World Housing Encyclopedia
an Encyclopedia of Housing Construction in
Seismically Active Areas of the World

an initiative of
Earthquake Engineering Research Institute (EERI) and
International Association for Earthquake Engineering (IAEE)

HOUSING REPORT
Half-timbered house in the "border triangle" (Fachwerkhaus im Dreiländereck)

Report #	108
Report Date	01-05-2004
Country	SWITZERLAND
Housing Type	Timber Building
Housing Sub-Type	Timber Building : Wood frame (with special connections)
Author(s)	Maria D. Bostenaru
Reviewer(s)	Mauro Sassu

Summary

This type of construction can be found in both the urban and rural areas of Germany, Switzerland, northern France, and England. The main load-bearing structure is timber frame. Brick masonry, adobe, or wooden planks are used as infill materials depending on the region.

This report deals with the two latter types, because they are located in areas where strong earthquakes occur every century. However, this construction has proven particularly safe, and some of the buildings have existed for 700 years. These buildings have characteristic windows and a rectangular floor plan, with rooms opening to a central hall, which were later replaced by a courtyard. Typically, each housing unit is occupied by a single family. While in the past this was the housing of the poor, today affluent families live in these historic buildings. The load-bearing structure consists of a timbered joists and posts forming a single system with adobe or wooden infill. The walls consist of a colonnade of pillars supported by a threshold on the lower side and stiffened by crossbars and struts in the middle. On the upper part they are connected by a "Rahmholz." The roof is steep with the gable overlooking the street. The floors consist of timber joists parallel to the gable plane with inserted ripples. The only notable seismic deficiency is the design for gravity loads only, while numerous earthquake-resilient features - the presence of diagonal braces, the achievement of equilibrium, the excellent connections between the bearing elements, the similar elasticity of the materials used (wood and eventually adobe) and the satisfactory three-dimensional conformation - have completely prevented patterns of earthquake damage. Since 1970, buildings in Switzerland are regulated by earthquake codes (latest update 1989). The 2002 edition will incorporate EC8 recommendations.

1. General Information

Buildings of this construction type can be found in Switzerland (fig. 2; in regions located at a specific distance from mountainous areas), in northern France (figures 6 and 7), and in southern (fig. 3) to central (fig. 5) Germany as well as in Tirol. Uhde (1903) documents the existence of such buildings in France in Normandie, Bretagne and Alsace (Dreux, Laval, Annonay, Bayeux/stone infilled), Morlaix, Dol, Yville, Compiegne/stone infilled, Rouen, Rheims, Abbeville, Boulogne, Beauvais, Angers, Lisieux, St. Brieux, Caen, Strassbourg). Except in central Germany, these areas are affected by Alpine earthquakes with epicenters originating in Switzerland. The earthquake on the 22nd of April, 1884 was recorded to badly damage the area of Essex in England. Buildings of this type remained nevertheless well preserved. Some of many half timbered house in the town centre of Colchester, Essex, England are illustrated on http://www.camulos.com/virtual/guidec.htm (2004), the Virtual Tour of Colchester. Uhde (1903) documents such buildings in England (Shrewsbury, Coventry, Cheshire, Lanchshire, Darthmouth, York, Bristol, Chester). This type of housing construction is commonly found in both rural and urban areas.

See figure 1 for examples of urban and rural buildings of this type in southern and central Germany.

This construction type has been in practice for more than 200 years.

Currently, this type of construction is being built. In Germany, there are about 2 million houses of this type (source: http://www.fachwerk.de/fachwerkhaus/fachwerk.html, 2004). The "new" ones began to be built after 1970 (fig. 4). This type of housing has been constructed in this area since Roman times (Uhde, 1903). The first documented building is a house constructed with 2 upper and 2 roof stories in Marburg in 1320. Most of those still existing, however, are 150 years older than this one. The historical development can be seen at:
http://www.fachwerk.de/fachwerkhaus/15_Jahrhundert.html (2004) - 15th century
http://www.fachwerk.de/fachwerkhaus/16_Jahrhundert.html (2004) - 16th century
http://www.fachwerk.de/fachwerkhaus/17_Jahrhundert.html (2004) - 17th century
http://www.fachwerk.de/fachwerkhaus/18_Jahrhundert.html (2004) - 18th century
http://www.fachwerk.de/fachwerkhaus/19_Jahrhundert.html (2004) - 19th century Particularly relevant is the information on the homepage of the town of Wtzlar in mid-Germany, featuring a house from exactly 1356 (the year of the big earthquake in Basel, Switzerland); a typical middle age building:
http://www.wetzlarvirtuell.de/asp/main_frame_addr.asp?address_id=115 (2004) Abraxas Basel GmbH (2004) documents on the own webpage their domicile in a Half-timbered house in Basel, protected as monument. The construction type is said to correspond to that of the 12th century, when the house was built: between two sandstone struts of the church of St. Martin, and that it survived the big earthquake of 1356. The back is built by a natural rock. It has several upper floors and was carefully renovated by the owners over more years: - View from inside at: http://www.meteoriten.ch/www/laden1.html (2004) - View from outside at: http://www.meteoriten.ch/www/laden.html (2004).

Figure 1: "Fachwerk" houses in Germany: a. in an urban area; b. and c. in rural areas; a. and c. southern Germany; b. central Germany. a. and c. photo by M. Kauffmann.

Figure 2: Historical houses in Switzerland. Source: Uhde(1903), Fig. 354 on page 305, after Gladbach.

Figure 3: House from mountaineous areas from Southern Germany. Photo by M. Kauffmann.

