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TIMBER 2.0:
RESILIENCE AND VULNERABILITY OF WOOD CONSTRUCTION IN EARTHQUAKES AND FIRES

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Abstract.

This paper traces how both earthquakes and fires have shaped the history of timber construction in what is now Turkey and in the much more recently established city of San Francisco, California. It also touches upon how the historical spread of both the Ottoman and Persian empires influenced the adoption of timber construction technologies not only in Eastern Europe but as far east as Kashmir and other parts of India. The paper will describe the effects of earthquakes on traditional timber and masonry buildings, with comparisons to the performance of modern structures of reinforced concrete which are often found adjacent to the traditional wooden structures.

The paper then takes on the subject of urban fires in Istanbul neighborhoods with timber buildings, and the impact this has had on the ultimate prohibition of new timber construction, and the gradual decline and abandonment of the historic houses in urban core of the city. This history, both of earthquakes and fires, is then compared with that of San Francisco, with its much shorter history, but with its earthquakes in the mid-19th century and its most famous earthquake in 1906, which spawned the fire that burned over a large part of the city – a far larger area than that which is reported as the largest of the fires which destroyed a section of Istanbul.

The paper concludes with a more hopeful look at how timber construction, with mitigations against the incidence and spread of fires, could become again a safer alternative to reinforced concrete in earthquake areas subject to non-engineered construction and failures to comply with building codes or acceptable construction practices. It closes with the point that the "Turkish House" is something more than just a structure that is safe in earthquakes. It is an evocative and socially meaningful icon of Turkey's heritage and art.

1 FROM CONSTANTINOPLE TO ISTANBUL: THE EARTHQUAKE OF 1509

One of the largest earthquakes of the many that have struck what is now Anatolia over the centuries occurred in 1509, only 56 years after Constantinople was captured by the Ottomans in 1453 in the reign of Sultan Mehmet II. This earthquake resulted in the issuance of an Imperial Edict which declared a state of emergency in what was then the "*entire country*," requiring that *"all able bodied males be available to serve the rebuilding activities."* The edict also bestowed 20 gold pieces to every family whose home had collapsed. What also stands out "*is that it forbade new construction near coastal areas where damage was heaviest and made stone block construction illegal, demanding timber-frame buildings."* [1]

Traditional Turkish timber residential construction for the last several hundred years can be divided into three typologies. First, there is horizontal timber lacing in masonry bearing walls, each of which is called a *hatil* and the plural is *hatillar*. This consists of a timber ring beam, shaped like a ladder but laid horizontally in the wall. The historical precursor to this involved laying rings of brick masonry in ancient Roman concrete and stone walls, including the Theodosian walls in Istanbul.[2]

The second is a timber frame with masonry infill known in Turkey as *hımış*, (in English called "half-timber"). Here, the masonry is usually a single "wythe" or layer, often with the bricks laid at angles to fit between the studs, or alternatively if stone is used, random rubble set into thick layers of mortar. Depending on the locale the mortar is commonly a lime mortar, but in some rural areas a mud mortar may be used. In *hımış,* the combined timber and masonry wall is only as thick as the timbers – meaning only plus or minus 12cm (5 inches), and thus, when one considers how thin the walls are it seems counterintuitive that this system would be safe and resilient in large earthquakes - but the frame confines the masonry making it an integral part of the structural system. From a structural engineering standpoint, trying to calculate this structure is ultimately frustrating because it comes in many variations, all of which are non-engineered and thus based on intuition rather than rules or codes. (Figure 1)

Figure 1: house with *hımış* on the 1st and 2nd floors, and *hatil* on the ground floor in Safranbolu.

Figure 2: Stud framing typical in central Istanbul without infill masonry.

Figure 3: San Francisco 19th century house with timber framing exposed.

The third timber structural system most resembles construction as is common in the USA and Canada – 100% timber with closely spaced studs and joists covered on the exterior with sawn wood cladding and on the interior with lath and plaster over a hollow wall.[3] (Figure 2&3+18-20+24-26) Except for wood-abundant countries such as the U.S. and Canada, buildings built entirely of wood are quite rare. Turkish *hımış* construction has thinner walls than masonry bearing-wall buildings, and is thus easier and more economical to construct. It also serves as overburden weight on masonry walls below for earthquake resistance. (Figure 1)

Today this system of using sawn wood siding nailed to the framework would seem to be more simple to construct than quarrying and dressing the stone and making and placing the mortar to form the walls between the timber posts and beams, but before the age of power saws and the invention and manufacture of wire-cut nails, the seeming ease and practicality of working with wood siding was elusive. The saws that did exist made the precision cutting of the lightweight framework possible, but cutting of a massive number of boards to cover the walls remained impractical. (Figure 4) Returning to the second typology, *hımış* construction is a variation on a shared construction tradition that has existed through history in many parts of the world, from Elizabethan England to 19th Century Central and South America. In Britain, for example, it would be referred to as "half-timbered," in Germany as "*Fachwerk*," in France and Haiti as "*colombage*" (which did well in the 2010 Haiti quake, as seen for example in Figure 5), in Kashmir, India as "*dhajji-dewari*," and in El Salvador as "*bahareque*."[4] Ancient Roman examples have been unearthed in Herculaneum, several involving interior partitions, but one involving an entire two-story row house.[5] The palaces at Knossos have been identified as having possessed timber lacing of both the horizontal and the infill frame variety. This history sets the date of what can be reasonably described as timber-laced masonry construction back to as early as 1500 to 2000 BC.[6]



