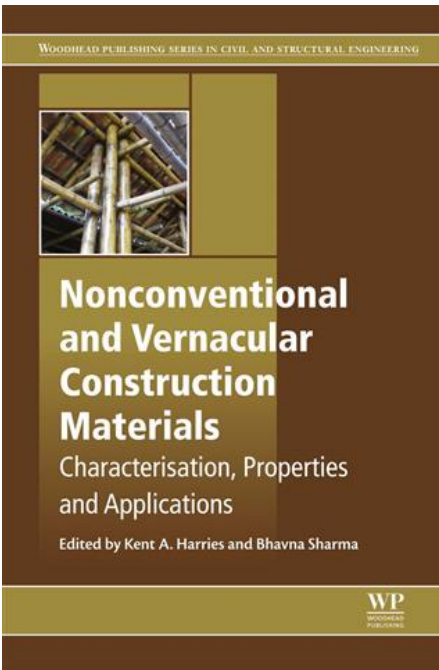


CHAPTER 1 - Excerpt from:

# Nonconventional and Vernacular Construction Materials

Characterisation, Properties and Applications



*Edited by*

***K.A. Harries,  
B. Sharma***



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# Contents

## **Part One Nonconventional materials and vernacular construction**

	<b>1</b>
<b>1 What we learn from vernacular construction</b>	<b>3</b>
<i>Randolph Langenbach</i>	
1.1 Bam	<b>3</b>
1.2 Vernacular	<b>7</b>
1.3 Vernacular architecture	<b>9</b>
1.4 The “vernacular” of industrial architecture	<b>10</b>
1.5 Srinagar, Kashmir, India	<b>13</b>
1.6 The great 1906 San Francisco earthquake and fire	<b>19</b>
1.7 Skeleton-frame construction	<b>22</b>
1.8 Frames and solid walls	<b>26</b>
1.9 Conclusion: the “ecology” of the vernacular	<b>28</b>
Sources of further information	<b>33</b>
References	<b>33</b>

# What we learn from vernacular construction

1

*Randolph Langenbach*

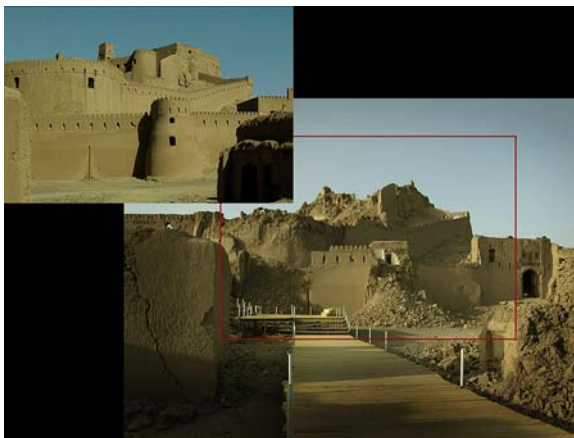
Conservationtech Consulting Oakland, California, United States

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## 1.1 Bam

On December 26, 2003, while people were still sleeping, an earthquake with a magnitude of 6.6 (USGS 2004) struck the ancient city of Bam in Iran. Despite the relatively modest magnitude, the surface shaking was intense enough to devastate the city, killing approximately 30,000 people, one-third of the population. Many of the news photographs that circled the globe were of the devastated ruins of the city's most iconic heritage site, the ancient citadel recognized as the largest earthen structure in the world, the "Arg-e-Bam" (Fig. 1.1). Because of these dramatic views of the pulverized parts of the Arg in the news, many people assumed that most of the 30,000 people who were killed died in the ancient earthen buildings of the Arg. In fact, they did not. The death toll was almost exclusively caused by the collapse of buildings in the modern city, almost all of which had been constructed during the past 30 years.

The "Arg" was an ancient walled city that became an archeological site and museum of the history of the city. After being continuously occupied from as early as the 6th century BCE, it had fallen into disuse in the early 19th century, when people



**Figure 1.1** The Arg-e-Bam archeological site in Bam, Iran, before and after the 2003 Bam earthquake.



**Figure 1.2** Earthquake destruction of the restored parts of the Arg-e-Bam photographed four months after the earthquake.

felt safe enough to abandon their houses the walls and move into their date palm orchards that were planted around the Arg. By the middle of the 20th century, well after the Arg buildings had fallen into roofless ruins, a major restoration project was begun to turn the Arg into a tourist attraction. Over the course of the half-century preceding the 2003 earthquake, a wide swath of buildings from the main gate to the Governor's House on the hill were restored (Figs. 1.2 and 1.3). These included the main market street, two caravanserais, the main mosque, the Governor's House, and a large part of the fortifications. By the time of the earthquake the restored site, with its undulating earthen walls, had successfully become a world-famous attraction.

The 2003 earthquake rendered the Arg almost unrecognizable. Many of the formless rubble piles actually stood higher than the walls that were left still standing. The site quickly became a symbol for the earthquake in the same way as did the National



**Figure 1.3** View of an archeological site in Bam with high walls that came through the 2003 earthquake with very little damage.

Palace in Port-au-Prince, following the 2010 Haiti Earthquake. When I arrived to inspect the site as a delegate in a UNESCO-organized international reconnaissance and conference held four months after the earthquake, the conventional wisdom was that the damage could be explained by the simple fact that the Arg was constructed of unfired clay.

For those of us who arrived in Bam shortly after the earthquake, the argument that the Arg collapsed simply because it was unfired clay did not immediately seem to be unreasonable. This impression was reinforced by what could be witnessed in the surrounding settlement, where many modern steel-frame buildings had also collapsed. In fact, prior to my arrival in Bam I had been told by a seismic engineer in Tehran that earthen construction should be banned, despite its continued use and practicality in the desert climate and a shortage of timber in Iran and the rest of the Middle East.

At first glance, after entering the Arg-e-Bam there was little to be seen to disabuse one of such an opinion. The devastation was vast. However, on traversing the site more than one time, there were increasing visual signals that being made of unfired clay could not alone explain the nature and extent of the damage. First, there was almost no evidence of diagonal tension cracks in the collapsed or still-standing walls. Instead, almost everywhere the walls looked as if they collapsed vertically — like a slump test with too much water in a concrete mix [1].

Looking further, it became evident that some walls and structures had appeared to survive almost entirely intact, while others were only a pile of rubble. As I continued to look a pattern began to emerge. This was particularly evident when I came upon an area that had *not* been restored. The standing walls of unrestored structures, abandoned for more than a century and a half, had survived with little damage, while those that collapsed were almost always the ones that had been restored in recent decades. In addition, when examining the military fortifications, counterintuitively, the thicker the wall the *more* likely it was to have been collapsed by the earthquake.

As I continued to look, I also discovered that in a random sampling of the cracked open sections of the collapsed or broken walls, there was frass (insect excrement) in practically every single one. The Iranian archeologists told me this was from a local species of termites. *Termites*? In an archeological site with walls dating back 2000 to 8000 years? This comment launched me on a study that in the end had more to do with materials science than with structural engineering (Fig. 1.4).

