



Challenge Journal of STRUCTURAL MECHANICS

Research Article

Comparative analysis of timber-framed structural systems across different regions: Seismic energy dissipation and controlled damage mechanisms

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ABSTRACT

This study presents a comparative evaluation of the seismic performance of traditional timber-framed structural systems developed in different geographical regions, including Hıms, Dhajji Dewari, Pombalino, Fachwerk, Casa Baraccata, and Chuandou. A literature-based assessment was conducted focusing on energy dissipation mechanisms, ductility characteristics, and damage development processes. The findings indicate that, despite regional and structural differences, these systems exhibit comparable behavioral tendencies under seismic loading. The observed behavior may be interpreted through a multi-stage response mechanism in which seismic demands are progressively distributed through infill materials, connection details, and secondary structural components. In this process, energy dissipation is achieved through the interaction of these elements rather than through the action of a single structural component. Based on the behavioral trends reported in the literature, this study proposes the concept of a “first seismic defense line” as a conceptual framework for interpreting the contribution of secondary components during the early stages of seismic response. Comparative observations suggest that infill elements play a significant role in the energy dissipation process of Hıms and Dhajji Dewari systems, whereas frictional behavior at connection interfaces is more prominent in Chuandou structures. The Pombalino system demonstrates a balanced interaction between stiffness and ductility, while the behavior of Fachwerk and Casa Baraccata systems is governed by frame–infill interaction and the integrated action of timber and masonry components. Overall, these traditional systems exhibit performance-oriented characteristics that are consistent with fundamental principles of modern earthquake engineering and provide valuable insights for contemporary seismic design.

ARTICLE INFO

Article history:

Received – April 13, 2026
Revision requested – May 16, 2026
Revision received – June 1, 2026
Accepted – June 8, 2026

Keywords:

Timber-framed structures
Seismic behavior
Energy dissipation
Ductility
Controlled damage



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Citation: Arslan B (2026). Comparative analysis of timber-framed structural systems across different regions: Seismic energy dissipation and controlled damage mechanisms. *Challenge Journal of Structural Mechanics*, 12(3), 194–204.

1. Introduction

Timber has gained increasing importance in sustainable construction due to its renewable nature, low embodied carbon, and carbon storage capacity. Compared with conventional construction materials such as concrete and steel, timber-based structural systems offer lower life-cycle carbon emissions and contribute to the

reduction of greenhouse gas emissions, leading to growing interest in their application in contemporary building design (Gün and Anıktar 2020; Flanagan 2017). Previous studies have also indicated that the ecological footprint of locally sourced timber materials is generally lower than that of modern industrial construction alternatives (Ozdemir 2025; Yılmaz Karaman and Tanaç Zeren 2015; Dikmen 2010).

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The seismic performance of timber-framed structures depends not only on the characteristics of the primary structural system but also on connection details, the behavior of infill materials, roof loads, soil conditions, and the physical changes experienced by timber over time. In particular, connection discontinuities, geometric irregularities, heavy superstructure elements, and material degradation caused by biological or environmental effects have been identified as key factors influencing seismic response (Dışkaya 2004). Earthquake-related damage is not limited to the direct effects of ground motion, as secondary hazards such as fire, flooding, and geotechnical failures may also threaten structural safety (Aksoy 2003). Consequently, reducing seismic risk requires not only the design of new structures but also the assessment of existing and historic buildings and the planning of appropriate conservation and rehabilitation interventions (Arslan 2006).

Although traditional timber-framed construction systems evolved in different geographical regions and historical periods, they are generally based on similar structural principles. The combined use of timber members and masonry infill dates back to ancient civilizations and has led to the development of various timber-framed construction traditions across Europe, Anatolia, and Asia. Over time, distinct systems such as Pombalino in Portugal, Casa Baraccata in Italy, Fachwerk in Germany, Hımsı in Türkiye, and Dhajji Dewari in South Asia emerged. Despite differences in structural detailing, these systems share a common characteristic in which the timber frame plays an active role in resisting lateral loads while interacting with infill elements to enhance overall structural stability (Vasconcelos et al. 2013).

From a structural engineering perspective, timber-framed systems provide a ductile load-resisting mechanism capable of accommodating lateral forces and deformations induced by earthquakes. Infill components contribute to the mass and stiffness of the structure; however, when adequate interaction with the timber frame is not achieved, they may become vulnerable to brittle damage. Observational studies conducted after major seismic events have demonstrated that properly detailed and well-constructed timber-framed buildings generally exhibit superior seismic performance compared with unreinforced masonry structures. This tendency has been confirmed through post-earthquake damage assessments and field observations following the 1999 İzmit Earthquake, the 2005 Kashmir Earthquake, the 2015 Gorkha Earthquake, and the 2023 Kahramanmaraş Earthquakes (Vieux-Champagne et al. 2014; Qu et al. 2020; Tan et al. 2024). Similarly, Korkmaz (2007) reported that seismic performance varies significantly depending on the structural system and that timber-framed structures generally perform better than conventional masonry buildings. Historical records following the 1509 Great İstanbul Earthquake also indicate that Hımsı structures exhibited better seismic performance and resulted in fewer casualties than masonry buildings (Aktaş 2011). These observations highlight the importance of examining the behavioral characteristics of traditional structural systems and conducting comparative evaluations among different timber-framed construction traditions.

Traditional timber-framed systems represent important examples of indigenous seismic knowledge developed by communities living in earthquake-prone regions. Although known by different names across various geographical contexts, these systems are generally characterized by similar structural principles and by the interaction between a flexible timber frame and infill components (Gani et al. 2021; Vasconcelos et al. 2015; Langenbach 2007) (Fig. 1).

Known as Fachwerk and Pombalino in Europe, Dhajji Dewari in South Asia, Chuandou in China, and Casa Baraccata in the Mediterranean region, these systems have attracted considerable attention due to their adaptable and resilient behavior under seismic loading.