Figure 4: Hand cutting timber planks in Nepal, 2016. **Figure 5:** *Colombage* (Half-timber) house with almost no damage from the 2010 earthquake in Haiti. **Figure 6:** Half-timber 3 story house with almost no damage in 2001 earthquake in Ahmedabad, Gujarat.

One likely reason why this building tradition can be found in much of eastern Europe and in South Asia is because of the reach and influence of both the Ottoman and Persian Empires, which together extended into modern-day Pakistan and directly influenced the Mughal Empire, which controlled large parts of India from the 16th to the 19th centuries. *Hımış* was a characteristic form of construction in many parts of Ottoman Turkey and has continued in common use up until it was rapidly displaced by reinforced concrete frame with hollow clay block infill construction beginning in the middle of the 20th Century.



Figure 7: URM stone house in Bhuj after 2001 Gujarat earthquake. **Figure 8:** This man survived but his mother didn't, and he is cremating her, and holds her picture. **Figure 9:** Another view of the ruins of both stone houses and concrete houses in Bhuj.

Observing the places where this method did not become a predominant building type supports this hypothesis. For example, in India, the Gujarat earthquake of 2001 revealed that the Mughal city of Ahmedabad in its historic walled city core had similar timber-laced construction (Figure 6), while the historically Hindu city-states of Bhuj (Figures7-9), Anjar, Morvi, and Jamnagar did not share this construction tradition. In the 2001 earthquake the Hindu cities were devastated, while in Ahmedabad the occupied and maintained houses in the Walled City survived with very little or no damage. As proof that Ahmedabad was also well within the damage district, many reinforced concrete buildings surrounding the city collapsed.[7]

In the case of Kashmir, the architecture and construction traditions came to the region with the influx of Muslim Sufis preachers from Central Asia and Persia, beginning in the early14th century, and the subsequent invasions and migrations of people from Persia, who also brought the handicrafts and carpet weaving for which now Kashmir is famous. In fact, *dhajji dewari*, which means “patchwork quilt wall,” comes from ancient Persian.[8]

2 KOCAELI AND DÜZCE EARTHQUAKES 1999

We now return to Turkey, not for ancient or medieval history but because of two catastrophic earthquakes that occurred in 1999. The first of these, the Mw 7.6 Kocaeli (or Marmara or İzmit) earthquake, was on August 17, 1999, followed on November 12th by the Mw 7.2 Düzce earthquake. The first quake caused approximately 20,000 fatalities, and the second added another 1,000. Views of collapsed buildings were all over the news at that time, but little was broadcast about timber-laced masonry buildings. For unreinforced masonry, there was the arresting aerial photograph taken in Adapazari showing a stone mosque standing with all of its minarets intact, completely surrounded by reinforced concrete (RC) buildings that had pancake collapsed. (Figure 10)

I knew that construction techniques existed in Turkey that were similar to those I had documented in Kashmir, but I did not know if such buildings existed in the 1999 earthquake affected cities. When I spoke to a returning reconnaissance team member I asked if he had seen any timber with infill masonry buildings, and he said he did see some and they were still standing. Then when I asked if he had taken any photos of them, he replied: “*no*.” Despite the fact that they might hold evidence of a key to resilience in this and future quakes, the vernacular buildings were to him neither relevant nor of value. It was at that moment that I decided that I must go to Turkey to explore this situation more fully. Thus my research on traditional timber-laced masonry construction moved from a study in the British Library about the 1885 earthquake in Kashmir to a view of the damage in 1999 from under a hard hat. (Figure 11)



1999 EQ photos: Figure 10: Mosque and minaret still standing in Gölcük with collapsed RC buildings around it. (Al Jazeera) **Figure 11:** *Hımış* house next to an entire row of collapsed RC buildings in Adapazzari. **Figure 12:** *Hımış* house next to destroyed RC building. **(**Adem Doğangün)

In some areas of Gölcük and Adapazari, the first of the two earthquakes destroyed more than a third of all housing units, almost all of them in reinforced concrete buildings. I soon found that there were clusters of *hımış* houses still standing in the heart of these districts, mostly dating from the early part of the 20th century. They were thus significantly older than the reinforced concrete apartment blocks surrounding them that had collapsed.[9]