Figure 4: Typical new building in Southern Germany: perspective view, view of the gable and detail (photo by M. Kauffmann)

2. Architectural Aspects

2.1 Siting

These buildings are typically found in flat, sloped and hilly terrain. They share common walls with adjacent buildings. Urban houses are adjacent; rural houses have varying separation distances

2.2 Building Configuration

The building configuration is rectangular. Village dwellings consisted of a middle floor where cooking could be done, and a staircase. To the left of the stairs were the storage rooms and the stables, and to the right, the living quarters and bedrooms, which were oriented to the street (fig. 12). Urban houses do not have side openings. The central hall (fig. 23) is accessible from the street through a passageway and opens onto a courtyard. The kitchen is a separate room, but the front and back rooms remain connected at all levels by the galleries. The residential spaces are situated mainly in the upper floors (figures 13 and 14). Windows slide open from bottom to top. Doors were not adapted to the position of the pillars. Builders made use of the "Rahmholz" (fig. 9) to configure these differently. Doorways end at the upper side in arcs (fig. 19). In the Middle Ages, and from the 16th century on, doors were increasingly rectangular in shape.

Figures 15, 17 and 18 show typical windows and their ornaments.

2.3 Functional Planning

The main function of this building typology is single-family house. Different patterns dividing the storage, work, and living space areas occur in various regions of Germany, Switzerland, and Tirol, but generally they follow the scheme mentioned above. In a typical building of this type, there are no elevators and 1-2 fire-protected exit staircases. The means of escape is through the middle hall and through the courtyard and galleries as described at 2.6. In these spaces either rectangular or spiral-shaped staircase(s) can be found. Unlike today, there were no staircases with windows. The staircase was part of the hall and illuminated through the opening. Rural buildings have two escape doors - one into courtyard and one into the hall; urban houses are accessible through a passage as explained in 2.6. (fig. 23).

2.4 Modification to Building

Some pillars or transversal connections have been demolished. During restoration, several positive modifications have become possible, such as new floors or new infills, but also some negative changes have been introduced as shown at http://www.fachwerkhaus.de/fh_haus/basis/suenden.htm (2004).

Figure 5: Half timbered houses in central Germany: R

Figure 6: The chef-d-oevre of the style: detail of a half-timbered house in Strassbourg, France.

Figure 7: Half timbered houses in Strassbourg, France. See the relationships between the dome and the narrow medieval streets and/or facades.

Figure 19: Typical door

Figure 20: Ornamented pillar (Photo by M. Kauffmann)

Figure 22: Interior details. Source: Lachner(1885)

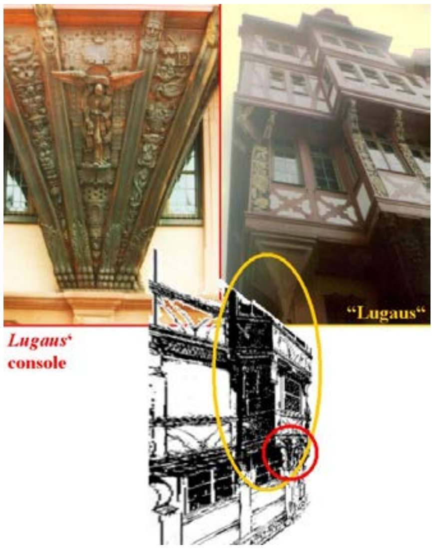

Figure 25: Details of a "Lugaus": photo of such a form in central Germany/Frankfurt, Maine (top right), console detail/Frankfurt, Maine (top left), drawing after examples of Lachner(1885) (bottom)

3. Structural Details

3.1 Structural System

Material	Type of Load-Bearing Structure	#	Subtypes	Most appropriate type
Masonry	Stone Masonry Walls	1	Rubble stone (field stone) in mud/lime mortar or without mortar (usually with timber roof)	☐
		2	Dressed stone masonry (in lime/cement mortar)	☐
	Adobe/ Earthen Walls	3	Mud walls	☐
		4	Mud walls with horizontal wood elements	☐
		5	Adobe block walls	☐
		6	Rammed earth/Pise construction	☐
	Unreinforced masonry walls	7	Brick masonry in mud/lime mortar	☐
		8	Brick masonry in mud/lime mortar with vertical posts	☐
		9	Brick masonry in lime/cement mortar	☐
		10	Concrete block masonry in cement mortar	☐
	Confined masonry	11	Clay brick/tile masonry, with wooden posts and beams	☐
		12	Clay brick masonry, with concrete posts/tie columns and beams	☐
		13	Concrete blocks, tie columns and beams	☐
	Reinforced masonry	14	Stone masonry in cement mortar	☐
		15	Clay brick masonry in cement mortar	☐
		16	Concrete block masonry in cement mortar	☐
		17	Flat slab structure	☐
		18	Designed for gravity loads	

			only, with URM infill walls	☐
Structural concrete	Moment resisting frame	19	Designed for seismic effects, with URM infill walls	☐
		20	Designed for seismic effects, with structural infill walls	☐
		21	Dual system – Frame with shear wall	☐
	Structural wall	22	Moment frame with in-situ shear walls	☐
		23	Moment frame with precast shear walls	☐
	Precast concrete	24	Moment frame	☐
		25	Prestressed moment frame with shear walls	☐
		26	Large panel precast walls	☐
		27	Shear wall structure with walls cast-in-situ	☐
		28	Shear wall structure with precast wall panel structure	☐
Steel	Moment-resisting frame	29	With brick masonry partitions	☐
		30	With cast in-situ concrete walls	☐
		31	With lightweight partitions	☐
	Braced frame	32	Concentric connections in all panels	☐
		33	Eccentric connections in a few panels	☐
	Structural wall	34	Bolted plate	☐
		35	Welded plate	☐
Timber	Load-bearing timber frame	36	Thatch	☐
		37	Walls with bamboo/reed mesh and post (Wattle and Daub)	☐
		38	Masonry with horizontal beams/planks at intermediate levels	☐
		39	Post and beam frame (no special connections)	☐
		40	Wood frame (with special connections)	☑
		41	Stud-wall frame with plywood/gypsum board sheathing	☐
		42	Wooden panel walls	☐
Other	Seismic protection systems	43	Building protected with base-isolation systems	☐
		44	Building protected with seismic dampers	☐
	Hybrid systems	45	other (described below)	☐

Pillars are not placed vertically one over the other.