Field observations and experimental studies have shown that these structures may exhibit more controlled damage patterns during major earthquakes compared with modern reinforced concrete systems (Doğangün et al. 2006; Gülhan and Özyörük Güney 2000). These observations suggest that such systems may provide enhanced energy dissipation capacity and improved ductile response.

The seismic performance of these systems has been investigated from various perspectives in the literature. In Pombalino structures, the contribution of bracing members to energy dissipation and their relatively high ductility capacity have been extensively documented (Poletti and Vasconcelos 2015). For Hımsı systems, frame-infill interaction has been identified as a key mechanism governing energy dissipation behavior (Gani et al. 2021; Ozdemir 2025). In Chuandou structures, friction-based mechanisms developing at connection interfaces have been shown to provide considerable energy dissipation capacity (Li et al. 2025; Yang et al. 2021). Similarly, the cellular wall configuration of Dhajji Dewari systems has been reported to enhance structural stability by distributing damage across multiple small panels (Ali et al. 2012).

In addition to these structural characteristics, factors such as topographic conditions and material properties also play an important role in structural response. Geometric irregularities associated with sloping terrain may adversely affect seismic performance (Pan et al. 2023). Furthermore, the type of infill material directly influences both energy dissipation capacity and dominant damage mechanisms (Ozdemir 2025).

Existing research indicates that the successful seismic performance of traditional timber-framed systems is rooted in a set of common structural principles. Nevertheless, the reported behavioral characteristics reveal notable differences among systems in terms of load-transfer mechanisms, deformation capacity, and damage distribution patterns. While bracing elements play a dominant role in maintaining structural stability in some systems, in others the interaction between infill components and the timber frame, or localized mechanisms developing at connection regions, exerts a greater influence on structural behavior. These observations suggest that, despite sharing similar structural principles, the seismic performance of traditional timber-framed systems may vary according to material characteristics, construction techniques, and regional building traditions.

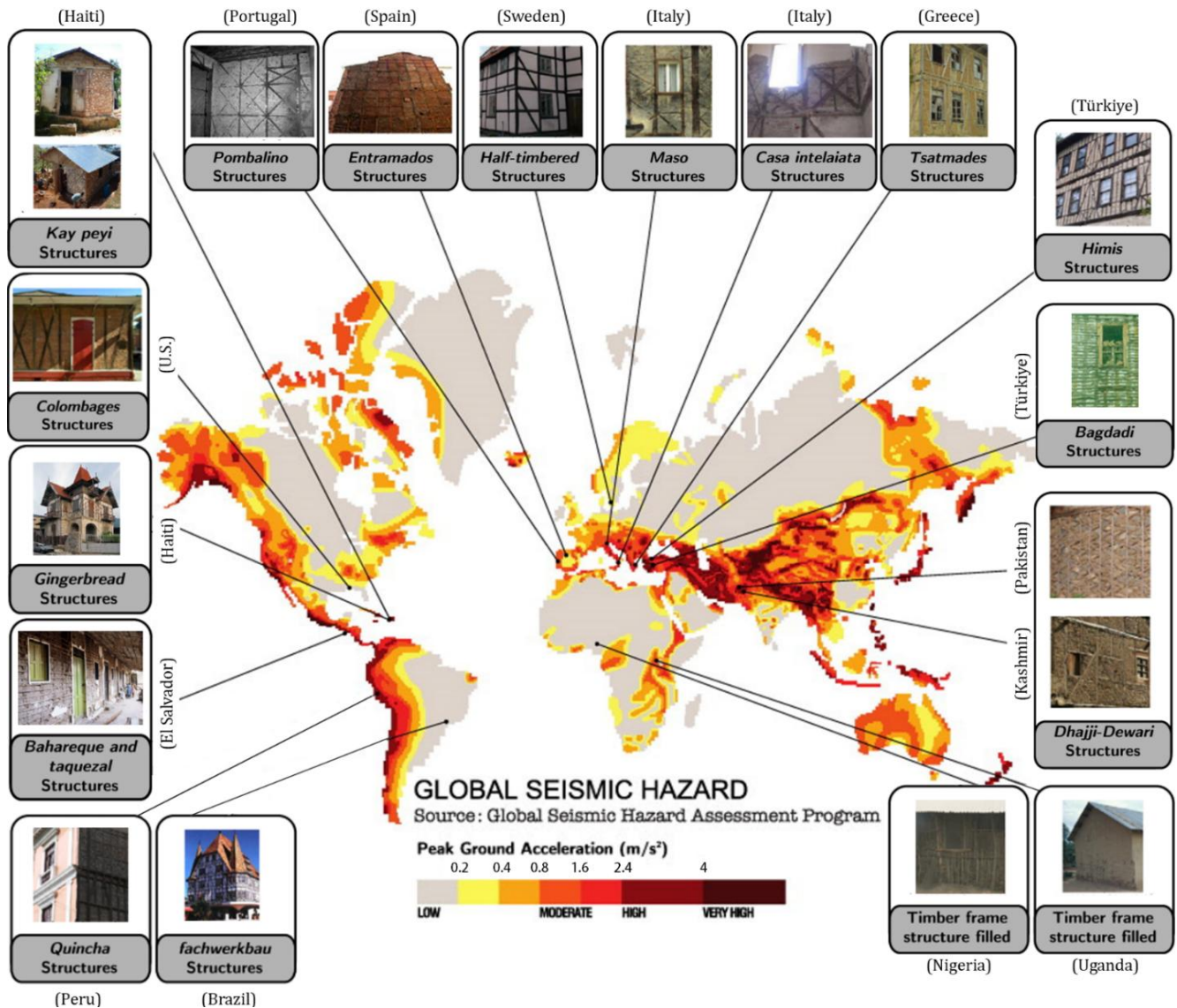


Fig. 1. Examples of timber-framed structures worldwide (adapted from Vieux-Champagne et al. (2014)).