Two Turkish engineering researchers (Demet Gülhan, and Inci Özyörük Güney) conducted a detailed statistical study in several areas of the damage district, and they found a wide difference in the percentage of modern reinforced concrete buildings that had collapsed, compared to those of traditional construction. In one district in the hills above Gölcük where 60 of the 814 reinforced-concrete four-to-seven-story structures collapsed or were heavily damaged, only 4 of the 789 two-to-three-story traditional structures collapsed or had been heavily damaged. The reinforced concrete buildings accounted for 287 deaths compared to only 3 in the traditional structures. In the heart of the damage district in Adapazari, where the soil was poorer, their research showed that 257 of the 930 reinforced concrete structures collapsed or were heavily damaged and 558 were moderately damaged. By comparison, none of the 400 traditional structures collapsed or were heavily damaged and 95 were moderately damaged. For more discussion of this and to see the graph, please go to this footnote link.[10]

These statistics reveal that the difference between the traditional and the modern systems is not the materials used or the size of the buildings. Ironically, it is because *hımış* is a non-engineered traditional building technology, while reinforced concrete is dependent on being an engineered building system. When reinforced concrete is used for non-engineered construction and where both design and construction departs from correct building practices, the risk of collapse in earthquakes is significantly increased. This is not a problem for a traditional technique such as *hımış*, as it is intended to be a non-engineered building system, and as demonstrated by the statistics it is more forgiving. Variations in quality and methodology are inherent in this system, just as commonly occur in traditional construction in general, but the occupants are protected by its inherent redundancy and flexibility. (Figure 12)

3 THE ORTA (ÇANKIRI) EARTHQUAKE OF JUNE 6, 2000 (MW 6.0)

In June 2000, less than a year after the 1999 earthquakes, an earthquake measuring 5.9 on the Richter scale occurred near the rural town of Orta, 100 km north of Ankara. This earthquake has provided an opportunity to evaluate the performance of *hımış* construction in a smaller earthquake in a rural setting, together with other construction types including unreinforced rubble stone and modern reinforced concrete. The rubble masonry was used primarily for barns and it fared the worst, with a number of farm animals killed by collapsing walls. The reinforced concrete construction, however, was, with a few exceptions, only slightly damaged. What was particularly interesting to find was that many of the examples of *hımış* construction appeared to be damaged to about the same degree as found in the *hımış* houses subjected to the much larger 1999 earthquakes. There was some cracked and fallen plaster with some dislodgement of the masonry infill, but collapses were limited to long abandoned structures with rotted timbers. See [11] for more details and photo-documentation.

The 2000 Orta earthquake illustrates the problem of comparative analysis of earthquake performance of existing buildings. Looked at superficially it would appear that *hımış* suffered significant damage, but this fails to take into account the mechanism by which traditional construction resists earthquakes – flexibility and energy dissipation rather than strength and stiffness. Its survival in the much larger and longer 1999 earthquake illustrates that the *hımış* is capable of maintaining stability over many cycles. To do this, however, the deflection of the structure and friction in the infill must begin at the onset of shaking. Thus the shedding of the plaster in both the larger 1999 Kocaeli earthquake and much smaller Orta earthquake was similar. By comparison, although only lightly damaged in this and other smaller earthquakes, the non-engineered concrete buildings often exhibited a rapid and catastrophic degradation of strength in larger earthquakes, often leading to collapse. This happened because they are inflexible and lack the reserve capacity that has been found to exist in both *hatıl* and *hımış* construction. The brittle hollow tile block infill walls in the concrete frame buildings are initially stiff, and then, once cracked, tend to collapse, leading rapidly to a soft story failure.[12]

Figure 13: Yuva family in damaged house.

Figure 14: Yuva from top of minaret, with new village visible on hill above.

Figure 15: Elden old village below and new village above.

Figure 16: Elden old village.

Another important lesson to be learned from the Orta earthquake involves the failure to properly account for two important concerns at a government level when undertaking disaster recovery: (1) the need for the government personnel, particularly the engineers and inspectors, to understand that cracked plaster does NOT mean a traditional *hımış* house is damaged beyond repair, and (2) the cultural and social factors that must be understood and respected in an affected community.

The fates of two rural farming villages near Orta, Turkey demonstrate these points in a sad and tragic way. Yuva and Elden suffered damage in the 2000 earthquake. Rather than helping the residents repair their houses the government recommended the villages be demolished and relocated to what was described by their geologists as safer ground. The residents voted to accept the government's proposal because it came with the promise of new houses in exchange for their old ones. The new sites were selected by a geologist rather than by an agricultural expert or social scientist. They were remote from all that is necessary for human agricultural settlements – water, trees, fertile soil, and protection from the wind. No provision was made for barns for the animals, nor for a community center, general store, or even a mosque. As a result, In September 2004 – more than 4 years after the quake – the new construction was still not finished, and only a handful of the houses had been occupied. Even more inexplicable is the fact that the houses that were built were not earthquake safe, but instead, were constructed of hollow clay tile block with heavy reinforced concrete roofs, as evidenced by one that had not yet been plastered in Yuva New Village.[13] (Figures 13-16)

4 2005 KASHMIR EARTHQUAKE

On October 8, 2005 an earthquake devastated the mountainous area of the Pakistan section of Kashmir, killing over 80,000 and rendering most of the local survivors homeless. On the Indian side of the border the damage was much less, but another difference was noticeable: on the Pakistan side of the border where there was a massive death toll, the traditional construction as described above was quite rare.