The first question was: Why did the unrestored roofless buildings survive the earthquake better than the restored structures? And did the termites have something to do with this? To search for an answer to this question, I turned to a new subject of inquiry — the science of the cohesion of unfired earthen construction. The question was how it may have been compromised by the 20th-century restoration work. A chance meeting with an engineering doctoral student from the United Kingdom, Paul Jaquin, provided the first steps toward an answer. He had been doing detailed research on rammed earth construction, including its internal cohesion [2]. From him, and later also from colleagues at the French research and teaching institute CRATERRE, I learned that the most significant contributor to cohesion in unfired clay is the meniscus forces of water [3]. *Water*? In ancient structures in a hot dry desert?

**Figure 1.4** Evidence of termites in a wall in the Arg-e-Bam.



Jaquin and CRAterre's research had shown that the cohesive force from water is so effective that the use of stabilizers can on occasion reduce, rather than increase, the cohesion of the clay. Even in very dry climates such as that at Bam, there is a residual level of moisture that normally remains in intact earthen walls. This can be enough to hold the walls together, sometimes for centuries. So a plausible hypothesis of what had happened in Bam is that the residual moisture had disappeared prior to the earthquake. But *why*?

While in Bam I learned that the modern restoration work was reinforced with straw, while historically the clay was either without fiber reinforcement or reinforced with shredded date palm bark. Thus, the modern-day restorers had, in effect, been feeding the termites a banquet, whereas historically the builders had used a material, date palm bark, which was resistant to termites. There had been, in effect, a loss of traditional knowledge between the time when the Arg was last inhabited and when it was restored a century and a half later.

To understand how this may have made a difference, I could see that the termites had perforated the walls by consuming the straw reinforcement. This then likely contributed to a desiccation of the walls, resulting in a loss of suction provided by the residual water that had given the walls a large part of their cohesive strength.

This investigation then led to the evidence of other causes of a loss of clay cohesion that may have been more significant than the termite infestations alone. Perhaps the most important pathology was that over centuries of occupancy, with erosion and repair, the ancient walls had evolved from having horizontally bedded mud layers to walls with vertical construction joints. The later restoration work, which included the reconstruction of the missing upper parts of the walls and roofs, added overburden weight to the surviving lower parts of the walls. The high-frequency earthquake vibrations thus caused this new work to simply crush the older parts of the walls. This explained why the walls had collapsed in place rather than falling over, as evidenced by the location of the rubble piles with little still standing that remained recognizable [4].

## 1.2 Vernacular

So, what is the significance of this story in a book about “nonconventional and vernacular” construction materials? Since unfired clay may still be the most commonly used building material worldwide, how can it also be classified as being “nonconventional?”

Of course, one must first understand that the use of the terms “vernacular” and “nonconventional” in the context of architecture and construction technology are not meant to connote “primitive” or lacking in sophistication or scientific basis. For example, Roman concrete, which has demonstrated a remarkable resilience and longevity, continues to defy efforts to answer all questions about its original prehydration and carbonation constituents because of the complexity of its polymerization over many years into a sequence of different minerals. Like the labeling of a human language, from which the term “vernacular” originally has been derived, vernacular construction is founded on the duality alluded to in the previous sentence, namely that it has evolved from human observation and experience over hundreds, if not thousands, of years (Fig. 1.5), while at the same time is scientifically complex enough to justify many dissertations and books. This is one of those books.

The story of the earthquake-induced collapse of the Arg-e-Bam is a story of a shift from an empirically based traditional knowledge handed down over centuries and even millennia, to our own era in which that traditional knowledge has been lost – both because of the introduction of new materials and construction systems, changes in education, and increasingly disused construction systems and technologies forgotten through neglect. This time-honored empirically based knowledge has been replaced by some very sophisticated scientific research in the fields of materials science and structural engineering, but this sophisticated knowledge is not often communicated to masons, or even known by people where it is needed most: those on the construction site. While modern science has often confirmed the time-honored empirical knowledge, it has not and cannot entirely replace the kind of knowledge passed from generation to generation that made structures such as the Arg last as long as they have, based on trial and error experiences over centuries and even millennia.



**Figure 1.5** Continuation of a vernacular building tradition in Luong Prabang, Laos.

### 1.2.1 “Vernacular” defined

“Vernacular” has its origin in the Latin *vernaculus*: “domestic,” “native” from *verna*: “home-born slave,” a word of Etruscan origin. From the beginning of the 18th century, it came to mean the “native speech or language of a place” [5].

“Vernacular architecture” according to the Oxford English Dictionary is “Architecture concerned with domestic and functional rather than monumental buildings.” It is interesting to find that it is described in part as “contrasted against polite architecture which is characterized by stylistic elements of design intentionally incorporated for aesthetic purposes which go beyond a building’s functional requirements” [6]. This raises the question of aesthetic intentions within the domain of vernacular architecture. One can argue that vernacular architecture — particularly that which remains universally loved by people from most walks of life — shows evidence of many deliberate aesthetic intentions, such as are found in an English Cotswold cottage, a traditional Turkish Ottoman house, a farmstead in Kerala, India, or a shop house in Pingyao, China. The differences with “polite” architecture are not the presence or absence of aesthetic intentions but rather the predominant manifestation of time-honored locally based cultures (Fig. 1.6).

The same applies to the quarrying and harvesting of building materials. Vernacular architecture is most often created from materials obtained or manufactured locally. For example, while brick and lime mortar are manufactured products, brick and lime kilns were often erected in villages and towns where the raw materials, clay and limestone (or in Rome, sadly, the marble from the abandoned ancient Roman temples [7]) were available (Fig. 1.7). Where limestone was not available, mud mortar would serve almost as well. Where pozzolan or shale was mixed (at first by nature) with the limestone, natural hydraulic cement would result such as is found in the vernacular construction in Santorini, Greece, and in Italy close to Mount Vesuvius and the village of Pozzouli, from which the term “pozzolan” originated.

Romans turned this into a business by marketing pozzolan for the making of hydraulic cement mortars around the Mediterranean. One may thus ask if the resulting



**Figure 1.6** New construction in reinforced concrete next to a traditional earthen house near Thimphu, Bhutan, 2010.



**Figure 1.7** Traditional brick kilns near Kathmandu, Nepal, 2000.

constructions are “vernacular?” I will leave that question unanswered, using it only to point out that the definition that is best may be the one that allows for exceptions, in the same way that a vernacular language is a language that is not only local in its origins, but fluid and ever-changing.

### 1.3 Vernacular architecture

Perhaps the best distinction between vernacular and “polite” architecture and construction may be the fact that in vernacular buildings, the basic structural system is more often exposed or, at the most, covered with a contiguous layer of mud or lime plaster. This is in contrast to buildings with a veneer of nonstructural dressed stone or brick on the exterior and dropped ceilings and ornate finishes on the interior walls.

Therein lays the essence of the aesthetics of vernacular architecture. Not only are there simple design rules or “patterns” based on human-scaled proportions, as have been documented and described by Christopher Alexander in his influential book *A Pattern Language*, but also the aesthetics of the craftsmanship of the principal



**Figure 1.8** Contemporary design of a resort (Playa Viva) constructed with traditional materials near Zihuatanejo, Mexico.

structural elements, such as the masonry, timber frames, or earthen walls [8]. In a sense, the demands on the quality of the craftsmanship of the original builders is even greater than in “polite” architecture, where the finish work hides the structural walls or frames. For example, the tied bamboo joints or the undulating mud stucco surface laid over the adobe blocks on the interiors and exteriors is the architectural aesthetic of vernacular buildings (Fig. 1.8). This difference is apparent when one compares these buildings with many modern concrete-frame buildings, where the many rock pockets (gaps in the concrete where the unconsolidated aggregate forms a dam) and other construction faults must be covered by finishes.