However, most existing studies focus on specific regional construction traditions or individual structural systems, whereas comparative investigations evaluating different timber-framed systems within a common performance framework remain limited. This highlights the need for a comprehensive framework capable of identifying both shared and distinct behavioral mechanisms among traditional timber-framed systems.

Within this context, the present study provides a comparative assessment of Hımiş, Dhajji Dewari, Pombalino, Fachwerk, Casa Baraccata, and Chuandou systems developed in different geographical regions. The primary objective is to examine their seismic behavior within a common analytical framework and to identify their similarities and differences. Accordingly, a conceptual framework referred to as the “first seismic defense line” is proposed to interpret the interaction between infill elements, connection regions, and secondary structural components during the energy dissipation process under seismic loading. This approach offers a conceptual and analytical perspective for understanding the interactive behavior between the primary structural system and secondary components.

2. Investigated Systems and Methodology

2.1. Traditional timber-framed systems

This study evaluates traditional timber-framed structural systems developed in different geographical regions and widely investigated in literature with respect to their seismic behavior. The selected systems exhibit distinct characteristics in terms of structural configuration, infill arrangements, connection details, and energy dissipation mechanisms. Accordingly, Hımiş (Türkiye), Dhajji Dewari (Himalayan region), Pombalino (Portugal), Fachwerk (Germany), Casa Baraccata (Italy), and Chuandou (China) were included in the comparative assessment.

2.1.1. Hımiş system

The Hımiş system is a traditional timber-framed construction technique widely used in Anatolia and neighboring regions. Following the 1509 Great İstanbul Earthquake (Kıyamet-i Suğra), the Ottoman administration restricted the construction of masonry buildings and en-

couraged the use of timber-framed *Himış* structures. The system consists of a load-bearing timber frame composed of vertical and horizontal members, with infill materials placed within the frame bays. Adobe, stone, brick, and other locally available materials are commonly used as infill. While the timber frame constitutes the primary load-resisting system, the infill elements act as secondary components that contribute to overall structural behavior. *Himış* buildings are typically constructed using local materials and are predominantly employed in low-rise residential buildings. Their structural response is governed by a hybrid mechanism defined by the interaction between the timber frame and infill elements (Aktaş et al. 2014; Aktaş 2011).

2.1.2. *Dhajji Dewari* system

Dhajji Dewari is a traditional timber-framed construction system developed in the Himalayan region. It is characterized by a cellular arrangement consisting of small timber-framed panels typically filled with stone or brick fragments. The primary structural system is formed by the timber frame, while the infill elements are divided into smaller compartments. This cellular configuration facilitates load redistribution throughout the structure and limits the concentration of damage in localized regions. Seismic construction traditions in the Himalayan region are not limited to *Dhajji Dewari* and also include timber-laced masonry systems and lightweight infill structures such as *Ikra*, which employ similar strategies based on material flexibility and deformation capacity (Gani et al. 2021; Ali et al. 2012).

2.1.3. *Pombalino* system

The *Pombalino* system is a traditional timber-framed structural system developed in Portugal following the 1755 Lisbon Earthquake to improve seismic resistance. Its principal component is the *gaiola pombalina*, a timber framework reinforced with X-shaped bracing members. This timber frame is integrated within masonry walls to form a composite structural system. The *Pombalino* system relies on the combined action of a braced modular timber frame and masonry walls. The interaction between the internal timber structure and the external masonry components defines its hybrid structural character. Within this arrangement, masonry walls provide protection against environmental effects and fire, while the timber frame contributes to seismic resistance (Aktaş 2011). The interaction between timber and masonry components enables the system to exhibit both stiffness and ductility characteristics (Parrotta 2017; Poletti and Vasconcelos 2015).

2.1.4. *Fachwerk* system

Fachwerk is a traditional timber-framed construction system widely used in Germany. The system consists of a structural skeleton composed of timber posts, horizontal members, and diagonal braces, with infill panels placed within the frame. Brick and adobe are commonly used as infill materials. The timber frame serves as the primary load-resisting system, whereas the infill ele-

ments function as secondary components. The construction technique is characterized by an exposed structural frame visible on the exterior façade, creating a distinctive modular architectural appearance (Parlak Biçer and Şahin 2020).

2.1.5. *Casa Baraccata* system

Casa Baraccata is a traditional timber-masonry hybrid structural system developed in the Calabria region of Italy following the series of destructive earthquakes that occurred in 1783. The system is based on a structural configuration in which timber framing and masonry elements are used together, with timber bracing members positioned on the wall surface rather than embedded within the wall section (Aktaş 2011). The structural arrangement consists of a grid-like timber framework combined with infill components. The interaction between timber and masonry elements constitutes the primary mechanism governing structural behavior. *Casa Baraccata* therefore represents a hybrid structural organization in which timber and masonry components act together to resist seismic actions (Gani et al. 2021; Parrotta 2017).

2.1.6. *Chuandou* system

The *Chuandou* system is a traditional timber structural system widely used in China. It is based on a frame composed of columns and beams connected through mortise-and-tenon joints. The primary load-resisting system consists entirely of the timber frame, while infill components may contribute to structural response without constituting the principal load-transfer mechanism. Traditional construction relies on carpentry techniques without the use of nails. The system is characterized by a modular framing arrangement in which the behavior of connection interfaces plays a critical role in overall structural performance (Li et al. 2025; Yang et al. 2021).

Representative examples of the traditional timber-framed systems investigated in this study are presented in Fig. 2. The selected examples were chosen to illustrate the characteristic architectural appearance and construction features of each structural typology.

Representative schematic drawings of the investigated timber-framed systems were developed within the scope of this study and are presented in Figure 3. These drawings were prepared based on photographs, survey drawings, and structural representations reported in the literature and were redrawn using a standardized graphical format to ensure consistency in the visual presentation of the different structural typologies. Based on the structural characteristics illustrated in Fig. 3, the main descriptive features of traditional timber-framed systems are comparatively summarized in Table 1.