On the Indian side, however, the performance of the timber-laced traditional construction confirmed earlier findings. Professors Durgesh Rai and C.V.R. Murty reported: *"In Kashmir traditional timber-brick masonry [dhajji-dewari] construction consists of burnt clay bricks filling in a framework of timber to create a patchwork of masonry, which is confined in small panels by the surrounding timber elements. The resulting masonry is quite different from typical brick masonry and its performance in this earthquake has once again been shown to be superior with no or very little damage.*" They cited the fact that the "*timber studs…resist progressive destruction of the…wall…and prevent propagation of diagonal shear cracks…and* *out of plane failure*.” They went on to recommend that: *“there is an urgent need to revive these traditional masonry practices which have proven their ability to resist earthquake loads*.”[14]

The most impressive example of a new acceptance of traditional construction for earthquake hazard mitigation to date is in Pakistan. There, a year after the 2005 Kashmir earthquake after the recommendations by a number of creative leaders in UN-HABITAT and other NGOs working in Kashmir, the Government of Pakistan approved *dhajji* construction as ‘compliant’ for government assistance. *Dhajji dewari* is the Kashmiri version of half-timber or *hımış* construction. A year after that, they also approved *bhatar* (a timber–laced bearing wall masonry construction). Now, nearing a decade after the earthquake, there are more than 150,000 new homes in this region of Northern Pakistan constructed in either of these two traditional typologies.[15]

From a hazard mitigation perspective, the example of the re-adoption of these traditional local technologies represent a potentially sustainable approach to housing construction in many parts of the developing world, as an alternative to the now ubiquitous use of RC frames. While it will not entirely displace the continued construction of RC frame structures, it can perhaps displace what would otherwise inevitably be the most collapse-prone of them. Thus, it can help provide the basis for establishing a better balance where not every building must be in concrete. Hopefully, the local knowledge of the risks of RC frames done badly will become better known, moving people away from the notion that this is the only way to have a modern house. In truth, the exclusive embrace of concrete as “modern” has been very destructive of the architectural traditions and itinerant craft traditions in many parts of the world. A re-adoption and re-learning of the kind of crafts needed for the reemergence of local vernacular architecture can help preserve other aspects of the traditional culture of a community as well.[16]

5 FIRE IN 1865 IN ISTANBUL

We return to the city where we started. Three and a half centuries after the Ottoman Sultan issued the edict that mandated that the reconstructed houses after the earthquake of 1509 be made of wood, a new disaster struck on September 18, 1865. This time it was not an earthquake but fire. It was the biggest fire in Istanbul’s history, covering one third of the Sultanahmet peninsula, a larger area than any of the many other fires that had plagued the city for centuries.[17] This fire was named the “*Hocapaşa* Fire,” and otherwise became known as the *harik-i kebir*, or “Big Fire.”[18]

Just as occurred after the earthquake in 1509, the fire affected construction standards in the city, except this time it was a move away from building houses out of timber. Andrew Finkel, Journalist for the Guardian in Turkey observed: *“Istanbul was a city plagued by fire …but this was not because the houses were made of wood but because they were close together.”* One can even make comparisons to the narrow twisty streets that were a cause of the spread of the Great Fire of London in 1666, almost exactly two centuries earlier.[19]

Thirty years prior to the fire, in 1836, the Sultan had established guidelines to mitigate against such disasters, but it was not until after the fire that both the motivation and opportunity existed to apply them over a large area. A report was prepared after the fire which focused on two provisions defined in 1836: (1) that new buildings should be of “*kârgir*,” that is of cut stone or brick and mortar rather than of timber, and (2) the streets should be regularized and widened to get rid of the *“crooked, narrow holes* (cul-de-sacs) *with abrupt ascents and descents”* to allow room for evacuation and fire equipment access.[20]

Figure 17: Houses with firewalls.

The "*Hocapaşa* Fire was preceded by only nine years in 1856 by a fire in Aksaray, and followed by another in 1870 called the Pera Fire, both of which were also influential on the future town planning in Istanbul.[21] After the Pera fire, brick and stone construction became mandatory in certain zones in 1875, and in other secondary zones timber was occasionally allowed, provided that masonry firewalls were constructed between the wooden buildings.[22] Because masonry was more costly than timber, this served to make reconstruction unaffordable for many except in certain areas. (Figure 17)

Over time, these developments began the long process of deterioration and gradual abandonment of many of what had been fairly upscale wooden houses with their iconic wide projecting rectangular bays. This deterioration also served to create a more apparent division between the wealthy and poorer residents in Istanbul. This happened in spite of the fact that all taxes on brick and mortar were eliminated, and a government commission for road improvement, the *Islahat-i Turnk Komisyonu* (I.T.K.) even set up its own factories to produce these building materials at an economically favorable rate.[23]

Reinforced concrete made its entrance into the Turkish construction market in the early 20th century, and now the majority of buildings are made of reinforced concrete with brick infill walls. In fact, what proved to be particularly vulnerable in the 1999 earthquakes was the fact that the brick used for the infill walls was what is called *tula* block, which is an extruded hollow clay tile brick that is initially quite strong, but very brittle – a dangerous combination in earthquakes.

