); yellow and orange correspond to moderate hazard (8-24% g); pink and red correspond to high hazard (24-40% g) and dark red and brown correspond to very high hazard (> 40% G).
(From Giardini D., Grüntal G., Shedlock K., Zhang P., 1999 (?), *The GSHAP Global Seismic Hazard Map*. From: www.seismo.ethz.ch/GSHAP/)

For the research it is very important to understand the difference between risk and hazard because the construction techniques and the degree of conservation of timber structure together with the population density are important vulnerability factors.
"Frequent, large earthquakes in remote areas result in high seismic hazard but pose no risk; on the contrary, moderate earthquakes in densely populated areas entail small hazard but high risk."[1] For this reason we have to evaluate every site studied and every construction technique has to be evaluated in relation to the characteristics of the territory.

The comparison between the "Global Seismic Hazard Map" and the map of the "*Wooden World Heritage*" shows that there is a considerable overlap with seism prone areas and timber structures. It is possible to list about thirty countries where we have found there is a great deal of documented wooden structures and that are represented with warmer colours in the "Global Seismic Hazard Map". As a reference and to find the correspondence on the figure 1, these Countries are:

AFRICA: Ethiopia
ARAB STATES: Costal areas of Algeria and Tunisia.
ASIA and PACIFIC: Afghanistan, China, Iran, Japan, Uzbekistan.

[1] *Giardini D., Grüntal G., Shedlock K., Zhang P., 1999 (?), cit.*
[2] *idem*

EUROPE (Progress Report): Albania, Bulgaria, Greece, Italy, Romania, Slovenia, Turkey, Yugoslavia.
LATIN AMERICA and CARIBBEAN: Argentina, Bolivia, Chile, Colombia, Cuba, Dominican Republic, El Salvador, Guatemala, Haiti, Mexico, Nicaragua, Panama, Peru, Venezuela.

It is very interesting to remark that countries like Indonesia, New Zealand, Philippines etc, which are in very high hazard zones, are not listed above. The first reason is because there is no information about timber structures in the World Heritage Dossiers and the second reason is because some of these Countries have almost all their natural sites inscribed on the List. The problem of this kind of inscription is that a very large number of very interesting wooden vernacular architectures are at risk of disappearing.

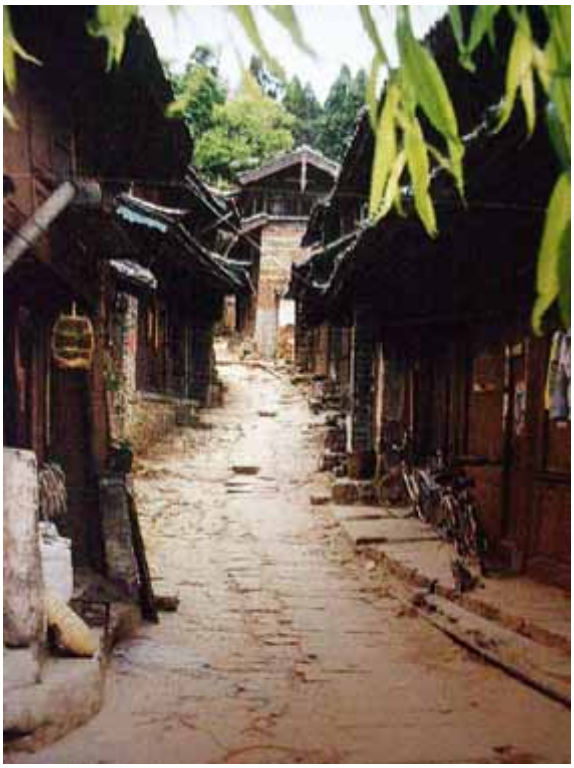
3. "World Heritage Dossiers" (Nomination Form by the State Party + ICOMOS Evaluation) and Seismic Risk: documentations, studies and strategies