2.2. Methodology

This study adopts a literature-based comparative analysis approach. The primary objective is to evaluate the seismic behavior of traditional timber-framed structural systems developed in different geographical re-

gions within a common analytical framework and to comparatively interpret the behavioral tendencies reported in the literature. The investigated systems were assessed based on criteria including first seismic defense line behavior, damage hierarchy, energy dissipation

mechanisms, connection behavior, preservation of the primary load-resisting system, and ductile deformation capacity. These criteria enable the evaluation of structural response at both the macro scale (system level) and the micro scale (component level).

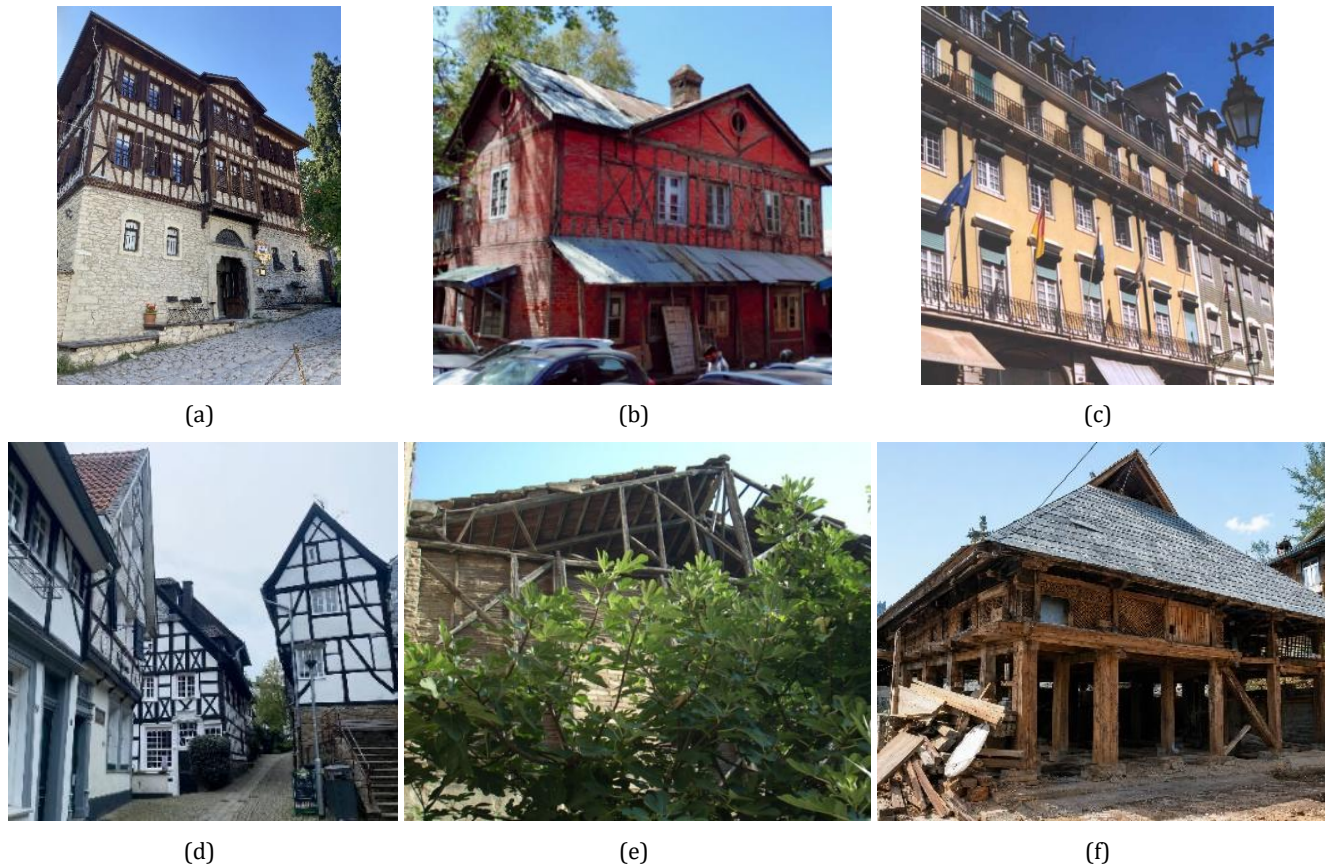


Fig. 2. Exterior views and characteristic structural details of traditional timber-framed systems: (a) Hımiş (author's archive), (b) Dhajji Dewari (Gani et al. 2024), (c) Pombalino (Cardoso et al. 2004), (d) Fachwerk (author's archive), (e) Casa Baraccata (Ruggieri and Zinno 2014), (f) Chuandou (Ren et al. 2018).