Over the course of the last century the wooden houses of Istanbul have gradually fallen into disrepair, even as many were still lived in, but usually by tenants without an interest in their maintenance. Many have been demolished and replaced with stone and concrete apartment houses under a process which has come to be called "*yap-sat*" (build-sell) where an owner sells his property to a builder-developer, who then builds a condominium form of ownership apartment house and the previous owner is given one of the units as compensation for the sale of the property. (Figures 18-20)

Figure 18, Figure 19, Figure 20: Deteriorated wooden houses in Sultanahmet, Istanbul, with modern concrete apartment house visible to the left in #18.

French author Théophile Gautier (1811–1872) had written "*In four months I have seen six great fires*." In his own life growing up in Istanbul, he reported that he saw *"wooden buildings burned by greedy owners who wanted to live in larger modern concrete apartment blocks*."[24] Prof. Carel Bertram, in her book "*Imagining the Turkish House - Collective Visions of Home,* described how this process has continued in the middle of the 20th century: "*In 1950, the country was taken over by the political populism of Adnan Menderes, who set into motion a process of easy and cheap construction (yap-sat) that allowed the destruction of the remaining traditional fabric of most urban areas….The old houses and konaks that had not been destroyed or relegated to slums found themselves surrounded by concrete."*[25]

6 SAN FRANCISCO

There is one city on the other side of the globe similarly at risk of earthquakes that is also filled with wooden houses, which resembles that of Istanbul to a remarkable degree. Even the architecture in Istanbul with its horizontal parapets, square bay windows and shiplap siding resembles that of San Francisco's shiplap clad balloon framed Victorian buildings. It is almost as if a ship filled with designers and carpenters from Istanbul had set sail from Istanbul and docked in San Francisco and commenced construction. This story of San Francisco begins like Istanbul's described above – with an earthquake. This is not the 1906 earthquake that the city is famous for, but of October 8, 1865, only 20 days after the Great *Hocapaşa* Fire. This was followed only three years later with even larger one on October 21, 1868.

San Francisco in 1865 was a rapidly expanding post-gold rush frontier town in the American west. These earthquakes were large enough to cause widespread damage, particularly to large masonry courthouses and commercial buildings. In fact, in a paper published in 1930 in the "*Bulletin of the Seismological Society of America*," San Francisco consulting engineer, Walter L. Huber states: "*Contrary to popular opinion, these earlier earthquakes were at least comparable in intensity to that of 1906*."[26]

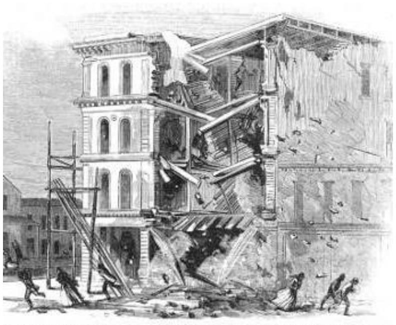

Figure 21: 1865 EQ. (web)

Figure 22: 1868 EQ. (Bancroft)

Figure 23: 1906 EQ. (Genthe)

More recently, in an article published in 2016, Jack Boatwright, a geophysicist at the USGS states that his research has shown that "*The 1868 quake was twice as big as the standing model we had of it*." The San Jose Mercury newspaper the day after the quake reported "*buildings and trees seemed to pitch about like ships in a storm at sea*,"[27] and Mark Twain's commentary on his own experience of the 1865 earthquake is one of the most informative and graphic descriptions of experiencing an earthquake ever written.[28] Thus in this case, the effect of these was not unlike that of the earthquake in Istanbul of 1509 – and like that earthquake, they encouraged a continuation of what was already the widespread construction of multi-story stud-framed wooden buildings. (Figures 21-23)

7 WOODEN BUILDINGS IN NORTH AMERICA

One important difference between San Francisco and Istanbul, however, is that, while the timber frame buildings were in decline and even banned for new construction in Istanbul, in San Francisco they were being built rapidly with increasingly ornate and colorful detailing by rich and poor alike. But then, *what about fire?* The Turkish author Orhan Pamuk has said that in Istanbul there was a *"tradition of watching fires*."[29] Did this not also occur in San Francisco with all these wooden buildings? Huge urban fires did happen across the United States, including the famous Chicago Fire of 1871, but instead of the repetition of many fires, these great fires that spread over a large area were usually not repeated more than once in the same city.