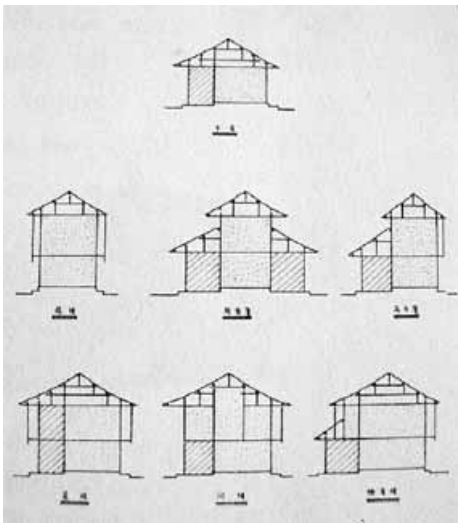
The study carried out about the typologies and strategies of conservation of wooden structures in the sites inscribed on the World Heritage List becomes very important for the specimens located in a seism prone area. The strategies of conservation are different and often there is to learn from the past and discover reliable anti-seismic methods.
The inscription on the List has a very important task: the preservation of the cultural heritage for the present and future generations and this task includes a good analysis of the risks especially when the risk may cause the disappearance of a property in a very short time.
The first step to preserve a listed architecture is a good documentation about all its aspects, especially a study able to let understand its mechanism, because this is the first responsible for the survival of the property itself. Unfortunately the List is mainly based on old traditional concepts related to aesthetic and historic values and only little attention is paid to the load bearing structures. Obviously the same lack of documentation that has been found in the "World Heritage Dossier" about timber structures has repercussions on the description and the interpretation possibility of the timber seismic mechanisms. The present study, based on the most important wooden architectures in the world, starts from the preliminary information taken from the World Heritage Dossiers and then it is based on the existing documentation collected elsewhere.

4. FORMS on "Timber Structures and Architectures in Seism Prone Areas" in the UNESCO World Heritage List

Among the analysed dossiers have been chosen some of the most meaningful ones.

China, 1997, Old Town of Lijiang – Site n°811, (C ii, iv, v)	
Geographical location	The Old Town of Lijiang is situated in the central part of Southern China, in the North-western part of the Province of Yunnan at the foot of the Yulong (jade dragon) Mountain.

Brief description of the property from the point of view of the building types	The dwellings have a unique ethnic style. There are several plane layouts: 1. *Sanfangyizhaobi* (one main house, two side houses and a screen wall facing the main house) 2. *Sihewutianjing* (a compound with houses around a square courtyard) 3. *Yijingduoyuan* (a compound with multiple courtyard in a vertical row) The houses are usually built on slopes and most of them are two-storied.  **Dwellings in Lijiang.** From: China, 1994, *World Heritage List Nomination of the Old Town of Lijiang*
Chronology of earthquakes	**19th June 1481**. The quake destroyed many walls, and was followed by about 80-90 after-tremors day and night until 24th June. **6th May 1515.** An earthquake hit Dali affecting Lijiang and all the dwellings were destroyed. **1624.** An earthquake measuring 5 on the Richter scale hit Lijiang. The intensity of the tremor was 6 magnitude and some of the houses were destroyed. **25th May 1751.** An earthquake measuring 6.5 on the Richter scale and with an intensity of 9 magnitude hit Jianchuan and affected Lijiang. 242 houses were destroyed and 18 people were killed. **20th December 1895.** An earthquake measuring 5,5 on the Richter scale and with an intensity of 7 magnitude. After tremors continued till March of the following year. Some houses collapsed. **1st March 1933.** Lijiang was hit by an earthquake measuring 5 on the Richter scale. **21st December 1951.** Lijiang was affected by an earthquake measuring 6.5 on the Richter scale, with the epicentre in Jianchuan. In all 65 people were killed and 633 wounded and 4345 houses were destroyed. **8th April 1961.** Lijiang was hit by a tremor measuring 5 on the Richter scale. **3rd February 1966.** Lijiang was hit by a strong earthquake measuring 7 on the Richter scale. The intensity at the epicentre was 9 magnitude. Some houses in the old town were seriously damaged. **9th June 1977.** Lijiang was hit again by an earthquake measuring 5 on the Richter scale.