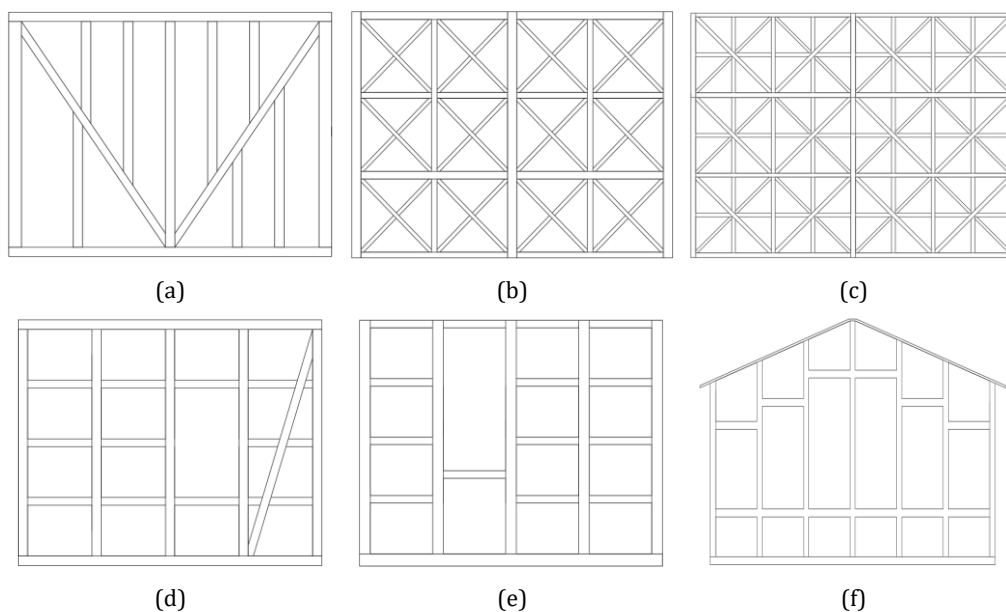


Fig. 3. Representative schematic drawings of traditional timber-framed systems developed based on the structural layouts reported in the literature: (a) Hımiş (Aktaş 2011); (b) Dhajji Dewari (Hicyilmaz et al. 2011); (c) Pombalino (Aktaş 2011); (d) Fachwerk (Perrin 1960); (e) Casa Baraccata (Niglio 2011); (f) Chuandou (Qu et al. 2020).

Table 1. Descriptive characteristics of the investigated traditional timber-framed systems.

System	Region	Primary Structural Feature	Load-Bearing System	Infill Type	Connection Type	Structural Organization	References
Hımsı	Türkiye	Timber frame with infill	Timber frame	Adobe, stone, or brick infill	Nailed timber joints and traditional carpentry details	Infill-frame interaction	Aktaş (2011), Ozdemir (2025)
Dhajji Dewari	Himalaya	Cellular timber frame system	Timber frame	Stone or brick infill with mud mortar	Traditional carpentry joints and nailed connections	Cellular timber frame with distributed infill panels	Hicyilmaz et al. (2011), Gani et al. (2024)
Pombalino	Portugal	Three-dimensional Gaiola Pombalina timber frame system	Hybrid (timber frame + masonry)	Masonry infill	Timber joints with diagonal bracing members	Three-dimensional timber frame embedded within masonry walls	Lopes et al. (2013), Meireles et al. (2012)
Fachwerk	Germany	Timber frame with posts, beams, and braces	Timber frame	Brick, adobe, or wattle-and-daub infill	Mortise-and-tenon and traditional timber joints	Timber frame with independent infill panels	Liu (2022), Gani et al. (2024)
Casa Baraccata	Italy	Timber-reinforced masonry system	Dual system (timber frame + masonry)	Stone or brick infill	Traditional carpentry joints and iron connectors	Integrated timber-masonry structural system	Ruggieri and Zinno (2014), Parrotta (2017)
Chuandou	China	Post-and-beam timber framing system	Timber frame	Timber panels, wattle-and-daub, or masonry infill	Penetrating mortise-and-tenon joints	Post-and-beam frame with infill panels	Qu et al. (2020), Li et al. (2025), Guo et al. (2021)

The literature review included peer-reviewed journal articles, experimental investigations, numerical studies, and other relevant academic publications addressing the seismic behavior of Hımsı, Dhajji Dewari, Pombalino, Fachwerk, Casa Baraccata, and Chuandou systems. The review process was conducted through searches performed in the Scopus, Web of Science, and Google Scholar databases. Searches were carried out using combinations of keywords including “timber-framed structures”, “seismic behavior”, “Hımsı”, “Dhajji Dewari”, “Pombalino”, “Fachwerk”, “Casa Baraccata”, and “Chuandou”. Studies providing technical data or observations related to energy dissipation mechanisms, connection behavior, damage development, ductility characteristics, and overall seismic performance were considered for inclusion. The information used in the comparative assessment was derived from experimental findings, numerical simulation results, and field observations reported in the selected studies.

The data evaluated in this study were obtained from investigations conducted at different scales, under different boundary conditions, and using different experimental methodologies. The reviewed studies included quasi-static tests, shaking-table experiments, numerical analyses, and post-earthquake field observations. Therefore, the comparisons were not intended to provide direct quantitative performance evaluations but rather to support a conceptual interpretation of behavioral tendencies and common structural mechanisms. Consequently, the findings should not be interpreted as normalized performance values obtained under standardized experimental conditions.

Particular emphasis was placed on the behavioral contribution of infill elements, connection regions, and secondary structural components during the early stages of energy dissipation under seismic loading. Within this context, the concept of the “first seismic de-

fense line” is considered a conceptual assessment framework describing the critical stage at which energy dissipation initiates and damage begins to develop in a controlled manner. Comparative analyses were performed through the integrated evaluation of evidence obtained from experimental studies (Poletti and Vasconcelos 2015; Li et al. 2025), numerical investigations (Ozdemir 2025), and field observations reported in the literature. This approach enables a conceptual assessment of the behavioral tendencies and underlying structural principles reported for the investigated systems. The findings contribute to the identification of common behavioral trends and a better understanding of the mechanisms governing structural response. The study presents a conceptual and literature-based framework, while experimental validation is recommended for future research.

3. Findings

3.1. First seismic defense line behavior

In the investigated systems, seismic demands are accommodated through the interaction between the timber structural frame, infill components, and connection regions. However, secondary components appear to play a more prominent role during the early stages of the energy dissipation process. These components, including infill materials, connection details, and auxiliary structural elements, collectively form a behavioral interaction level that may be interpreted as the “first seismic defense line”. This concept is considered a multi-stage behavioral model in which energy dissipation develops progressively through the interaction between infill components, connection regions, and the primary structural frame.

A comparative assessment of this behavior across the investigated systems is presented in Table 2. The table highlights commonalities and differences among traditional timber-framed systems developed in different regions with respect to energy dissipation mechanisms, damage development processes, and in-plane (IP) and out-of-plane (OOP) behavior. The information presented

is compiled from studies employing different experimental methodologies, scales, boundary conditions, and analytical approaches. Therefore, the reported values are not intended to represent standardized performance comparisons but are provided as a conceptual interpretation of the relative behavioral tendencies reported in the literature.