3.2 Gravity Load-Resisting System

The vertical load-resisting system is timber frame load-bearing wall system. The gravity load-bearing structure consists out of a timbered joist-and- post system forming a unitary schelet with infill (figures 8 and 11). This infill can be of adobe on willow basketry. In mountainous regions the masonry infill is replaced by wooden planks. The stories aren't usually placed one over the other, but are built as consoles, thus the upper floors progressively become enlarged from the street level. Not all joists are horizontal and thus different crossing figures out of "braces" and "ties" are created. The figures drawn out of posts, braces and ties give hints about the time the "Fachwerk" building was constructed (figures 9, 11 and 18). Joists are situated at about 0.9m distance, pillars at about 1.2m. Beams are about 30cm high and joists about 10 x 1 cm. Typical structural details can be seen in Böhm (1991) in the chapter, "The Half

Timbered Wall," especially from pages 204-264.

3.3 Lateral Load-Resisting System

The lateral load-resisting system is timber frame load-bearing wall system. The key load-bearing elements and their original German names are depicted in fig. 9. Basically, in this schelet structure the gravity and the lateral load-bearing structure are the same (fig. 8). According to Lacher (1885), the outside walls consist out of an array of pillars ("Ständer" in German, fig. 20). They are supported from a threshold ("Schwelle" in German) on the bottom, and stiffened by crossbars ("Riegel" in German) and struts ("Streben" in German) in the middle. In the upper part they are connected by a "Rahmholz". Windows are placed arbitrarily as dictated by the interior function and are set out of the wall plane (fig. 17). The pillars are firmly connected with the threshold and "Rahmholz" and there is no danger of out-of-plane failure. Thus there are no diagonal pillars to reinforce the connection between the pillars and the threshold (fig. 11). A characteristic of the Fachwerk houses in this region are the scantlings ("Eckholz" in German), which are placed in the orthogonal angle between the threshold/Rahmbalken and pillars (fig. 16). The panels are infilled with willow basketry (fig. 10) with puddle and plastered. Thus the fields are of smaller area compared to the northern German ones, where brick infill was common. Small bars are introduced, with both a decorative and constructive role (fig. 37). Sometimes the infill is made of wooden planks (fig. 2 and 3). In isolated cases the wall is covered with timber planks. The roof is steep and there are two attic floors (fig. 4). The gable overlooks the street in most cases. Several "Kehlbalken" constitute the main load-bearing parts of the roof. Some longitudinal beams on free posts support them. Angle bonds and bows strengthen the connections in both directions. The rafters are set through tapping and indenting the roof joists and are supported at the bottom end ("Auschieblinge), which are plated directly on the ends of the roof joists in the facade plane (This gable solution originated from Switzerland and spread over southern Germany.) The roof is cantilevered over the wall surface, in order to protect this from weather. The wall frame joists of the longitudinal side run out from the gable wall and "head bands" ("Kopfband" in German) are added to support them. In order to support the "Aufschieblinge" and the rafters end pieces of an interrupted gable threshold lay on the wall frame joists. This solution is also widespread in Alsace. The floors consist of parallel joists with inserted ripples (fig. 21), so that the lower side remains visible. Sometimes cassette ceilings are seen. In instances with spans crossing larger spaces, beams were added to the floor joists. The joists are parallel to the street while long orthogonal walls are common on the street side between neighboring buildings. The distance between the joists is as low as 1 1/2 joist thickness. Characteristic of this type of construction in southern Germany are outbuildings and annexes, like "Erker," "Chörlein," "Ecktürmchen" (fig. 5), "Lugaus," and "Dacherkertürmchen" (combination of balconies and towers). "Lugaus" are rectangular front buildings spanning more stories, starting either on ground floor level or in a console/cantilever over the stone ground floor. At the upper side it ends with an independent little tower (figure 25). "Erker" and "Chörlein" are polygonal front buildings spanning a single story only, while the first one begins at street level and the second one at the console. "Rundchörlein" are round front buildings. Multiple combinations are possible.

3.4 Building Dimensions

The typical plan dimensions of these buildings are: lengths between 8 and 20 meters, and widths between 6 and 10 meters. The building has 1 to 8 storey(s). The typical span of the roofing/flooring system is 1.2 meters. Typical Plan Dimensions: There is a great variety of plan dimensions. Typical Number of Stories: Typical are two "normal" stories and a two-storied attic. Historical Fachwerk-houses have had up to eight stories (according to http://www.fachwerkhaus.de/fh_haus/basis/suenden.htm, 2004). Today, for example, 7.40m to the corniche are prescribed in some local codes (see http://www.fachwerkhaus.de/fh_haus/info/drei.htm, 2004). Typical Story Height: This is an average height, as story heights of 2.1m (even today!) or of 4.0m (the higher stone ground floor) are possible. According to Stade (1904) there was one intermediary horizontal element in cases where the height was 2.5m, two elements at a height of 3.5m, and three at 4m or more. Typical Span: This distance describes that found between pillars. Unequal distances between pillars are characteristic. Spans are typically in a range between 1 and 2m though spans of 0.6-1.5m for intermediary fields and 1.5-1.6m for corner fields are also found. The fields were typically 0.6-0.9m high according to Stade [1904]). See figures 38 and 39 for interior details reflecting the different spans. The typical storey height in such buildings is 2.5 meters. The typical structural wall density is up to 10 %. 6% - 10% These are not load-bearing infill walls.