## 1.4 The “vernacular” of industrial architecture

My research on the subject of traditional building construction did not begin in the rural countryside of a distant land, but rather in the heart of the first industrial cities of the United States. In the mid-1960s I began a documentary study of the early architecture of the industrial revolution – the first generation of masonry and timber textile mills and planned industrial cities in early 19th-century New England [9]. These brick and stone buildings were constructed with timber plank and beam floors. They were



**Figure 1.9** Nineteenth-century mill buildings with water power canal, Amoskeag Millyard, Manchester, New Hampshire, USA, in 1966. The buildings on the right have since been destroyed and the canal filled in for roads and parking as part of a U.S. government funded “urban renewal” program in the late 1960s and 1970s, before their heritage value was recognized.

usually five or six stories in height, but in some rare cases rose to as high as nine stories, making them the largest and tallest multistory buildings of their time — further complicated in that they were heavily loaded with cast iron machinery and wares.

Over the course of the 19th century, these water-powered factory complexes and mill towns evolved into strikingly impressive examples of architecture and urban design. However, unfortunately, at the time of this research and documentation in the middle of the 20th century, these historic factories in New England were largely abandoned and many were being demolished — and just as with the ancient marbles in Rome — they were quarried for their brick, stone, and timber for new construction, which was often only used for suburban houses for the wealthy (Fig. 1.9).

It is interesting to consider whether these early American industrial buildings and their counterparts in Great Britain, where the Industrial Revolution gained its first foothold, meet the definition of “vernacular construction.” When one studies the evolution of building construction from the pre-industrial era to the present, one must recognize one important fact which separates most building construction from industrial products: for the most part, even in the present, buildings are still constructed by hand. True, more of the materials and larger elements are manufactured and preassembled, but the process of building a structure is still usually unique and thus dependent on on-site craftsmanship as much as on off-site manufacturing. In the case of 19th-century factory buildings the stone, brick, and timber were obtained as locally as possible. Limestone and granite quarries were opened and brick kilns constructed very close to the sites.

In Britain, where coal was locally plentiful but structural timber largely depleted, cast and wrought iron were more often used for the interior post and beam framework. Interestingly, in the United States cast iron was more commonly used for columns in the early part of the 19th century than it was later, because in 1855 in Lawrence, Massachusetts a large mill collapsed in the middle of a workday as a result of flaws in its cast columns. From that day forward well into the 20th century, textile mills were constructed with what one would think would be the less “industrial” material — timber. However, wood had proved to be more resilient for the heavy loads and strenuous vibrations of a mill filled with oscillating power looms than had cast iron.

Today, one can only reflect on the fact that if the *Rana Plaza*, an eight-story reinforced concrete frame industrial building near Dhaka, Bangladesh, had instead been supported on timber columns, the 1,129 people who lost their lives in the 13th of May 2013 collapse of the structure would still be alive. Thus, one can also say that an important additional definition of vernacular construction is that it is more easily understood by local owners and builders than is construction that is dependent for structural reliability on complex scientific processes and theoretical analysis with differential equations, as is reinforced concrete (Figs. 1.10 and 1.11).

Princeton Professor Robert Mark in 1994 touched on this issue when he made the following counterintuitive yet prescient observation: One of the reasons for the success of the builders of monumental masonry structures over the past two millennia “*is the forgiving nature of typical masonry construction as compared with the relatively ‘high strung’ nature of slender modern structural elements of reinforced concrete and steel*” [10].



**Figure 1.10** Front façade of the *Rana Plaza*, Bangladesh before collapse. Elevation view of front façade of *Rana Plaza* near Dhaka, Bangladesh. This rectified image was constructed by author from a combination of news media TV video images to show the façade prior to collapse. This photo reconstruction of the building serves to bring into focus a fact that, in addition to its structural failings, it was unremittingly ugly as a work of architecture. I would say that these two aspects of building design are actually closely related — the developer Sohel Rana’s grotesque failure even to grasp the truth of his own engineers’ warnings of imminent collapse are of a piece with his ignorance and even contempt for architectural expression that is in any way responsive to the local and national culture (see TEDxAmoskeagMillyard talk [11]).



**Figure 1.11** *Rana Plaza* after 2013 pancake collapse that killed 1,129 people. Photo by Rijans, Wikimedia CC.

## 1.5 Srinagar, Kashmir, India

While it can be argued that the construction technology found in 19th-century factories is consistent with the definition of “vernacular *construction*,” few would argue that all but the most remote rural factories are examples of “vernacular *architecture*.” While I have always enjoyed vernacular architecture, my more in-depth engagement with it as a topic of research followed a visit in 1981 to Srinagar, Kashmir, in northern India [12]. At that time, more than a third of a century ago, entering Srinagar was like going back a half a millennium in time. The houses appeared to be ancient and timeless, with much evidence of wear and tear. V.S. Naipaul made the observation in 1964:

*It was a medieval town, and it might have been medieval Europe, It was a town of smells: of bodies and picturesque costumes... a town...of disregarded beauty... a town of narrow lanes and dark shops and choked courtyards [13].*

Srinagar was in 1981 a densely packed city full of houses (Fig. 1.12). Unfortunately, over the last 30 years much has disappeared to be replaced by roads widened for military vehicles and “modern” reinforced concrete buildings. In the oldest portions