Table 2. Comparative seismic behavior characteristics of traditional timber-framed structural systems.

System	Early-Stage Interaction Component	Predominant Early-Stage Dissipation Component	Energy Dissipation Mechanism	Damage Mechanism	IP–OOP Behavior	References
Hımiş	Infill-frame interaction	Infill wall	Infill cracking, friction, and connection deformation	Infill damage and local connection deformation	Timber frame-supported wall behavior	Aktaş (2011), Özdemir (2025)
Dhajji Dewari	Cellular timber frame and infill panels	Infill panels and bracing members	Panel-frame interaction and connection deformation	Distributed infill damage	Enhanced in-plane and out-of-plane stability through cellular configuration	Hıcıymaz et al. (2011), Gani et al. (2024)
Pombalino	Timber frame–masonry interaction	Timber frame and bracing members	Timber frame deformation and connection behavior	Progressive infill and connection damage	Lateral stability provided by the three-dimensional gaiola system	Lopes et al. (2013), Meireles et al. (2012)
Fachwerk	Timber frame–infill interaction	Infill panels	Timber joint deformation and infill separation	Infill cracking and local frame deformation	Frame–infill interaction-controlled behavior	Liu (2022), Gani et al. (2024)
Casa Baraccata	Timber frame–masonry interaction	Timber frame and masonry infill	Interaction between timber and masonry components	Progressive infill damage and local connection deformation	Box-type behavior resulting from timber–masonry integration	Ruggieri and Zinno (2014), Parrotta (2017)
Chuandou	Mortise-and-tenon joint interaction	Mortise-and-tenon joints	Rotation and friction at timber joints	Joint loosening, local deformation, and infill damage	High deformation capacity governed by joint behavior	Qu et al. (2020), Li et al. (2025), Guo et al. 2021)

The findings indicate that the energy dissipation process is initiated through localized deformations and damage mechanisms developing within different structural components of the investigated systems. Cracking, frictional effects, and connection deformations dissipate a significant portion of the seismic energy, resulting in a gradual and controlled reduction in structural stiffness. However, the dominant components contributing to energy dissipation vary among the investigated systems. In Hımiş and Dhajji Dewari structures, energy dissipation is largely associated with the behavior of infill elements. In Pombalino and Casa Baraccata systems, the interaction between timber and masonry components plays a significant role, whereas in Chuandou structures a considerable portion of the energy dissipation process is associated with rotational and friction-based mechanisms developing within mortise-and-tenon joints. These differences suggest that, despite variations in construction techniques, the investigated systems may exhibit comparable behavioral tendencies under seismic loading.

3.2. Damage hierarchy

The comparative assessment indicates that damage development follows a generally consistent sequence across the investigated systems. Damage is commonly initiated within infill elements or connection regions during the early stages of seismic response. The subsequent distribution of damage varies according to system characteristics, extending into the primary structural

system in some cases while remaining concentrated within connection regions in others.

This progression enables the controlled dissipation of seismic energy throughout the structure. The tendency of infill components to act as the first damaged elements contributes to overall energy dissipation capacity while also assisting in the preservation of the primary load-resisting system. This mechanism appears to be particularly evident in Hımiş and Dhajji Dewari structures.

Nevertheless, the spatial distribution of damage differs among the systems. In Dhajji Dewari structures, damage tends to be distributed throughout the cellular wall configuration, whereas in Pombalino systems it is more likely to concentrate within specific regions. In Chuandou structures, damage is predominantly localized at connection interfaces.

One of the critical stages within the damage hierarchy is the influence of in-plane (IP) damage on out-of-plane (OOP) stability. Damage occurring within infill components may weaken wall integrity and increase the susceptibility to out-of-plane failure. This observation highlights the importance of maintaining connection continuity for preserving overall structural stability.

3.3. System-based behavioral summary

Although the investigated systems were developed in different geographical contexts, they exhibit several common behavioral principles under seismic loading. Nevertheless, the mechanisms through which these responses develop vary among the systems.

In Hıms structures, cracking within infill components constitutes a primary energy dissipation mechanism, whereas the cellular configuration of Dhajji Dewari systems promotes a more uniform distribution of seismic demands. The Pombalino system exhibits a balanced structural response through the combined contribution of stiffness and ductility. In Fachwerk structures, structural behavior is largely governed by the interaction between the timber frame and infill panels, whereas friction-induced movements at connection interfaces play a dominant role in Chuandou systems. In Casa Baraccata structures, the interaction between timber framing and masonry components is the principal mechanism influencing structural response.

From a comparative perspective, the contribution of infill components to the energy dissipation process appears to be more pronounced in Hıms and Dhajji Dewari systems, while frictional behavior within connection regions plays a more dominant role in Chuandou structures. The Pombalino system, by contrast, represents a relatively balanced interaction between stiffness and ductility.

3.4. IP–OOP behavior and stability

Among the investigated systems, in-plane (IP) and out-of-plane (OOP) responses constitute key parameters governing structural stability. While in-plane deformations reflect the energy dissipation capacity of the system, out-of-plane behavior plays a critical role in maintaining overall stability.

Damage occurring within infill components reduces structural stiffness and may consequently weaken out-of-plane stability. In particular, the loss of infill integrity represents a significant factor that may increase the risk of wall overturning and out-of-plane collapse. This effect appears to be more pronounced in systems where the behavioral contribution of infill components is greater, whereas it remains relatively limited in systems where connection behavior constitutes the dominant response mechanism. This observation suggests that the mechanisms governing structural stability vary according to the structural configuration of the system.

4. Discussion

The “first seismic defense line” concept proposed in this study should not be interpreted as a structural isolation mechanism. Under seismic loading, the timber structural frame, infill components, and connection regions act together in accordance with the principle of displacement compatibility. Within this context, the concept is considered a conceptual interpretative framework describing the dominant contribution of secondary components during the early stages of the energy dissipation process.