3.5 Floor and Roof System

Material	Description of floor/roof system	Most appropriate floor	Most appropriate roof
Masonry	Vaulted	☐	☐
	Composite system of concrete joists and masonry panels	☐	☐

Structural concrete	Solid slabs (cast-in-place)	☐	☐
	Waffle slabs (cast-in-place)	☐	☐
	Flat slabs (cast-in-place)	☐	☐
	Precast joist system	☐	☐
	Hollow core slab (precast)	☐	☐
	Solid slabs (precast)	☐	☐
	Beams and planks (precast) with concrete topping (cast-in-situ)	☐	☐
	Slabs (post-tensioned)	☐	☐
Steel	Composite steel deck with concrete slab (cast-in-situ)	☐	☐
Timber	Rammed earth with ballast and concrete or plaster finishing	☐	☐
	Wood planks or beams with ballast and concrete or plaster finishing	☐	☐
	Thatched roof supported on wood purlins	☐	☐
	Wood shingle roof	☐	☑
	Wood planks or beams that support clay tiles	☐	☐
	Wood planks or beams supporting natural stones slates	☐	☐
	Wood planks or beams that support slate, metal, asbestos-cement or plastic corrugated sheets or tiles	☐	☐
	Wood plank, plywood or manufactured wood panels on joists supported by beams or walls	☐	☐
Other	Described below	☑	☑

Wood planks on wood joists, sometimes forming cassette ceilings. Rafter ("Sparrendach" in German) or stringer roof ("Pfettendach" in German).

3.6 Foundation

Type	Description	Most appropriate type
Shallow foundation	Wall or column embedded in soil, without footing	☐
	Rubble stone, fieldstone isolated footing	☐
	Rubble stone, fieldstone strip footing	☐
	Reinforced-concrete isolated footing	☐
	Reinforced-concrete strip footing	☐
	Mat foundation	☑
	No foundation	☐
Deep foundation	Reinforced-concrete bearing piles	☐
	Reinforced-concrete skin friction piles	☐
	Steel bearing piles	☐
	Steel skin friction piles	☐
	Wood piles	☐
	Cast-in-place concrete piers	☐
	Caissons	☐
Other	Described below	☐

For new buildings. Old buildings had a masonry foundation, usually stone masonry (foundation stones).

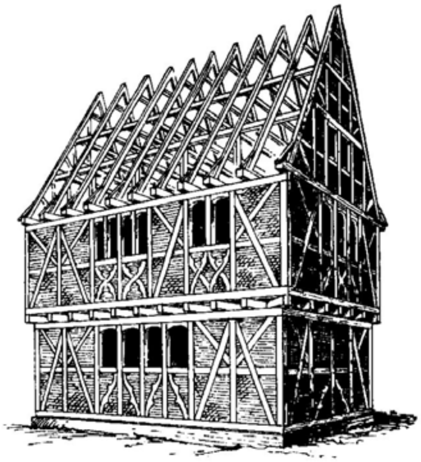

Fig. 1.

Figure 8: Configuration scheme of the sourthern Germany "St

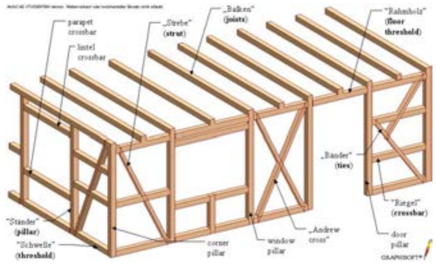

Figure 9: Names of the key load bearing elements.

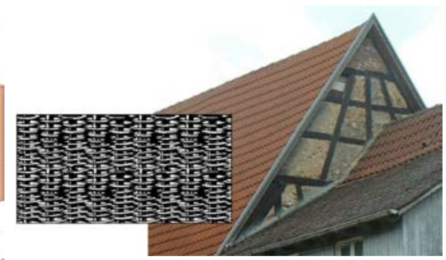

Figure 10: The infill material: on the left - drawing of willow basketry, used for infilling; on the right - close view of adobe infilled panels.

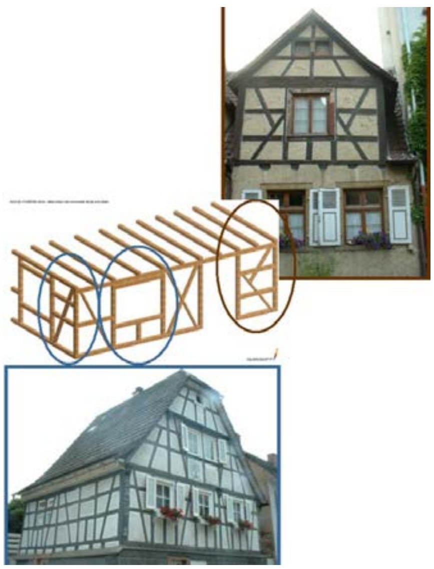

Figure 11: Key load bearing elements exemplified on two typical buildings. Photos by M. Kauffmann.

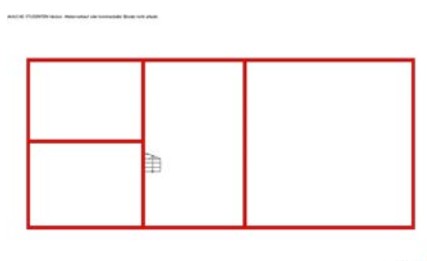

Figure 12: Scheme of the floor plan of a rural building.

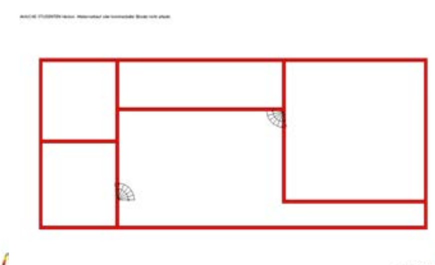

Figure 13: Scheme of the ground floor plan of an urban building.

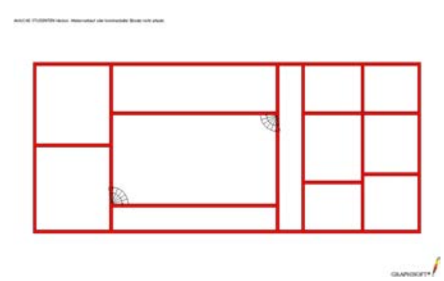

Figure 15: Typical window. Photo by M.

Figure 16: Connection between horizontal and vertical load bearing elements: side wall (top) and

Figure 14: Scheme of the upper floor plan of an urban building.