For San Francisco its time would come, and it came following another earthquake that caused as many as 50 to 60 fires to break out. It was the Great Earthquake of 1906. The fires coalesced into several great fires that burned for days, consuming the entire central business district plus the most of the splendid wooden mansions on Nob Hill as well as other residential areas on the eastern edge of the city. But, wait! Isn't San Francisco famous for its wooden Victorian houses today? (Figures 24-26)



Figure 24, 25: San Francisco Victorians, 1940 (HABS), and today. **26:** The "Painted Ladies" (B. Mittal)

This is where it gets interesting, because these now famous wooden houses did survive the fires. There were, of course, an equal or greater number of wooden buildings that burned, but a large part of the destroyed area was the central business district with brick and stone buildings with interior wood floors, some of which were even equipped with fire shutters. However, what makes this particular fire remarkable is that not only did it get into the brick buildings which then were left as collapsing shells; it also burned out every downtown highrise building of fireproof construction. These were first generation skyscrapers of skeleton steel frame construction with brick floors of jack-arch construction, a structural technology that had its first origins in Chicago only two decades before. Despite their fireproof construction, it was the contents of the buildings that were flammable – just as occurred in the World Trade Center buildings in New York on 9/11 almost 100 years later. Despite the best efforts of the fire department the fire could not be stopped from getting into the buildings. Interestingly, despite the fact that they had suffered both earthquake damage and were completely burnt out, most of these buildings were repaired and many are still extant today, over a century later.[30]

However, this story does not explain why the areas of continuous blocks of side-by-side wooden houses survived, even though they lack the firewalls that were mandated in mid-19th century in Istanbul. This question has no simple answer, and to a large degree the reason may simply be good luck. The streets were wider and on a regular grid, in contrast to the medieval layout of pre-19th century Istanbul. In addition, San Francisco possessed the best firefighting equipment available at that time, and also had installed cisterns under certain intersections of the city streets holding water specifically to fight fires. However, much of this system failed from earthquake damage. Also the dynamiting of buildings to try to create firebreaks proved instead to spread the fire.[31] In the end, salvation came with the wind off of the ocean from the west. For the first two days of the fire this normally prevailing wind was absent, but on the third day it finally gathered enough strength to arrest the westward progress of the fire across the rest of the city.

Figure 27: Google Map of San Francisco, with 1906 Fire to scale with Istanbul 1865 Fire, and on **Figure 28:** Lisbon 1755 earthquake & Fire and Tokyo 1923 earthquake and Fire.

As can be seen in (Figure 27 & 28), the San Francisco fire area was vastly larger than Istanbul's 1865 "Big Fire," and Europe's most famous earthquake and fire, the 1755 Lisbon earthquake, fire and tsunami. However, one only needed to wait another 20 years before another earthquake started a fire that burned an area vastly larger than that in San Francisco – the Great Kantō earthquake, which was followed by a fire that wiped out the center of Tokyo.

The lesson of a fire devastating the interiors and contents of fireproof steel and masonry buildings, while leaving vast numbers of wooden buildings untouched to be enjoyed for the more than a century since that tragic day, is that while wood buildings are particularly vulnerable to fire because they serve as the fuel for a blaze as well as suffer resulting destruction, their destruction is not inevitable. Now in the modern day, with electricity and safer sources for heating and cooking as well as sprinklers and other prevention technologies, as well as plaster board and intumescent paint, the risk of the starting and spreading of fires is now much less than the history and folklore of such has been in the history of Istanbul.

Figure 29: Wooden houses on Howard street, only one of which remains still centered on its foundation. Most interesting is that they managed to hold the line against the fire with these houses facing ones burning. (The Atlantic, 4/11/16) **Figure 30:** John Shultz House after the 1889 Johnstown dam burst, a remarkable visual testament to the resilience of 19th century stud frame construction. (Bettmann/Getty Images)

8 EARTHQUAKES AND WOODEN STRUCTURES

I now leave fires and return to the question of earthquake risk and performance of wooden structures. There is strong evidence that the current prevalence of timber construction for both houses and large multi-story apartment buildings on the West Coast is a product of the earthquake risk. Certainly, even in recent earthquakes, not every wooden structure has survived without serious damage, but there are almost no instances where the structural failure of wooden buildings has resulted in fatalities.

When they were in the Schultz House (Figure 30) that was washed almost a half mile downstream all six family members inside survived. In floods wooden houses float and in earthquakes their lightness is both an asset and a problem that needs to be consciously addressed. They need to be secured to the foundation, or the rocking from the earthquake can literally make them "walk off" the foundation or collapse the weak cripple wall framework that supports the house below the ground floor level, as seen in (Figure 29). The modern introduction of garages under houses and multi-family structures without lateral resisting moment frames or shear walls have led to soft-story collapses and near-collapses in the most recent earthquakes in California such as the Loma Prieta earthquake of 1989, which affected the Bay Area, and the Northridge earthquake, which affected the Los Angeles area.

It is crucial to note that timber stud-frame structures do not resist earthquakes as frames, but as membrane structures where all of their walls are part of their lateral force resisting system. This is true for both the structures with nailed horizontal wood siding - in both San Francisco and in Istanbul - and is also true for the masonry infilled *hımış* construction as well. In fact, it is most likely that the almost universal use in both of these cities of the shiplap siding, which is nailed along the top and bottom of each board flush to the studs instead of traditional clapboards, may be because of its effective contribution to lateral strength and stiffness.