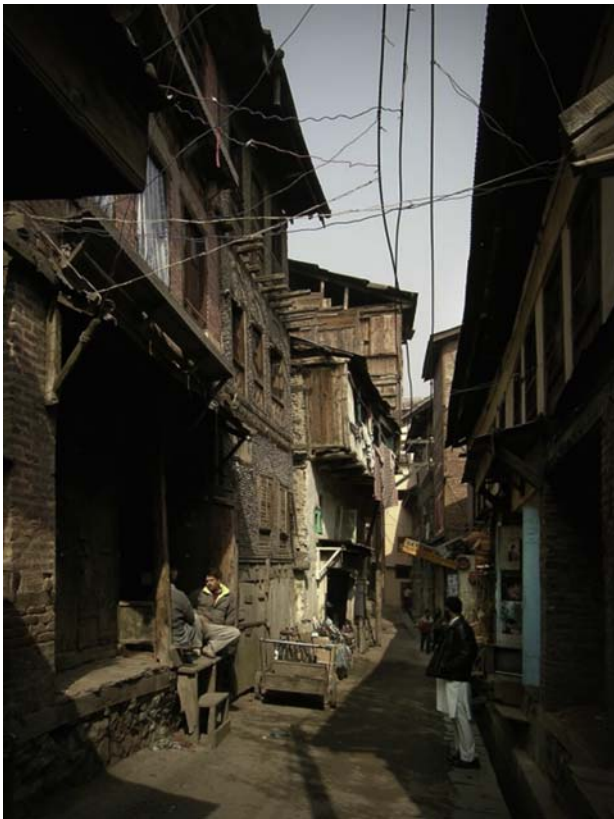


**Figure 1.12** Traditional houses along the Raniwari Canal, Srinagar, Kashmir, 2005.

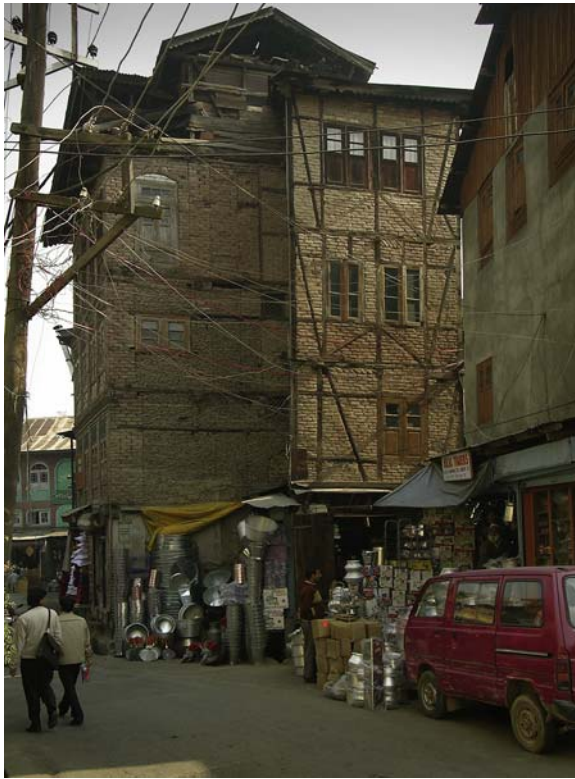
of the city in 1981, the residences were mixed together with shops and even small manufacturing industries, such as carpet weaving and metalworking. The view of this dense development and teeming activity was like a scene out of the pages of Dickens or a canvas by the 16th-century Dutch painter Bruegel.

The houses themselves were (and many continue to be) what formed the backdrop to this remarkable scene. They appeared rickety and insubstantial, almost as if they were deliberately built only as a stage set for the human pageant which took place around them. These buildings provided an opportunity to study the linkage between traditional construction technology, vernacular design, and a traditional way of life (Fig. 1.13 and 1.14).

When embarking on historical research of Srinagar, I came across remarkable mid- and late 19th-century descriptions of the buildings by British writers who described their observations of two separate earthquakes that occurred in 1868 and 1885. These observations were of particular interest to me, as I was in the process of moving to the earthquake-prone area of California in 1984. To find masonry buildings recognized in the mid-19th century as earthquake resistant provided an interesting point of



**Figure 1.13** Narrow lane with timber-laced masonry bearing wall buildings in central Srinagar, Kashmir, 2005.



**Figure 1.14** View of four- and five-story buildings of traditional *taq* (on the left) and *Dhajji dewari* (on the right) construction in the city center of Srinagar, Kashmir, 2005.



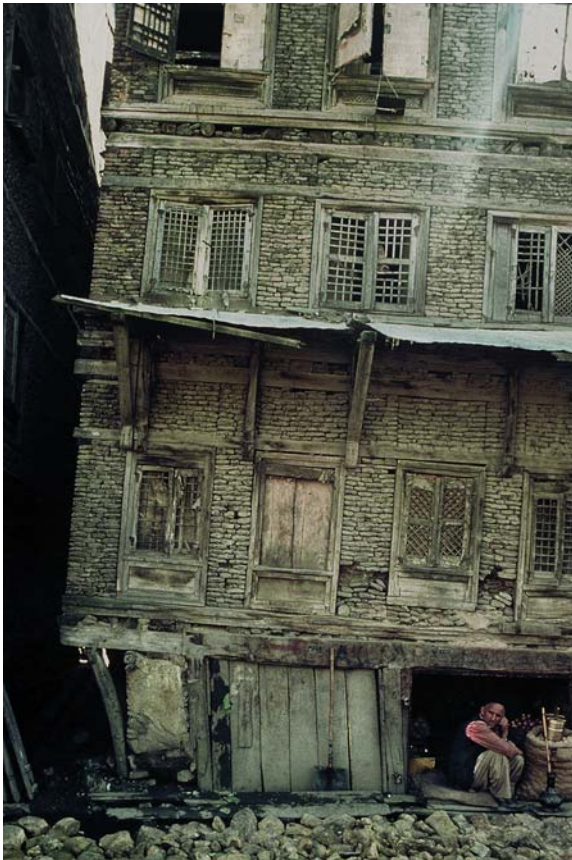
**Figure 1.15** Contemporary continuation of preindustrial technique of sawing timbers into boards in Kashmir.

Photo by Abbid Hussain Khan, INTACH, 2006.

comparison to the United States at a time when historic unreinforced masonry buildings were broadly being condemned and either torn down or retrofitted with their masonry walls entombed behind steel and concrete.

Wood in the Himalayan region was comparatively plentiful before the modern era, but it had to be sawn by hand as there were no saw mills. Also, nails were hand forged rather than purchased by the box. Thus, the primary locally available building material in the Vale of Kashmir was clay, which was fired into bricks or used for mortar. Timber, however, was used not only to support the floors and roof but also to reinforce the masonry (Fig. 1.15).

Most of the traditional buildings in Srinagar can be divided into two basic systems of construction. The first system, referred to as *taq* in Kashmiri and *bhatar* in Pashtun, consists of thick load-bearing masonry piers with thinner masonry walls in between



**Figure 1.16** Canalside building of *taq* construction in central Srinagar, showing the timber-laced masonry construction, photographed in 1981. Notice that the windows do not line up vertically and that the masonry is divided into panels and piers, which is only possible structurally because of the timber ring beams in the masonry walls.

(Fig. 1.16). These separate sections of masonry walls and piers are then laced together with timbers that form ring beams around the exterior walls and are held together with wooden ties that pass through the walls at each floor level. This timber lacing is configured like ladders laid horizontally in the wall. They are laid below and above the joists at each floor level, which then tie the walls together with the floors because of the friction provided by the overburden weight of the masonry above.

What is important to note regarding this system is that there are no vertical timbers or any other form of vertical tension reinforcement. This is something that seems counterintuitive to most engineers today, including the engineers in India who produced the otherwise remarkably forward-thinking Indian Building Code IS 13828 for “non-engineered” construction that is based on this system [14]. As a result of their insecurity with having only horizontal reinforcement: this code recommends that a cement grout-encased steel reinforcing bar be embedded in the masonry in each exterior corner. My concern is that this column of steel-reinforced concrete over time is likely to prevent the natural changes in dimension of the surrounding load-bearing masonry laid in soft mud mortar. In the event of an earthquake, it could disrupt the masonry in such a way that it will be much more difficult or impossible to repair [15].

The second system, known as “*dhajji dewari*” construction, consists of a braced timber frame with masonry infill. It is brick-nogged timber-frame construction that in Britain is known as “half-timber.” *Dhajji-dewari* comes from the Persian words for “patch quilt wall” (Figs. 1.17 and 1.18). It is similar to what in Turkey is called *hıms* [16].



**Figure 1.17** *Dhajji-dewari* building showing the single-leaf construction of the walls. The building was under demolition for a road widening, 2005.



**Figure 1.18** New construction in *dhajji-dewari* photographed in 1989. More recently, this form of construction has largely gone out of use, in favor of reinforced concrete.

After the October 2005 Kashmir earthquake, structural engineering Professors Durgesh Rai and Challa Murty of the Indian Institute of Technology Kanpur reported that

*“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 crack, and out-of-plane failure.”* They went on to suggest that: *“there is an urgent need to revive these traditional masonry practices which have proven their ability to resist earthquake loads”* [17].