Kauffmann.

typical gable solution (bottom). Photos by M. Kauffmann.

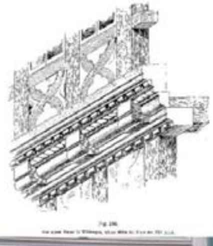

Figure 17: Parapet ornaments: top - at a house in Wildungen, built in the middle till end 16th century. Source: Uhde(1903), Fig. 288 on page 252; bottom - at a house in Durlach. Photo: M. Kauffmann.

Figure 18: Various kinds of ornament around the windows. Photos by M. Kauffmann.

Figure 21: Construction details of floors (new building): from bottom to top different steps in finishing.

Figure 24: Key seismic features. (Photo by M. Kauffmann)

4. Socio-Economic Aspects

4.1 Number of Housing Units and Inhabitants

Each building typically has 1 housing unit(s). 1 units in each building. The number of inhabitants in a building during the day or business hours is less than 5. The number of inhabitants during the evening and night is 5-10.

4.2 Patterns of Occupancy

Until the 19th century one family (spanning several generations) occupied a house. After that, different rooms or floors might be rented out.

4.3 Economic Level of Inhabitants

Income class	Most appropriate type
a) very low-income class (very poor)	☐
b) low-income class (poor)	☐
c) middle-income class	☐
d) high-income class (rich)	☑

Applicable today. In the Middle Ages these houses were inhabited by the poor. Economic Level: The ratio of price of housing unit to the annual income can be 4:1 for rich families.

Ratio of housing unit price to annual income	Most appropriate type
5:1 or worse	☐
4:1	☐
3:1	☐
1:1 or better	☑

What is a typical source of financing for buildings of this type?	Most appropriate type
Owner financed	☐
Personal savings	☑
Informal network: friends and relatives	☑
Small lending institutions / micro-finance institutions	☐
Commercial banks/mortgages	☑
Employers	☐
Investment pools	☐
Government-owned housing	☐
Combination (explain below)	☐
other (explain below)	☐

In each housing unit, there are 2 bathroom(s) without toilet(s), 1 toilet(s) only and 2 bathroom(s) including toilet(s).

The numbers above refer to contemporary buildings. Bathrooms exist only in buildings from the 19th century and after. Latrines were not always part of the main building until then. .

4.4 Ownership

The type of ownership or occupancy is renting, outright ownership and ownership with debt (mortgage or other).

Type of ownership or occupancy?	Most appropriate type
Renting	☑
outright ownership	☑
Ownership with debt (mortgage or other)	☑
Individual ownership	☐
Ownership by a group or pool of persons	☐
Long-term lease	☐
other (explain below)	☐

5. Seismic Vulnerability

5.1 Structural and Architectural Features

Structural/ Architectural Feature	Statement	Most appropriate type		
		Yes	No	N/A
Lateral load path	The structure contains a complete load path for seismic force effects from any horizontal direction that serves to transfer inertial forces from the building to the foundation.	☑	☐	☐
Building Configuration	The building is regular with regards to both the plan and the elevation.	☐	☑	☐
Roof construction	The roof diaphragm is considered to be rigid and it is expected that the roof structure will maintain its integrity, i.e. shape and form, during an earthquake of intensity expected in this area.	☐	☑	☐
Floor construction	The floor diaphragm(s) are considered to be rigid and it is expected that the floor structure(s) will maintain its integrity during an earthquake of intensity expected in this area.	☐	☑	☐
Foundation performance	There is no evidence of excessive foundation movement (e.g. settlement) that would affect the integrity or performance of the structure in an earthquake.	☑	☐	☐
Wall and frame structures- redundancy	The number of lines of walls or frames in each principal direction is greater than or equal to 2.	☑	☐	☐
Wall proportions	Height-to-thickness ratio of the shear walls at each floor level is: Less than 25 (concrete walls); Less than 30 (reinforced masonry walls); Less than 13 (unreinforced masonry walls);	☐	☐	☑
Foundation-wall connection	Vertical load-bearing elements (columns, walls) are attached to the foundations; concrete columns and walls are doweled into the foundation.	☐	☑	☐
Wall-roof connections	Exterior walls are anchored for out-of-plane seismic effects at each diaphragm level with metal anchors or straps	☐	☑	☐
Wall openings	The total width of door and window openings in a wall is: For brick masonry construction in cement mortar : less than ½ of the distance between the adjacent cross walls; For adobe masonry, stone masonry and brick masonry in mud mortar: less than 1/3 of the distance between the adjacent cross walls; For precast concrete wall structures: less than 3/4 of the length of a perimeter wall.	☐	☐	☑
Quality of building materials	Quality of building materials is considered to be adequate per the requirements of national codes and standards (an estimate).	☑	☐	☐
Quality of workmanship	Quality of workmanship (based on visual inspection of few typical buildings) is considered to be good (per local construction standards).	☑	☐	☐
Maintenance	Buildings of this type are generally well maintained and there are no visible signs of deterioration of building elements (concrete, steel, timber)	☑	☐	☐
Additional Comments				

5.2 Seismic Features

Structural Element	Seismic Deficiency	Earthquake Resilient Features	Earthquake Damage Patterns
Wall frame	Designed for gravity loads only. Joists not always in the same plane as the pillars.	- Presence of diagonal braces (fig. 24); - Astonishing feeling of the carpenters of the time for equilibrium; - Very well-made connections between the wooden frame elements; excellent technique in cutting the wood for doing this.	
Frame infill	Designed for gravity loads only.	Similar elasticity to that of the frame in this type (infill is out of adobe or wood) as compared to the northern type (infill is out of bricks). Contemporary construction uses brick more and more.	
Floors	Designed for gravity loads only. Joists not always in the same plane as pillars, and thus are supported by beams instead of directly by pillars.	Timber floors and joists ensure a uniform distribution of rigidities in-plane and energy absorption. Similar elasticity to that of the walls.	
Roof	Designed for gravity loads only.	Good three-dimensional conformation of the roof. Similar elasticity to walls and floors.	