Now, as traditional and vernacular forms of construction have gained increasing interest by students and professors alike, a number of engineering papers indicate that the masonry infill is largely missing from the engineering analysis except as dead weight. There is, for example, much emphasis on the need for diagonal timbers within the frame to act as lateral braces. In actual practice, there are many traditional infill frame structures - for example in the Vale of Kashmir and in Pakistan – which do not have diagonals, but which have proven to be as resilient as the others in the 2005 earthquake. This was also true with some *hımış* buildings in Turkey during the 1999 earthquakes. (Figure 31)

Figure 31: Srinagar, Kashmir *dhajji* structure without diagonals

Figure 32: House in Düzce, Turkey after 1999 EQ, showing the 'working" of *himis* wall

Figure 33: Collapsed RC building in 1999 showing shear failure of hollow clay tile infill wall.

In recent decades, engineers have struggled to figure out a way to analyze and do calculations on reinforced concrete frames with infill masonry, and one of the important methodologies that has been developed is to include what is now called the "*equivalent diagonal strut*." This is the compression strut that occurs as the building's frame deforms and transfers compression load onto the infill masonry. In an earthquake, this causes the characteristic "X" cracks. However, one almost never sees an "X" crack in a *hımış* or *dhajji* structure. This means that there is a very important and beneficial difference between the traditional infill systems, and the infill walls found in modern concrete frame buildings. (Figures 32 & 33) The most counterintuitive difference is that the mortar in traditional construction is most often either mud or weak lime mortar, in contrast to cement mortar used in modern RC construction. The second is that the infill panels are much smaller than those found in modern RC structures. This is linked to a need to rediscover what had been traditional knowledge, not unlike what was observed after the 1885 earthquake in Srinagar by Arthur Neve, in the quote referenced above: *"…wood is freely used, and well jointed; clay is employed instead of mortar, and gives a somewhat elastic bonding to the bricks, …. If well built in this style the whole house, even if three or four stories high, sways together, whereas more heavy rigid buildings would split and fall.*"[32]

9 CONCLUSION

Finally, one must focus on the most important purpose for our interest in timber construction of all types. Keeping us safe through the 15 or 30 seconds of the next earthquake is of course important, but it is the meaning that our homes have to us over the years between two earthquakes that is of equal importance. In her book *Imagining the Turkish House*, Carel Bertram opens by describing her experience as a Fulbright Scholar of Islamic History traveling to remote towns in Turkey when people asked her what she was doing. When she responded with the "*simple answer*" that she "*had come to do research on the Turkish house*," she reports that "*What I found, to my surprise, was that I had only to utter those three words to have my interlocutors' faces become positively beatific. In fact, I came to expect a glow, as they repeated the words with a reverent love:* 'the Turkish house.'*"*[33] Perhaps by coming to understand how these houses can keep one safe for the essential 15 seconds, they can also once again be embraced, loved, lived in, and created anew for the enjoyment of lives today and yet to come.

Figure 34: Safranbolu, Turkey

[1] Ergünay,O and Gülkan, P. 1993, Land-use Planning as Instrument of Earthquake Hazard Mitigation, in Comprehensive Approach to Earthquake Disaster Mitigation, Andreas Vogel, ed, Vieweg & Sohn Verlag,Wiesbaden. P246.

[2] For further information on this, see: 2007, From "Opus Craticium" to the "Chicago Frame, Earthquake Resistant Traditional Construction," *International Journal of Architectural Heritage*, Taylor & Francis, Vol. I: p29-59, 2007.(www.conservationtech.com)

[3] Langenbach, R. 2008, "Building Tall with Timber, A Paean to Wood Construction," Structural Engineering International (SEI), "*Journal of the International Association for Bridge and Structural Engineering*" (IABSE), Volume 18, N. 2,

[4] Correia, Mariana, (2003). Escola Superior Gallaecia, Portugal, oral discussion and unpublished paper; and Langenbach, Randolph (2006). "From 'Opus Craticium' to the 'Chicago Frame': Earthquake Resistant Traditional Construction, *Proceedings of the Structural Analysis of Historical Constructions Conference*, New Delhi. (Available at www.conservationtech.com)

[5] Langenbach, R. 2013, "Timber Frames and Solid Walls: Earthquake Resilient Construction from Roman Times to the Origins of the Modern Skyscraper", *Historical Earthquake Resistant Timber Frames in the Mediterranean Area,* Nicola Ruggieri *et* al editors, Springer Publishers.

[6] Kienzle, Peter, (1998). Conservation and Reconstruction of the Palace of Minos at Knossos, DPhil Thesis, IAAS, York (UK), pp122-134.