This contemporary observation is not without precedent. In the 19th century, British geologist, Frederic Drew, said in a book published in 1875 that the Srinagar houses have *“mixed modes of construction [that] are said to be better as against earthquakes (which in this country occur with severity) than more solid masonry, which would crack”* [18]. He thus notes not only that the houses demonstrated a level of earthquake resistance but also that this attribute was recognized by the local population.

Later, the British physician and award-winning writer Arthur Neve, in a book describing his experiences during 30 years in Kashmir during the late 19th and early 20th centuries, described at length the resilience demonstrated by the traditional Srinagar houses of both systems during the earthquake of 1885. After describing these Srinagar houses as *“tumbledown and dilapidated to a degree”* (which was not unlike my first impression a century later), he went on to say that their construction was *“suitable for an earthquake country.”* His explanations of why the traditional construction worked so well are particularly significant. After observing that *“Part of the Palace and some*

*other massive old buildings collapsed... [but] it was remarkable how few houses fell,*" he goes on to explain that "*wood is freely used and well jointed,*" but then he made the counterintuitive claim that "*clay is employed instead of mortar, and gives a somewhat elastic bonding to the bricks.*"

In describing the *taq* construction, he says that the bricks are constructed "*in thick square pillars, with thinner filling in,*" by which he describes the bearing wall masonry construction that is constructed as a series of wall sections with unbonded construction joints between the sections, as seen in Fig. 1.16. This construction, he says "*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*" [19].

Both of these 19th-century commentaries seem as remote from modern engineering theory and practice as the buildings they describe are picturesque. Neither Drew nor Neve was an architect, engineer, or mason. In addition, the comparative sizes and characteristics of the earthquakes are only vaguely documented. What is interesting, though, is that these quotes can be used to shed light on what has proved to be revolutionary changes that have occurred over the past century and a half in the design and construction of buildings. These changes effectively have divorced the building technical community, including architects, engineers, and builders, from the kind of tactile understanding of traditional materials and construction systems that these 19th-century quotes demonstrated — a problem that has only recently begun to be recognized and addressed, as shown by the previous quote by Professors Rai and Murty.

## 1.6 The great 1906 San Francisco earthquake and fire

Turning to the United States, consider the engineering study describing the damage from an earthquake half-way around the planet from the one in Kashmir — the 1906 San Francisco earthquake and fire. Six years prior to the publication of Arthur Neve's book about Srinagar, the American Society of Civil Engineers (ASCE) in their *Transactions* published the "*The Effects of the San Francisco Earthquake of April 18th, 1906 on Engineering Construction.*" In their committee report on the damage to buildings one finds the following statement:

*It may be stated, as one of the most obvious lessons of the earthquake, that brick walls, or walls of brick faced with stone, when without an interior frame of steel, are hopelessly inadequate. As a method of building in earthquake countries, such types are completely discredited* [20].

Later in the report they repeatedly emphasize this point, as follows:

*The writers simply reiterate the statement that, speaking generally, buildings of brick walls and wooden interiors cannot be built which will not be wrecked in a severe shock, it being a fault of design and not of materials or workmanship* [21].

This was followed by some heated rebuttals in the "Discussion" portion of the publication, in which 25 ASCE member engineers contributed their own reports. While

seven offered strong rebuttals to the Committee's position, two expressed unequivocal support, adding their endorsement to the evidence of the transition from empirical observation to theoretical analysis in engineering. (The others were either neutral or did not discuss masonry building performance.) One supporting member, C. Derleth, wrote: "*It is not right to argue that brick buildings are adequate for earthquake countries because a hundred buildings stood in certain places*" [22], while another, J.D. Galloway, said: "*It is strange that engineers will still champion this material which, analytically and by evidence, proves itself to be 'hopelessly inadequate'*" [23].

In defense of masonry, one engineer, Edwin Duryea, made the following apt observation: "*This conclusion is so severe that, if it were true, it would entirely exclude the safe use of ordinary brick buildings, for any purpose, on the San Francisco peninsula*" [24]. All of this flowed from the repeated observations that only some, but by no means all unreinforced masonry buildings were damaged by the earthquake. Another engineer, W.W. Harts, made the even more directed rebuttal of the absolutist nature of the Committee's position, basing his position as a defense of empirical methodology and evidence:

*It is very dangerous, in any scientific discussion, to formulate sweeping general rules....The explanation has been made that the test of engineering structures is not experience, and that the majorities [of engineering professionals] cannot be relied upon...to discover the truth as to their stability. Can it be maintained that the science of engineering is not the resultant of years of experience? Can it be said that successes are not guides and that failures are not warnings?* [25].

His colleague, Bernard Bienenfeld, then made the more specific observation:

*Regarding the contention of the Committee that the ordinary brick construction is inelastic, observation of the action of the brick walls of wrecked buildings that were being torn down subsequent to the earthquake and fire would indicate that there is indeed a considerable and surprising internal elasticity in this form of construction* [26].

This quote is the one that comes closest to the 1885 observations by Arthur Neve cited above, when he said that weak clay mortar gives a somewhat elastic bonding to the bricks, which allows the masonry buildings to "*sway together.*" [19]. It is interesting in light of this debate over the behavior of masonry to also take note of the famous 19th-century French architect Viollet-le-Duc's description of masonry behavior as showing *élasticité*, by which he meant that masonry has the ability to structurally adapt to changes in loading and even allow for cracking, without losing its stability. (He was describing it in general, not specific to earthquakes.) Thus, we are confronted with the use of the term "*elastic*" to describe phenomena that includes inelastic behavior of a structural system. As described next, this seeming anomaly may in fact lie at the core of what makes masonry construction difficult for engineers to analyze and accept when confronting the mitigation of earthquake risk.

While these quotes concern the engineering analysis of the unreinforced masonry buildings in San Francisco, most of these buildings had probably not been designed

by engineers, except for the simple static load calculations and detailing of internal framing elements. However, the most historic watershed is that this is the first earthquake to affect steel skeleton-frame buildings with curtain walls of masonry, rather than load-bearing exterior masonry walls with internal post and beam framing like that of the British and American 18th and 19th-century industrial buildings (see Fig. 1.9). This system of construction, now so common as to seem unremarkable, had only first been used 20 years earlier in Chicago.

From an engineering perspective, mid- and high-rise skeleton-frame buildings represent much more than the simple replacement of the exterior bearing walls with an extra bay of posts and beams. As Donald Friedman states in his book *Historical Building Construction*, the few short decades before the 1906 earthquake also mark the “change in structural theory from masonry-based compression forms such as bearing walls and arches to flexure-based designs such as knee-braced portal frames” [27]. At this same time, the industrial production of large quantities of steel made possible after the invention and proliferation of the Bessemer converter and open hearth furnace, replaced wrought and cast iron within less than a decade after 1880. These two changes made the skeleton frame possible, which inevitably led to the construction of much taller buildings that became known as ‘skyscrapers’, a word for which came from the top sails on ocean-going sailing ships. Only then did the skeleton frame conform to what the engineering term-of-art means by the word “frame” — that is, a braced or moment frame with rigid beam/column connections.

The invention of the skeleton-frame skyscraper fits well with the other remarkable inventive engineering feats of the age, such as bridges and towers. The most remarkable of these towers at the time was most certainly the Eiffel Tower. However, there was a profound difference: unlike bare steel bridges and towers, buildings require interior and exterior walls. Also, as a consequence of the flammable nature of their contents, the steel frame itself must be protected against collapse from the heat of a raging fire inside a building (Figs. 1.19–1.21). For more on 1906 Fire, see Ref. [28].