5.3 Overall Seismic Vulnerability Rating

The overall rating of the seismic vulnerability of the housing type is D: MEDIUM-LOW VULNERABILITY (i.e., good seismic performance), the lower bound (i.e., the worst possible) is C: MEDIUM VULNERABILITY (i.e., moderate seismic performance), and the upper bound (i.e., the best possible) is E: LOW VULNERABILITY (i.e., very good seismic performance).

Vulnerability	high	medium-high	medium	medium-low	low	very low
	very poor	poor	moderate	good	very good	excellent
Vulnerability Class	A	B	C	D	E	F
	☐	☐	☑	☐	☑	☐

5.4 History of Past Earthquakes

Date	Epicenter, region	Magnitude	Max. Intensity
1356	Basel (30 km to south)		IX (MSK)
1601	Vierwaldstättersee		VIII-IX (MSK)
1755	Oberwallis near Brig/Visp		VIII-IX (MSK)
1946	Sanetschpass (Central Wallis)		VIII (MSK)

Damage due to the 1356 Basel earthquake occurred up to 300 km distance from its epicenter (Burgundy, France). This kind of building was not affected, though, and in Basel there are buildings still standing from ~1200, which survived the earthquake and the years since (http://www.meteoriten.ch/, 2004). See http://www.wetzlarvirtuell.de/asp/main_frame_addr.asp?address_id=115 (2004) for a typical Middle Age house from exactly the year of the Basel earthquake 1356 in Wetzlar, central Germany (Broadshirm street 6). Affected by the 1356 earthquake were constructions of stone, like castles and churches, and not the wooden construction inhabited by the poor. The 1601 earthquake was felt according to D-A-CH (1989) in the entire area of central Europe. Two historically strong earthquakes with epicenters in Oberwallis near Brig/Visp have occurred: one in 1755 as listed above and one in 1855 with IX (MSK) intensity. The earlier one was felt in the whole Alpine region as well as in southern Germany and northern Italy. The 1855 earthquake was the strongest earthquake in Switzerland in the 19th century and was strongly felt in southern Germany and northern Italy. In the time period between these two events, Switzerland was affected by a strong earthquake in 1774, with VIII MSK intensity and an epicenter in central Switzerland that affected numerous cantons. (after D-A-CH, 1989) The strongest earthquake in Switzerland in the 20th century occurred in 1946. It was felt in Austria (Innsbruck), France (Alsace, Grenoble), southern Germany (Stuttgart) and northern Italy

(Milano) (after D-A-CH, 1989). Data are available for several recent earthquakes with magnitudes over 4.0 occurring in Switzerland in the European Strong Motion Database (2002): an earthquake with magnitude 4ML in 1996 at Kirchberg, an earthquake with magnitude 4.3ML in 1999 in Fribourg, an earthquake with magnitude 4.9 Mw in 1999 in Piz Tea Fondada, and an earthquake with magnitude 4.1Mw in 2000 with an epicenter in Monte Solena. A complete earthquake catalogue is available at: http://histserver.ethz.ch/intro_e.html (2004) See the general references for examples of historical earthquakes affecting this type of construction in Switzerland and Austria .

Figure 23: Courtyard of a house in Strassbourg from 1657 (left). Source: Uhde (1903) Fig. 307 on page 269 from "Strassbourg and its buildings" and passage to the courtyard in Durlach (right). Photo M. Kauffmann.

6. Construction

6.1 Building Materials

Structural element	Building material	Characteristic strength	Mix proportions/dimensions	Comments
Walls	Wall infill (less mountainous region): Adobe Wall infill (mountain region): Oak timber planks	Wall infill (less mountainous region): N/A Wall infill (mountain region): Elasticity modulus 70000-120000; tension 1310 kg/qcm; compression 510 kg/qcm; bending 1020 kg/qcm; shear 79 kg/qcm	Wall infill (less mountainous region): Clay (10%) Silt Sand Gravel 4-5 stabs (oak, 3-5cm wide) were needed to fill the basketry in 1m width timber frame. Often chaff was added. Wall infill (mountain region): 2.5-3.25cm planks. The resulting wall is 4-5cm thick. (Stade, 1904)	In new buildings, adobe prefabricated plates can be used (these are then cut to the dimension needed for the infill). However, using adobe today is expensive (personal costs) even if the material is almost free, so brick masonry is used more and more.
Foundation				
Frames (beams & columns)	Timber frame (old buildings): Oak (sometimes fir) wood Timber frame (new buildings): Douglas fir or laminated wood	Timber frame (old buildings): Elasticity modulus 70000-120000; tension 1310 kg/qcm; compression 510 kg/qcm; bending 1020 kg/qcm; shear 79 kg/qcm Timber frame (new buildings): Elasticity modulus 72000-144000; tension 250 kg/qcm; compression 1080 kg/qcm; bending 840 kg/qcm; shear -	"Ganzholz" (wood originating from a whole tree stem), "Halbholz" (half of a stem) and "Kreuzholz" (a quarter of a stem) Lower horizontal elements: 13/18, 13/20, 15/20, 13/21 or 16/21 cm (Stade, 1904). Upper horizontal elements: 12/12, 13/13, 12/14, 13/15, 13/18 cm. (Stade, 1904) Corner pillars: 13/13, 15/15, 13/16, 16/16, 21/21 cm (Stade, 1904). Intermediary pillars:12/12, 13/13, 12/14, 13/15, 12/16 or 13/16cm (Stade, 1904). Diagonals: 12/16 or 13/18 cm (Stade, 1904). Upper horizontal elements (sustaining the roof): 12/16, 13/18 or 16/21cm (Stade, 1904).	For traditional houses.
Roof and floor(s)	Oak timber	Elasticity modulus 70000-120000; tension 1310 kg/qcm; compression 510 kg/qcm; bending 1020 kg/qcm; shear 79 kg/qcm	Floors: Planks are 2-5 cm thick. The joists are between 2.5cm (0.80m span) to 16cm (4.5m span). Roof: Timber between 8/8 cm and 28/30cm. (Stade, 1904)	

6.2 Builder

The builder typically lives in this construction type, but regardless, it is not built for speculation.