The findings indicate that traditional timber-framed systems developed in different geographical regions exhibit similar fundamental behavioral principles under seismic loading. In these systems, energy dissipation occurs through the interactive deformation behavior between the primary structural frame and the infill and

connection components. This observation suggests that the concept of the “first seismic defense line” may assist in explaining the comparable behavioral tendencies observed across different structural systems. Experimental and numerical studies reported in the literature also support this conceptual interpretation. In Chuandou structures, a significant portion of energy dissipation has been attributed to friction and micro-deformations occurring at connection interfaces (Li et al. 2025). It is well established that neglecting frictional effects in analytical models may lead to substantial inaccuracies (Follesa et al. 2011). Similarly, the damping capacity observed in Hıms systems highlights the critical role of frame–infill interaction (Gani et al. 2021). Collectively, these findings indicate that energy dissipation is strongly associated with multi-component interaction mechanisms.

All investigated systems exhibit hybrid structural behavior, in which the interaction among infill elements, connection regions, and the structural frame constitutes one of the principal factors governing system performance. Consequently, the systems were evaluated according to the dominant behavioral tendencies reported in the literature rather than through rigid structural classifications. From the perspective of ductility, notable differences can be observed among the systems investigated. Pombalino structures exhibit a balanced structural response characterized by controlled deformation capacity (Poletti and Vasconcelos 2015), indicating that ductile behavior is substantially influenced by connection details. In this study, infill elements are considered not only as potential sources of structural weakness but also as active contributors to the energy dissipation process. In particular, the cellular configuration observed in Dhajji Dewari systems and the frame–infill interaction characteristic of Hıms structures contribute to a more controlled distribution of damage throughout the system (Ozdemir 2025).

The interaction between in-plane (IP) and out-of-plane (OOP) behavior represents one of the key factors influencing the structural response of traditional timber-framed systems. Damage and loss of integrity within infill components may reduce wall stability and adversely affect out-of-plane behavior (Li et al. 2025). In this context, in-plane damage may be interpreted not only as a deterioration process but also as one of the early stages of the energy dissipation mechanism. Nevertheless, the available literature does not provide the same level of detail and coverage regarding out-of-plane behavior for all investigated systems. Therefore, the interpretations presented herein are based on a comparative assessment of behavioral tendencies reported in the literature rather than on standardized performance comparisons.

Topographical conditions also play an important role in structural response. Variations in column heights on sloping terrain may induce torsional effects and promote the concentration of damage in specific regions (Pan et al. 2023). Such conditions may disrupt the uniform distribution of seismic demands and increase the sensitivity of connection regions.

Material selection constitutes another important factor influencing energy dissipation behavior. While adobe infill may provide greater energy dissipation capacity, stone infill generally exhibits a stiffer but more brittle re-

sponse (Ozdemir 2025). This finding emphasizes the importance of considering infill materials as integral components of controlled damage mechanisms.

The integration of traditional systems into modern engineering practice demonstrates that these principles are compatible with contemporary design approaches (Qi et al. 2023). In this regard, the findings suggest that the interaction-based energy dissipation mechanisms observed between secondary components and the primary structural frame are broadly consistent with the capacity design philosophy defined in Eurocode 8. These mechanisms are also compatible with the principles of performance-based seismic design adopted in modern earthquake engineering practice (Eurocode 8 2004). Furthermore, experimental studies have shown that traditional timber structures may exhibit higher damping capacity than modern rigid systems due to frictional and embedment effects developing between structural components (Xie et al. 2019).

From a comparative perspective, the contribution of infill elements to the energy dissipation process appears to be more pronounced in Himiş and Dhajji Dewari systems, whereas frictional and micro-slip mechanisms at connection regions play a more dominant role in Chuandou structures. The Pombalino system represents a balanced interaction between stiffness and ductility, while the behavior of Fachwerk structures is governed primarily by frame–infill interaction and the response of Casa Baraccata systems is shaped by the integrated action of timber and masonry components.

This study extends the existing literature, which has largely focused on individual structural systems, by providing an integrated comparative framework encompassing multiple traditional systems from different regions. Whereas previous studies have generally examined specific structural typologies, the present research evaluates similarities and differences across systems simultaneously and suggests that energy dissipation and damage development mechanisms may be interpreted within a common behavioral framework. In this respect, the study contributes to the integration of fragmented knowledge into a comprehensive analytical perspective.

Overall, although the investigated systems differ in terms of structural configuration, they share a common performance-oriented approach characterized by controlled energy dissipation and ductile response. Interpreting this behavior through the concept of the “first seismic defense line” provides a new perspective for understanding traditional structural systems within the context of earthquake engineering.

5. Conclusions

This study presented a comparative analysis of traditional timber-framed structural systems developed in different regions with respect to their seismic behavior. The findings indicate that, despite differences in construction traditions, these systems exhibit comparable energy dissipation processes and damage distribution mechanisms under seismic loading.

The analyses suggest that energy dissipation is achieved through multi-component interaction involve-

ing infill elements, connection details, and the primary structural frame. The controlled concentration of damage within specific components enables these systems to develop ductile behavior rather than experiencing brittle failure. Seismic performance indicators and behavioral observations reported in the literature support the comparative interpretation of behavioral tendencies observed across different studies.

The present study further suggests that this common behavioral pattern may be interpreted through the concept of the “first seismic defense line”. This concept is proposed as a conceptual framework for understanding the behavioral contribution of secondary components during the energy dissipation process under seismic loading. The observation of similar behavioral tendencies in systems developed across different geographical regions suggests that traditional construction practices may share common underlying behavioral principles.