**Figure 1.19** View of San Francisco showing three of the steel skeleton frame buildings after the fire had burned them out. These included the 315 foot high steel skeleton frame Call Building constructed in 1890. All of the surrounding buildings, except for the skeleton frame structures, were completely destroyed. These three skeleton frame structures, as well as most of the others in the city from that time, were repaired and about half of them still exist today.



**Figure 1.20** View of the 1904 steel skeleton frame with infill masonry Flood building after the 1906 San Francisco earthquake and fire.



**Figure 1.21** The same view shown in Fig. 1.20 but 100 years later. Most of the steel skeleton-frame buildings were repaired after the earthquake despite the fact that all were burnt out by the fire.

At that time, the walls and the fireproofing around the steel framework were still of unreinforced masonry resting on the steel frame, although these walls were no longer load bearing. Of course, such enclosure walls not only added weight but also complicated the engineering analysis of the frame. Because of the walls, this was a problem unique to buildings, rather than to bridges or the Eiffel Tower. This difference, as we shall see later, is more profound than was perhaps realized at the time.

## 1.7 Skeleton-frame construction

The steel skeleton frame skyscrapers in San Francisco which survived both an earthquake and uncontrolled fire stand at the threshold of a sea change in engineering and building construction. The conventional descriptions of the trajectory of architectural and engineering history of this time often described the changes of the late 19th and early 20th centuries as “progress,” as they led to the elimination of heavy masonry facades and interior walls and the opening up of floor plans. This was idealized by Le Corbusier in his model Domino House, an idealized drawing of a reinforced concrete post and slab structure, which was followed by the adoption of curtain walls of glass and lightweight panels to enclose such structures. The consequence of this in earthquake areas was only later to be confronted as successive earthquakes around the globe caused increasing numbers of collapses with many victims.

Interestingly, at the time of the 1906 earthquake, engineers had little idea how the masonry-clad skeleton-frame buildings would perform. As reported by A.L.A. Himmelwright, head of the Roebing Construction Company [29]:

*The successful manner in which the tall, steel skeleton-frame buildings withstood the effects of the earthquake and the fire is most reassuring, in fact wonderful, and proves*

*conclusively that the best modern practice is directed along correct and efficacious lines.. These buildings had never before been subjected to violent earthquake shocks, and many architects and engineers doubted their ability to withstand such surface movements without injury.... In all cases when the structural details were designed in accordance with the best modern practice and executed with skill and workmanship of only fair quality, the buildings passed through the earthquake without structural injury.*

Their remarkably good performance in 1906 San Francisco firmly established them in the ASCE Transactions Report as the structural system acclaimed to have the most resilience – despite the many earthquake-induced cracks in the masonry interior and exterior walls. The 1907 ASCE Committee Report observed that “*The damage to steel frames was almost negligible*” and “*the writers are of the opinion that the steel frame offers the best solution of the problem*” [30] after making the observation that “*buildings of this type were those most exposed to earthquake damage, the type including most of the tall buildings in the city*” [31].

This, of course, is where the *masonry* comes into the discussion. The report states that the exterior brick “*wall adds little, if any, to the bracing of a steel frame. Many of such walls were cracked badly, and moved on the supporting girder. No reliance should be placed upon them, as they are open to all the objections stated in connection with brick walls in general. The well-designed steel frame offers the best solution of the question of an earthquake-proof building, as all the stresses can be cared for*” [30]. With this and other observations, the committee makes it clear that they saw the masonry as simply a load on the frame, rather than working (in the engineering meaning of the term) in partnership with the frame to resist the lateral forces and dampen the destructive vibrations of the earthquake.

In contrast to this analysis, the author of what may be the first engineer’s text book on the subject of skyscrapers, Joseph Kendall Freitag expressed a diametrically opposing view in both the 1895 and 1901 editions of his textbook *Architectural Engineering With Special Reference to High Building Construction*. In his 1901 edition, he says:

*‘Skeleton Construction’... suggests a skeleton or simple framework of beams and columns, dependent largely for its efficiency upon the exterior and interior [masonry] walls and partitions which serve to brace the structure, and which render the skeleton efficient, much as the muscles and covering of the human skeleton (to borrow a comparison used by various writers) make possible the effective service of the component bones” [32].*

In a historically important way, Freitag’s quotes reveal the dialectic between that which is empirically obvious versus what is still an engineer’s reluctance to rely on that which cannot be calculated, described as follows:

*A building with a well-constructed iron frame should be safe if provided with brick partitions and if the base is a large proportion of, or equal to the height, or if the exterior of the iron framework is covered with well-built masonry walls of sufficient*

*thickness; for the rigidity of the solid walls would exceed that of a braced frame to such an extent that were the building to sway sufficiently to bring the bracing rods into play, the walls would be damaged before the rods could be brought into action [33].*

This was in fact a phenomenon that was confirmed years later by tests carried out on the Empire State Building in New York City [34]. Freitag, however, is critical of the total reliance on the infill masonry for lateral support:

*This method of filling in the rectangles of the frame by light partitions may be efficient wind bracing, but the best practice would certainly indicate that it cannot be relied upon, or even vaguely estimated [35].... While the steel frame is more or less reinforced by the weight and stiffening effects of the other materials, still no definite or even approximate values can be given to such items, except their purely static resistance or weight.... Any dependence placed on curtain walls [36] and partitions for lateral strength is opened to very grave question [37].*

Despite his “*muscles and skeleton frame*” metaphor describing the structural integration and dependency between the masonry walls and steel frames, Freitag himself reveals the inconsistency in his own views of the role of the masonry. In so doing he recognizes the very problem that continues to exist for engineers today – the lack of reliable ways to quantitatively analyze and calculate its role in a structural engineering design for multistory frame buildings. He thus anticipates the elimination of the masonry for lateral support when, on the very next page, he describes what he calls “cage” construction:

*The steel framework, originally introduced to carry vertical loads only, has been gradually developed and systematized as increased attention has been bestowed upon the questions of lateral strength and stiffness against wind or other external forces. The use of a well-braced frame now permits the substitution of curtain or veneer walls for the solid masonry construction formerly required, and the reduction in thickness of such walls to 12” or 16” protective veneer walls only, makes it possible to obtain much larger window areas ... [and] also possible to omit heavy interior walls [38].*

However, 12 to 16 inches of masonry is still a considerable amount of masonry infilling and cladding, and if called upon in an earthquake to resist the lateral forces, as it was in San Francisco in 1906, it could provide added resistance and damping from its cracking that serves to prevent the underlying steel building frame from deforming beyond its elastic range. This is empirically true, even if the original designers had disregarded it, as is shown by the fact that the ASCE committee in San Francisco concluded that it was of no value. Local regulations in Chicago and New York City at the turn of the century mandated thick exterior masonry walls, even for skeleton frame structures, but during the decades to follow such requirements were soon lifted.

While most of the historical focus is on the transition to the use of frames for taller buildings, the watershed event in this transition is not so broadly known – it is, within the field of structural engineering, the “invention” of a way of doing a portal frame

analysis using the contraflexure methodology for isolating moments.” In lay language, this method allowed the calculation of the bending stresses on multi-story frames by mathematically separating the frame into parts at each neutral point of bending reversal of the columns and beams. This then allows for the forces to be calculated using the three equations of equilibrium. Prior to that, the forces inherent in “frame action” could not be accurately calculated. As long as, in effect, columns were pin connected at the floor levels, this was not a problem (Fig. 1.23), but as structures grew taller, this was structurally inefficient. Modern skyscrapers in every practical sense date their origin to this change in engineering analysis methodology.