[7] see http://www.conservationtech.com/india-UNESCO/INDIA-home.htm

[8] Langenbach, R. 2009, *Don't Tear It Down! Preserving the Earthquake Resistant Vernacular Architecture of Kashmir*. UNESCO, New Delhi. See www.traditional-is-modern,net. The earthquake resistant vernacular ar-

chitecture of Kashmir, both in the Indian and Pakistan sides of the border is described at length in this and also in several published papers available open access at www.conservationtech.com, including an Earthquake Engineering Research Institute (EERI) *Reconnaissance Report on the Kashmir Earthquake of October 8, 2005.*

[9] Youd TL, Bardet JP, and Bray JD, Ed., Kocaeli. 2001, Turkey Earthquake of August 17, 1999, Reconnaissance Report, Supplement A to Volume 16, *Earthquake Spectra*,

[10] Gülhan, Demet, and Güney, Inci Özyörük (2000). "The Behaviour of Traditional Building Systems against Earthquake and Its Comparison to Reinforced Concrete Frame Systems; Experiences of Marmara Earthquake Damage Assessment Studies in Kocaeli and Sakarya," Istanbul, Turkey, *Proceedings for Earthquake-Safe: Lessons to Be Learned from Traditional Construction.*

For a paper with a composite graph from this data, see Randolph Langenbach. 2015, "Traditional is Modern: Traditional Building Technology for Resilience in the Modern Era," *Proceedings of the International Expert Meeting on Cultural Heritage and Disaster Resilient Communities* within the framework of the 3rd UN World Conference on Disaster Risk Reduction.

[11] Langenbach,R. 2010, "Earthquake Resistant Traditional Construction' is Not an Oxymoron: The Resilience of Timber and Masonry Structures in the Himalayan Region and Beyond, and its Relevance to Heritage Preservation in Bhutan," The Royal Government of Bhutan's International Conference on Disaster Management and Cultural Heritage: *Proceedings of Living in Harmony with the Four Elements*, Thimpu, Bhutan, 12-14-December.

[12] Langenbach, R. 2002, "Survivors among The Ruins: Traditional Houses in Earthquakes in Turkey and India," *APT Bulletin*, Vol. XXXIII, No. 2&3, Association for Preservation Technology, 2002.

[13] *Op.Cit.*see [8]

[14] Rai, Durgesh C. and Murty, C.V.R., 2005. *Preliminary Report On The 2005 North Kashmir Earthquake Of October 8, 2005*, Kanpur, India, Indian Institute of Technology, Kanpur, (available on www.EERI.org).

[15] International Federation of Red Cross and Red Crescent Societies (IFRC) *World Disaster Report 2014*, p 126 (available at http://www.ifrc.org/Global/Documents/Secretariat/201410/WDR%202014.pdf) ; *and* Syeda Abidi, Siddiq Akbar, Frédéric Bioret. "Post-Event Reconstruction in Asia since 1999: An Overview Focusing on the Social and Cultural Characteristics of Asian Countries." Dr. Abdul Qadir Bhatti. *Proceedings: International Conference on Earthquake Engineering and Seismology*, Apr 2011, Islamabad, Pakistan. 1 (1), pp.418-427, 2011. (available at http://hal.univ-brest.fr/hal-00740365/document).

[16] *IBID*, IFRC, p128

[17] Bertram, Carel. 2008, *Imagining the Turkish House, Collective Visions of Home* University of Texas, Austin, p52)

[18] Çelik, Zeynep. 1993, *The Remaking Of Istanbul*, The Univ. of California Press, Berkeley, Ca.,p55

[19] Andrew Finkel, WOOD CULTURE AND TIMBER HOUSES, Turkish Cultural Foundation (ND), (available at: http://www.turkishculture.org

[20] *IBID.* p55

[21] *IBID.* p53 & 55

[22] *IBID.* p52&79

[23] *IBID.* p58

[24] Langenbach, R, 2008, "Building Tall with Timber, A Paean to Wood Construction," Structural Engineering International (SEI), *Journal of the International Association for Bridge and Structural Engineering (IABSE),* Volume 18, N. 2, May, 2008, pp 130-132.

[25] Bertram, Carel *Op Cit.*, p228.

[26] Bulletin of the Seismological Society of America (1930 20:261-272)

[27] Julie Sevrens Lyons, *Mercury News*, Bay Area News Group, February 6, 2007 at 5:01 am | updated: August 14, 2016 at 9:06 am.

[28] An excerpt from *Roughing It*, by Mark Twain. See http://www.sfmuseum.org/hist6/65twain.html

[29] Pamuk, Orhan. public lecture at the San Francisco Jewish Community Center, Oct. 17, 2007.

[30] Langenbach, R. 2006, "Saga of the Half-Timbered Skyscraper: What Does Half-Timbered Construction have to do with the Chicago Frame?," *Proceedings of the Second International Congress on Construction History*, Cambridge University. (Available on www.conservationtech.com.)

[31] Van Dyke, Steve, SF Fire Department Water Supply System, (http://www.sfmuseum.org/quake/awss2.html)

[32] Neve, Arthur, 1913. *Thirty Years in Kashmir*, Edward Arnold, London. This quote can be found in: Langenbach, R., *Op.Cit.* p.9. [8]

[33] Carel Bertram, *Op.Cit.*, p1.[17]