Information about anti-seismic wooden structures <u>from the World Heritage Dossier</u>	
The traditional constructive systems	As Lijiang is located in an area prone to earthquakes, the local people have accumulated large experiences in anti-quake engineering. The unique wooden structures of their dwellings have very good resistance to earthquakes. In particular, special techniques are adopted to design the weight-bearing points, height and joints of he wooden frameworks so that even when the walls collapse the houses do not. It is for this reason that Lijiang old town has survived numerous earthquakes. The dwellings are normally 7.5 meter-high. The typical pattern consist of a *chuandoushi* wooden framework, adobe walls, a tile roof and an external corridor. The wooden framework is pretty flexible with two basic roof patterns: *Xuanshan* and *Yingshan*. All the main weight-bearing points have such devices as *lemagua*, *dijiao*, *chuanfang* and *qianjing* to reinforce the entire structure. All the pillars lean inward in a 1% degree of inclination, also to increase the stability of the structure. All the joints of the wooden framework use *liangdeng tenon*, *datou tenon* and *pingchan tenon*; hidden conical wedges are used to fasten the soft joints so that the whole structure can be resilient to earthquakes. The walls are heavy in the lower part (adobe) an light in the upper part (boards); they are also very strong.  **Constructive schemes in Lijiang.** From: China, 1994, *World Heritage List Nomination of the Old Town of Lijiang*
The earthquake repair and reconstruction	After the earthquake of 3rd February 1996 when the old town suffered considerable damage, plans were worked out to restore the city's style and features and to maintain its original urban space character. In the meantime, the density of ancient buildings and the density of the population have been reduced by demolishing some buildings that did not match with the city's overall style and features and some old and dangerous buildings in the high density areas. Living conditions, transportation and the ability to withstand and prevent disasters have been enhanced.
Additional information about anti-seismic wooden structure from documentation <u>found elsewhere</u>	
The traditional constructive systems	No further information is available to complete the World Heritage Dossier.
The earthquake repair and reconstruction	The additional information found is more detailed from the point of view of the costs and of the aids of the reconstruction after the last earthquake and is related to the organization of the repairs.

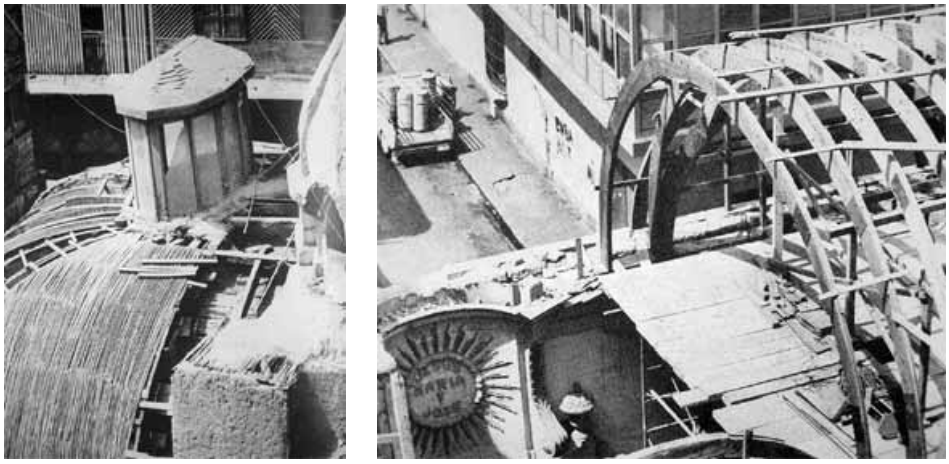
	The works of the earthquake repair focused not only on re-housing the population, but also on improving living standards, increasing the earthquake resistance of structures and preserving the World Heritage quality of the building and their urban environment. The damage could be classified into five categories: 1. collapse of the entire timber-framed structure; 2. collapse of mud bricks walls leaving the frame damaged but standing; 3. loss of roofing tile or the weatherproofing bond between tiles; 4. displacement of columns from their stone bases; 5. severe damage to internal structures and finishes. In many cases the traditional construction technique of connecting the walls to the timber frames loosely allowed the frames to shake without collapsing. The Provincial Construction Commission issued the "Design and Construction Technical Requirement for Houses in Lijiang Prefecture". These Guidelines, which were sent to every resident and enterprise in the Old city and were disseminated through television and newspapers, explained the reinforcing techniques and materials that should be used to make housing safer in future earthquakes, such as putting in place vertical and horizontal reinforcement poles, netting in the walls etc.