6.3 Construction Process, Problems and Phasing

Großmann (1986) describes in detail the construction process for a historical Fachwerkhaus (pages 10-44) and included illustrations of the materials, steps, typical drawings and tool kits used. After the planning is completed, the work is begun in the carpenter's workshop. There were two kinds of work: processing the wood from tree logs to lumber and creating tenons and related work. Saws, axes, knives, chisels, planers, and drillers were used. The joists, ties, pillars, etc. were marked for assembly. The assemblage was made often for a whole wall at once, especially for multi-storied buildings. Sometimes a safer construction method was used (depending on the number of persons available for the work), namely, connecting the pillars to the foundation and to the threshold and then adding the struts and bands. In Baden-Württemberg the floor was finished after each story was constructed. (? we are unsure of meaning or whether the words used accurately describe the construction process for this section) After the assemblage was connected, it was nailed together. The next step was infilling. Holes were created to add the basketry on which adobe was curled up in a single layer from both sides. Added chaff prevented the creation of cracks while the adobe was drying. The infills were then plastered with calc. Another kind of infilling was done with wooden planks. After this, the floors were constructed followed by the roofing. The next step involved constructing the windows and doors, as well as of stairs,wall wardrobes, and other smaller items, by the joiner ("Bautischler" in German). Plastering and painting the wood came last. The construction process for a new building is illustrated in a report at http://www.fachwerkhaus.de/fh_haus/info/drei.htm (2004). See http://www.fuhrberger.de/leistung/fachwerk/acer.shtml (2004) for images regarding the construction of a house, http://www.fuhrberger.de/leistung/sanierung.shtml (2004) for images regarding the rebuilding an old house after a picture and http://www.fuhrberger.de/leistung/bauzeitenplan.shtml (2004) for a construction plan. The construction of this type of housing takes place in a single phase. Typically, the building is originally designed for its final constructed size.

6.4 Design and Construction Expertise

According to Großmann (1986): Construction literature was used from the 17th century on, as is seen, for example, in C. F. Mayer (1778) for the region around Schwäbisch-Hall. These books were written for developers. The detailed planning was done by the master builder, usually a carpenter by trade. Architects played a role only from the end of the 19th century on. In the 19th century there were construction enterprises by carpenters and master masons. The carpenter had this role exclusively in urban areas until the 18th century and in rural areas until the 19th century. Specific plans for "statics" (structural plans) were drawn. These were used both for construction authorization process and for the construction itself. In previous centuries this was not so widespread as it is today. Contractors used books like "Architektura Civilis" by Johann Wilhelm, from Frankfurt am Main (Nürnberg, 1649 and 1668), which encouraged building models out of paper and wood. This book also recommended estimating costs in advance and drawing up a contract between the developer and the building overseer. The author emphasized the importance of the survey. Knowledge of geometrical forms was important for the planning. See 7.4.

6.5 Building Codes and Standards

This construction type is addressed by the codes/standards of the country. Switzerland: Norm SIA 160 "Einwirkungen auf Tragwerke" (Ausgabe 1989) des Schweizerischen Ingenieur- und Architekten-Vereins (SIA). For codes addressing the buildings in Germany see report #95. In France structures under seismic risk are addressed by Règles PS92, Norme NF P 06-13, 1992 (García et al, 2004) The Austrian seismic regulations are called ÖNORM B 4015 (García et al, 2004). The year the first code/standard addressing this type of construction issued was 1970 - SIA 160 Ausgabe 1970. Short descriptions of the provisions, especially regarding the seismic zoning, for Switzerland, Germany, France and Austria are included in García et al (2004), but not for the UK. The most recent code/standard addressing this construction type issued was Switzerland: 1989. A new code, update of the old, was updated into a new code (SIA 261), but SIA 160/89 will remain valid until 2004. The Austrian seismic regulations have been updated in 2002 (García et al, 2004). The French regulations are, according to García et al (2004), currently revised in view of Eurocode regulations. Title of the code or standard: Switzerland: Norm SIA 160 "Einwirkungen auf Tragwerke" (Ausgabe 1989) des Schweizerischen Ingenieur- und Architekten-Vereins (SIA). For codes addressing the buildings in Germany see report #95. In France structures under seismic risk are addressed by Règles PS92, Norme NF P 06-13, 1992 (García et al, 2004) The Austrian seismic regulations are called ÖNORM B 4015 (García et al, 2004) Year the first code/standard addressing this type of construction issued: 1970 - SIA 160 Ausgabe 1970. National building code, material codes and seismic codes/standards: Short descriptions of the provisions, especially regarding the seismic zoning, for Switzerland, Germany, France and Austria are included in García et al. (2004), but not for the UK. When was the most recent code/standard addressing this construction type issued? Switzerland: 1989. A new code, update of the old, was updated into a new code (SIA 261), but SIA 160/89 will remain valid until 2004. The Austrian seismic regulations have been updated in 2002 (García et al., 2004). The French regulations are, according to García et al. (2004), currently revised in view of Eurocode regulations.

Before 1970, no norms. 1970-1989 SIA 160 first edition (pushover analysis, depending on frequency only; no response spectra and no ductility factors) 1975-1989 SIA 160/2 recommendations (practical measures for protection of buildings against earthquakes) 1989-2002 SIA 160 1989 edition (three building classes, pushover curve varies according to structural type, response spectra, measures) 2002 SWISSCODES (ductility dasses, capacity) to incorporate EC8 recommendations.

6.6 Building Permits and Development Control Rules

This type of construction is a non-engineered, and authorized as per development control rules. Building permits are required to build this housing type.

6.7 Building Maintenance

Typically, the building of this housing type is maintained by Owner(s) and Tenant(s).