The contraflexure methodology of portal frame analysis [39], eliminates what Freitag described as the “table leg” principle — the pin connection of columns at each floor level which is required to avoid the complication of calculating an indeterminate (hyperstatic) structure that would exist if all connections were rigid (Fig. 1.22). Ironically, contraflexure-based analysis allowed for much greater precision and thus economy in the amount of steel needed for the frame, but in so doing, it reduced the structural redundancy that the earlier methods required and thus reduced the de facto safety margin in the event of earthquakes which exceed the elastic capacity of the frame structures. Since this refinement in the engineering calculations coincided with the reduction in the thickness of the masonry walls, the skeleton frames became significantly lighter and more flexible. Elwin Robinson in 1989 remarks on this when he says: “*The exterior curtain was continually reduced in mass until it eventually became a thin glass envelope, unable to contribute to the structural stability of the system in any way*”. This would come to have profound and even tragic consequences over the next century up to and beyond the present day [40].

To fully understand this historical phenomenon, we must jump ahead 100 years to the centenary of the 1906 earthquake and a report written by two of the most highly regarded seismic engineers in San Francisco today, Ronald O. Hamburger, and John D. Meyer.



**Figure 1.22** An office interior remodeling project in the south wing of the 1891–1893 steel-frame Monadnock Building in Chicago briefly revealed this view, an example of what Freitag defines as the “table leg” portal arch. The photograph was taken in 2005.

They address this topic from the perspective of the current day, and in so doing, they find some interesting counterintuitive facts:

*The outstanding performance of the infill steel-frame buildings in the 1906 earthquake remains an issue of considerable technical curiosity. Though many of these buildings had design deficiencies known to have caused very poor performance in more recent earthquakes, including soft and weak stories, torsional configuration, large seismic mass, and low stiffness, none collapsed, and essentially all were repaired and restored to service, many remaining in use to this day.... Certainly, this superior performance is not predicted when standard procedures for seismic evaluation and upgrade, such as ASCE-31 ASCE 2003 and FEMA 356 are employed.*

*[A] possible explanation lies in the accuracy, or lack of accuracy, with which our current evaluation techniques model buildings. Although some analyses of buildings of this type have been performed, accounting for the masonry and frame interaction effects in exterior walls..., we are not aware of any such models that also incorporated the effects of the hollow clay tile partitions [41].*

These comments are particularly interesting in light of what happened during the 1989 Loma Prieta earthquake in Oakland, across the bay from San Francisco. In that earthquake the epicenter was 60 miles (97 km) distant from the Bay Area, and it resonated with the soil under Oakland City Center at a frequency that affected early 20th-century skeleton-frame mid-rise buildings with masonry curtain walls. These included the 320 feet (98 m) high 18-story City Hall constructed in 1914, and a number of other buildings within the downtown area. None of these buildings came close to collapse during the earthquake, but, as expected, many manifested cracks in their masonry exterior walls. One such building, the former Hotel Oakland, an eight-story block-sized building recently converted to housing, sustained considerably more damage to its façade than the others. After the earthquake, it was surprising to find out that of all of the buildings of this type, this had been the only one that recently had been seismically upgraded. As part of that upgrade, all of the interior hollow clay tile masonry walls had been demolished and replaced with gypsum plasterboard on light weight steel studs.

The questions raised by Hamburger and Meyer point to the fact that the masonry in general, and the hollow clay tile interior walls in particular, fell outside of modern seismic analysis models, and that in a retrofit project, the typical decision was simply to eliminate them. However, their absence left the exterior walls during the earthquake to do all of the work. The better performance of the dozens of surrounding unretrofitted buildings, by their comparison with the Hotel Oakland, serves to demonstrate the positive contribution that the infill masonry does have in an earthquake — the very thing that was under-appreciated by the engineers, both in the post-1906 reconnaissance quoted above, and in the modern day [42].

## 1.8 Frames and solid walls

One may wonder why one focuses on the evolution of skeleton-frame construction. What does this have to do with “vernacular construction” and nonconventional materials? The answer is that the development of the analytics and mathematics that

accompanied the invention of the skeleton frame changed the practice of structural engineering, in such a profound way that it has served to build a conceptual barrier between the design of solid wall masonry structures in past centuries, and modern skeleton-frame structures.

This increasingly opaque barrier within the structural engineering profession between the empirical past and quantitative frame analysis of the present can be seen in Freitag's textbook when he says that: "*the stability of a building must depend entirely either upon the masonry, that is, the inertia or dead weight of the structure, or upon the steel framework*" [43]. "*In veneer buildings [masonry curtain wall buildings], which are being considered here in particular, the system of bracing the metal-work [with steel] must be used, with the [masonry] walls as light [meaning as thin] as possible*" [44].

More than any other, the process that led to these changes in the quantitative analytical methods now so commonly accepted in structural engineering is also what has created the barrier between the modern era and historical approaches to building design and construction. At the time this evolved, engineering education had largely shifted from the building sites to the university, with its attendant specializations and concentration on mathematical theory rather than empirical approaches to building construction combined with direct hands-on apprenticeship at the building sites. Frame analysis thus became the core of the curriculum, such that now both engineers and architects think and model most structures in their minds and on paper as frames to be analyzed mathematically. Shear walls, when included, are modeled as deep beams. Masonry walls, where they exist, most often have been treated simply as dead weight and given lateral resistance factors that only recognize their limited elastic capacities, rather than their ultimate strength, resilience, and energy dissipation.

Princeton engineering Professor Robert Mark touched on a significant part of the changes that have occurred when he states: "*it was only in the nineteenth century that the merger of science and the art of building, finally took hold, abetted by the introduction of new construction materials to which the old rules of building no longer applied and by the establishment of architecture and engineering as university subjects*" [45].

What is interesting is that now, a century later, there is still a struggle within the fields of architecture and engineering to find a balance between an empirical process founded on observation and experience, and quantitative approaches that are now a seamless part of engineering education and largely dictated by the building codes. In 2004, California-based engineer, Sigmund Freeman wrote a criticism of recent changes to the seismic building code, as follows:

*Making codes more restrictive and more complicated does not necessarily make for better buildings.... The analytical methods used are generally precise, but are they accurate? Materials can have many variables that are not accounted for in the analytical models.... Continued studies and interaction between engineers, as well as with other design professionals, is required. Engineers need to think more about how buildings perform than how to satisfy building codes* [46].

Freeman's observations are reminiscent of the comments a century earlier in defense of brick buildings by W.W. Harts, quoted above, in the ASCE Report on the 1906 San Francisco earthquake when he wrote:

*It is very dangerous, in any scientific discussion, to formulate sweeping general rules.... Can it be maintained that the science of engineering is not the resultant of years of experience? Can it be said that successes are not guides and that failures are not warnings? [47].*

## 1.9 Conclusion: the "ecology" of the vernacular

The evolution of modern skeleton-frame construction, and changes to the engineering profession in response to it, have without a doubt made possible the many extraordinary structures and structurally safe buildings of the modern era. These disciplines have become specialized, and the responsibilities for the safety of structures continue to be extensive and comprehensive.