Bibliographic references	▪ China, 1994, *World Heritage List Nomination of the Old Town of Lijiang* ▪ ICOMOS, 1997, *ICOMOS Evaluation of the Old Town of Lijiang* ▪ Ebbe K., Hankey D., 2000, *Case Study: Lijiang, China – Earthquake Reconstruction and Heritage Conservation,* God-made Printing (Culture in Sustainable Development – Social Development Departement, Urban development Sector Unit East Asia and Pacific Region, The World Bank)

Remarks	In the World Heritage Dossier it is high lightened the importance of the performances of the traditional dwelling structures for the seism resistance. This is a rare example of satisfactory World Heritage Dossier from this point of view.

Peru, 1988-1991, Historic Centre of Lima – Site n°500 bis, (C iv)

Geographical location	The city of Lima, capital of Peru, is located on the Peruvian Pacific coast.
Brief description of the property from the point of view of the building types	From the World Heritage Dossier only little information about the Complex of the Convent of San Francisco. (See in the paragraph about traditional constructive systems)
Chronology of earthquakes	**9th July 1586.** **4th February 1656.** **20th October 1687.** **1746.** The earthquake destroyed domes and bell towers and left only 25 of the 6000 houses in metropolitan Lima standing. **1966.** **1970.** **1974.**

Information about anti-seismic wooden structures **from the World Heritage Dossier**	
The traditional constructive systems	The first construction of this complex was built when Friar Francisco of Santa Ana took charge of some of the lots in Lima: he built a small chapel with walls and benches of adobe until a church was finally started in 1550. The temple of San Francisco weakened by alterations, defective roofs and continuous earthquakes, collapsing on the 4th February 1656, when a main pillar gave way. The Portuguese architect Constantino de Vasconcellos worked in the demolition of what remained of the temple and in the reconstruction of a new one. Attributed to Vasconcellos was the ingenious proposal to build roofs with a flexible response during earthquakes, using wood, cane and stucco, instead of stone or bricks, in order to constitute a light structure, at low cost and with efficient technical performance.
The earthquake repair and reconstruction	In 1657 Constantino de Vasconcellos adapted the baroque structures to the risk of earthquake by applying indigenous construction technique. During the last restoration-reconstruction after the terrible earthquake of 1974 maybe they used the same systems used by Vasconcellos. Unfortunately no technical information about these works is recorded in the World Heritage Dossier, but only some pictures without captions. Only suppositions are possible.  **Restoration of vaults and domes of San Francisco** From: A.A.V.V., 1985, *Proyecto Restauracion de San Francisco de Lima y Museo de Arte Virreinal, Restauración, Julio 78-85*
Additional information about anti-seismic wooden structures from documentation found elsewhere	
The traditional constructive systems	At present no additional data are available.
The earthquake repair and reconstruction	At present no additional data are available.

Bibliographic references	▪ ICOMOS, 1988, *ICOMOS Evaluation of the San Francisco de Lima* ▪ ICOMOS, 1990, *ICOMOS Evaluation of the Historic Centre of Lima* ▪ A.A.V.V., 1985, *Proyecto Restauracion de San Francisco de Lima y Museo de Arte Virreinal, Restauración, Julio 78-85* ▪ A.A.V.V., 1987, *San Francisco de Lima, Rescue of cultural Heritage,* Lima:

	Industrial Grafica ▪ Peru, 1990, *World Heritage List Nomination of the Historic Centre of Lima*

Remarks	In the World Heritage Dossier concerning Lima, the documentation about timber structures that was found, is very poor. It is a typical example of a site where there is plenty of interesting anti-seismic wooden structures but the subject is dealt with in a superficial way.

5. Conclusions

The historic and aesthetic values still prevail in the consideration and appreciation of the monumental buildings. The bearing mechanisms, though the expression of human intelligence and so essential for the survival of the buildings, still do not receive the attention and the consideration they certainly deserve.

The timber structures of the past, which are the ancestors of the contemporary structural systems made with modern materials and wood too, in spite of their excellent building characteristics, are neglected and abandoned to an humiliating fate of rottenness.

The aim of future research on the subject of the present paper is twofold, promote a better documentation of the known structural systems detected by means of the World Heritage List and "discover" other specimens. Important sources for the latter purpose are the historical centres inscribed in the List, where a globalizing documentation on the urban values did not allow the study of the single, differentiated components.

References from World Heritage Dossiers

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- Jurina L., Righetti M., 2000, *Traditional Building in Peru,* from Proceedings of "International Conference on the Seismic Performance of Traditional Buildings", Istanbul, 2000"