6.8 Construction Economics

According to a source in northern Germany (http://www.fuhrberger.de/leistung/index.shtml, 2004), construction prices today are as follows: - ca. $1,500/sq m; - meaning ca. $200,000 (+/- $40,000) for a single-family house, $350,000 for a two-family house, ca. $400,000 for a block of flats with four apartments. Comparable costs are found for similar buildings in northern France. Costs for Switzerland itself are unknown. Historical prices can be seen in Stade (1904) on page 90. According to Großmann (1986) the construction of an historical house (after the wood for it was processed to the necessary "fachwerk" elements, and the connection points created and correspondingly marked) took several days to few weeks. But many workers were needed therefore (for example, 8 carpenters and their helpers). Up to this point only half of the works are completed. For a new building it takes four days to build the "fachwerk" schelet (out of pre-fabricated timber parts) of three stories, and another three days for the complete roof - see http://www.fachwerkhaus.de/fh_haus/info/drei.htm (2004) See figure 42 for a typical work plan.

7. Insurance

Earthquake insurance for this construction type is typically available. For seismically strengthened existing buildings or new buildings incorporating seismically resilient features, an insurance premium discount or more complete coverage is unavailable. According to http://www.gvz.ch/GVZ%5CGVZHome page.nsf/WEBViewPages/Erdbebendeckung? (2004), open document buildings in the canton of Zürich have earthquake coverage under building insurance policies (see source for details). The earthquake hazard in this canton is the lowest in Switzerland and calculations are based upon the Basel earthquake from 1356. Customized earthquake insurance for single or multiple housing units is nevertheless available: for example, through Lloyds (source http://www.erdbeben.at/versicherung.htm, 2004). Even in this case, the premium is influenced primarily by the site. More typical are higher fire insurance premiums for these timber buildings. Typically, buildings and their contents can be insured.

8. Strengthening

8.1 Description of Seismic Strengthening Provisions

Not necessary, as this type of building was not damaged.

8.2 Seismic Strengthening Adopted

Has seismic strengthening described in the above table been performed in design and construction practice, and if so, to what extent?

Not applicable, as there is no seismic damage.

Was the work done as a mitigation effort on an undamaged building, or as repair following an earthquake?

Not applicable, as there is no seismic damage.

8.3 Construction and Performance of Seismic Strengthening

Was the construction inspected in the same manner as the new construction?

Not applicable, as there is no seismic damage.

Who performed the construction seismic retrofit measures: a contractor, or owner/user? Was an architect or engineer involved?

Not applicable, as there is no seismic damage.

What was the performance of retrofitted buildings of this type in subsequent earthquakes?

Not applicable, as there is no seismic damage.

Reference(s)

1. Internet-Site for European Strong-Motion Data
   Ambraseys,N., Smit,P., Sigbjornsson,R. Suhadolc,P., and Margaris,B.
   European Commission, Research-Directorate General, Environment and Climate Programme 2002

2. The Earthquake Provisions of the Code SIA 160
   Bachmann,H.
   Dokumentation D044, SIA, Z 1989

3. Manual of Timbered Constructions
   B
   Julius Springer, 1911. Reprint by Reprint-Verlag-Leipzig, 5th edition 1911

4. Communication Paper of the German Society for Earthquake Engineering, the Austrian Society for Earthquake Engineering, and the Swiss Society for Earthquake Engineering and Structural Dynamics
   D-A-CH
   in SIA nr. 3/1989 1989

5. Comparative Study of the Seismic Hazard Assessments in European National Seismic Codes
   Garc
   In: Bulletin of Earthquake Engineering, Kluwer, Netherlands, preprint

6. The Half-Timbered Construction in Germany: the Historical Half-Timbered House, its Genesis, Colouring, Funktion and Restoration, K
   Gro
   DuMont: 1998 (second edition; first edition 1986)

7. History of the Timber Construction in Germany
   Lachner,C.
   Second part: "The Southern German Pillar-Construction and the Block Construction". Leipzig. E. A. Seemann: 1887. (reprint in "libri rari" Hannover 1983)

8. Manual for Country and House Men in the Pragmatical History of the Whole Country and House Economy of the Kupferzell Department of the Hohenlole-Schilling Principate

Mayer,J.F.
N

9. The Timbered Constructions
Stade,F.
D

10. The Constructions and the Art Forms of Architecture. Their Genesis and Historical Development at Different Nations
Uhde,C.
Volume II "The Timber Construction". Berlin. Ernst Wasmuth: 1903

11. Architectura Civilis or Description and Predrawing of Many Adle Roof and Higher Pinnacles, Crossroofs, Recurrences, Welch Hoods, also of Celtic, fall bridges: Item various Presses, Scrolls, or Nappy Stairs and other Similar Mechanism Fabriques
Wilhelm,J.
Frankfurt 1649 and 1668

12. Fachwerk.de http://www.fachwerk.de/

13. Wetzlar virtuell http://www.wetzlarvirtuell.de/

14. Abraxas Basel GmbH http://www.meteoriten.ch/

15. Camulos - The Colchester Webpages http://www.camulos.com/

16. fachwerkhaus.de http://www.fachwerkhaus.de/

17. Earthquake Catalog of Switzerland http://histserver.ethz.ch/

18. Fuhrberger Zimmerei http://www.fuhrberger.de/

19. Building assurance canton Z

20. Earthquake - Assurance, http://www.erdbeben.at/versicherung.htm

Author(s)

1. Maria D. Bostenaru
researcher, History and Theory of Architecture & Heritage Cons, Ion Mincu University of Architecture and Urbanism
str. Academiei nr. 18-20, Bucharest 010014, ROMANIA
Email:Maria.Bostenaru-Dan@alumni.uni-karlsruhe.de FAX: 0040213077178

Reviewer(s)

1. Mauro Sassu
Associate Professor
Dept. of Structural Engineering, University of Pisa
Pisa 56126, ITALY
Email:m.sassu@ing.unipi.it FAX: 39 050 554597

Save page as