It is perhaps hard to appreciate this today, but where the difference between the pre-modern and the modern era became most apparent to me was on a visit to Kabul, Afghanistan, on an assignment in 2006 for The Turquoise Mountain Foundation, a UK-based nongovernment organization. This foundation had undertaken the restoration of a number of historic structures of traditional timber and masonry construction in a district of Kabul. The Afghan professional who was supervising and directing the teams of workmen was called by the honorific "Engineer" by his workmen and others in the community; his full name thus being "Engineer Hedayatullah" in all of the communications by the foundation. No drawings were used for the work, yet all work was carefully guided to meet the stringent restoration requirements of the foundation. Engineer Hedayatullah did not have a formal university-based education but rather had learned his discipline through the trade guild system that still exists there, just as it had existed throughout Europe before the modern era (Figs. 1.22–1.24).



**Figure 1.23** The Peacock House, Murad Khane, Kabul, Afghanistan, before and after restoration.

Photograph by Randolph Langenbach.



**Figure 1.24** The same house shown in Fig. 1.23 after restoration by the Turquoise Mountain Foundation.

Photo by Andre Ullal for the Turquoise Mountain Foundation.

Despite this anachronistic example, it cannot be a surprise that a Renaissance man approach to design in the premodern era is no longer seen as appropriate or even possible in more developed contemporary urban environments. With its disappearance, however, there has been a loss of knowledge about traditional materials and technologies that do not fall within the parameters of the current building codes, and the subjects taught in universities.

This evolution is parallel to the ongoing phenomenon of the disappearance of what may be termed “vernacular” languages — regional languages that are now disappearing with the spread of English and other major languages around the world. A recent PBS video included a report by David Crystal, a linguist, who said: “*Half of the languages of the world are so in danger that they are going to die out in the present century. That means one language dying out somewhere every two weeks*” [48]. This same program closed with a quote that in my opinion speaks also to the importance of traditional forms of construction within the fields of architecture and engineering (Fig. 1.25):

*Just as the physical ecology of the earth depends on the healthy interaction among plants and animals. there is an ecology of consciousness and interdependence of knowledge, culture and wisdom we find in and through our languages. Language is a lens through which we see the world.*

Vernacular architecture and construction belong in that same “ecology” and they both need to exist in the world seen through the “lens” of idiomatic local language and culture. It is no coincidence that the emergence of movements to save dying languages, including Welsh and Hawaiian, parallels a growing interest in alternative “vernacular” forms of construction that are more than simply architectural styles - but carry the substance of deeply historic construction technologies.

Thus, while it may seem a stretch to compare the establishment of frame theory and the displacement of traditional forms of construction with reinforced concrete moment frames worldwide to the loss of languages, when one sees how extraordinarily



**Figure 1.25** Srinagar, Kashmir, photographed in 1981 showing the collision of scale, architectural language, and construction technologies in the historic city after the construction of a large reinforced concrete building. In the three decades that have followed, many more buildings of similarly disruptive scale and design have been constructed in what had been a remarkably well-preserved historic city center.

dominant reinforced concrete construction has become, and the alien scale and visual language of the resulting architecture in many parts of the world, it is clear that something has been lost and not replaced (Fig. 1.25). What has disappeared has everything to do with the “*knowledge, culture and wisdom*” that had been unique to the particular regions and communities.

What is encouraging is that this disappearance has stimulated a growing interest around the world in nonconventional materials and vernacular construction. This is not because these materials and construction methods are new or, in the converse, have entirely ceased to be used, but because what are now conventional materials and construction typologies have become so distant from these previously common materials and systems as to be on the other side of the barrier that has emerged between what are now different disciplines.

Earthquakes are the ultimate test of buildings, and thus, the growing interest among engineering students in technologies that were spurned and totally absent from university curricula less than a decade ago gives a chance to revisit some of those same questions that confronted the engineers who climbed over the ruins of San Francisco in 1906, just as their predecessors had in 1755 in Lisbon, Portugal, and 1783 in Calabria, Italy. More recently, it is also just as the itinerant builders and residents have observed in Turkey after the 1999 Kocaeli and Duzce earthquakes (Figs. 1.26–1.29), and in Pakistan after the 2005 Kashmir earthquake (Fig. 1.30).

Following the example in Fig. 1.31 and other spontaneous examples, the government of Pakistan approved *dhajji* 1 year after the earthquake and *bhatar* 2 years after the earthquake for government assistance. By 2009, a mere four years after the earthquake, there are “*at least 150,000 new homes*” constructed in northern Pakistan in either of these two traditional typologies [49].



**Figure 1.26** View after the 1999 Düzce, Turkey, earthquake showing collapsed reinforced concrete building immediately adjacent to a traditional *humuş* residence with only one panel of brick infill missing. Photographer unknown, image provided courtesy of Adem Dogangun.



**Figures 1.27 and 28** This family were living in Düzce, Turkey, in the house in [Fig. 1.27](#) at the time of the 1999 Düzce earthquake. At that time he was constructing a new house of reinforced concrete. After the earthquake, when he saw that so many RC buildings had collapsed, he stopped the construction and began instead to build a house in *humuş* construction shown in [Fig. 1.28](#).



**Figure 1.29** The interior of the new house being constructed by this family shown in [Figs. 1.27 and 1.28](#) being built of traditional Turkish *humuş* construction.



**Figure 1.30** *Dhajji-dewari* building in rural Pakistan, Kashmir, after the 2005 earthquake, showing the few missing wall panels of infill masonry.



**Figure 1.31** The owner and carpenter of a new house under construction in rural Pakistan near to the building shown in Fig. 1.29 after the earthquake destroyed the owner's original rubble stone home, the ruins of which are on the right. The decision to reconstruct in *dhajji* construction was because the one home in the village that did not collapse was of that construction and the reinforced concrete village store collapsed.

Now, over the course of our new 21st century, there have been increasing numbers of students and professors of architecture and engineering turning their attention and interest toward examples of vernacular construction. Both Indian and Pakistani *dhajji-dewari* and Turkish *humuş* have begun to be explored for their seismic resistance in India and Pakistan, as well as in Turkey, Italy, and Haiti. Perhaps soon, the lessons to be learned from these premodern and preindustrial forms of construction that date back to ancient Rome and even to ancient Minoan civilization can become an inspiration not only for heritage preservation but also even for methods to introduce an increased resilience into modern buildings of steel and reinforced concrete.

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There is considerable interest in the modern engineering application of nonconventional materials driven by the interests of sustainable engineering and the newer trend toward 'engineering for humanity'. *Nonconventional and Vernacular Construction Materials* is a repository of information about the materials science and modern structural engineering application of ancient, vernacular, and nonconventional building materials. Leading experts have contributed chapters that focus on current applications and engineering of these construction materials.

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Kent Harries is an associate professor of structural engineering and mechanics at the University of Pittsburgh, USA. He has conducted extensive research on fibre-reinforced polymer (FRP) materials and full-culm bamboo and the characterisation of bamboo materials. He is the author of over 220 peer-reviewed technical articles, and is editor of the *Journal of Construction and Building Materials* and *FRP International*. Bhavna Sharma is a lecturer in the Department of Architecture and Civil Engineering, at the University of Bath, UK. Her research focuses on the use of natural fibre-reinforced composites and the properties of full-culm and engineered bamboo as an alternative construction material.



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