At the same time, notable differences were identified among the investigated systems. While infill components appear to play a more pronounced role in the energy dissipation process of Himiş and Dhajji Dewari structures, frictional and micro-slip mechanisms at connection regions are more influential in Chuandou systems. The Pombalino system represents a balanced interaction between stiffness and ductility, whereas the behavior of Fachwerk structures is governed primarily by frame–infill interaction and that of Casa Baraccata systems by the integrated action of timber and masonry components. These observations suggest that different structural strategies may lead to similar behavioral tendencies and energy dissipation mechanisms. The findings also highlight the critical role of connection details in the seismic response of traditional timber-framed systems. In particular, the stiffness, frictional characteristics, and deformation capacity of connection regions directly influence both energy dissipation processes and damage distribution patterns. Consequently, connections should be regarded not only as joining elements but also as active components governing overall structural performance.

The presence of similar behavioral principles in systems developed under different geographical conditions suggests that fundamental earthquake-resistant solutions emerged through empirical knowledge and accumulated construction experience. In this respect, traditional structural systems should be considered not only as elements of cultural heritage but also as valuable sources of engineering knowledge for performance-oriented design.

Overall, traditional timber-framed systems offer significant seismic advantages due to their low mass, high deformation capacity, and effective energy dissipation characteristics. These attributes provide valuable principles that may inform contemporary structural design. Integrating the behavioral principles observed in traditional systems with modern engineering approaches may contribute to the development of safer and more performance-oriented structures. Nevertheless, because the studies reviewed in this research differ in terms of experimental methodologies, scales, boundary conditions, and analytical approaches, the findings should not be interpreted as standardized quantitative performance comparisons. Rather, they should be regarded as

a conceptual interpretation of behavioral tendencies and common structural mechanisms reported in the literature.

An additional advantage of traditional timber-framed systems is that damage is often concentrated within specific components that can be repaired or replaced. However, the long-term performance of timber structures depends on addressing durability-related issues such as biological deterioration, moisture exposure, and environmental weathering. Therefore, maintenance, durability, and repair strategies should be considered alongside seismic performance when evaluating the long-term sustainability of these systems.

Future research should focus on examining the proposed “first seismic defense line” concept through experimental validation and advanced numerical modeling. Furthermore, investigating the integration of traditional structural principles with modern materials and hybrid structural systems may provide new directions for earthquake-resistant design.

Acknowledgements

None declared.

Funding

The author received no financial support for the research, authorship, and/or publication of this manuscript.

Conflict of Interest

The author declares no potential conflicts of interest with respect to the research, authorship, and/or publication of this manuscript.

Data Availability

The datasets generated and/or analyzed during the current study are not publicly available but are available from the corresponding author upon reasonable request.

AI Assistance

No AI-based tools were used in the preparation of this manuscript.

Author Contributions

The author declares sole responsibility for all aspects of the study, including conceptualization, methodology, formal analysis, investigation, data curation, visualization, writing of the original draft, and writing, review, and editing of the manuscript.

REFERENCES

- Aksoy D (2003). *Geleneksel ahşap karkas yapıların deprem davranışları*. Ph.D. dissertation, İstanbul Technical University, İstanbul, Türkiye.
- Aktaş YD (2011). *Evaluation of seismic resistance of traditional Ottoman timber frame houses*. Ph.D. dissertation, Middle East Technical University, Ankara, Türkiye.
- Aktaş YD, Akyüz U, Türer A, Erdil B, Şahin Güçhan N (2014). Seismic resistance evaluation of traditional Ottoman timber-frame houses: frame loadings and material tests. *Earthquake Spectra*, 30(4), 1711–1732.
- Ali Q, Schacher T, Ashraf M, Alam B, Naeem A, Ahmad N, Umar M (2012). In-plane behavior of the Dhajji-Dewari structural system (wooden braced frame with masonry infill). *Earthquake Spectra*, 28(3), 835–858.
- Arslan F (2006). *Depremden zarar görmüş tarihi yapıların güçlendirilmesi*. M.Sc. thesis, Gazi University, Ankara, Türkiye.
- Cardoso R, Lopes M, Bento R (2004). Earthquake resistant structures of Portuguese old Pombalino buildings. In: *Proceedings of the 13th World Conference on Earthquake Engineering*, Vancouver, Canada, Paper No. 918.
- Dikmen N (2010). An investigation on traditional timber-framed buildings in Çankırı province of Turkey. *Trakya University Journal of Science*, 11(1), 15–27.
- Dışkaya H (2004). *Kuzey Marmara Bölgesindeki 19. yüzyıl ahşap yapılarının depreme karşı güçlendirilmesi*. M.Sc. thesis, Mimar Sinan Fine Arts University, İstanbul, Türkiye.
- Doğangün A, Tuluk Öİ, Livaoğlu R, Acar R (2006). Traditional wooden buildings and their damages during earthquakes in Turkey. *Engineering Failure Analysis*, 13(6), 981–996.
- Eurocode 8 (2004). *EN 1998-1:2004, Eurocode 8: Design of structures for earthquake resistance - Part 1: General rules, seismic actions and rules for buildings*. European Committee for Standardization (CEN), Brussels, Belgium.
- Flanagan K (2017). Composite timber towers: the 80-storey timber skyscraper project. In: *Proceedings of the 5th Symposium on Conservation and Restoration in Timber Structures*, İstanbul, Türkiye, pp. 179–192.
- Follesa M, Fragiocomo M, Lauriola MP (2011). A proposal for revision of the current timber part (Section 8) of Eurocode 8 Part 1. In: *44th CIB W18 Meeting*, Alghero, Italy, Paper No. 44-15-1.
- Gani A, Rai DC, Banday JM (2021). Seismic behavior of timber-framed masonry: a comprehensive review. In: *17th World Conference on Earthquake Engineering*, Sendai, Japan, Paper No. 2d-0120.
- Gani A, Banday JM, Rai DC (2024). Seismic behavior of timber-framed structures infilled with dry brick masonry. *Bulletin of Earthquake Engineering*, 22(13), 6419–6446.
- Gülhan D, Özyörük Güney İ (2000). The behaviour of traditional building systems against earthquake and its comparison to reinforced concrete frame systems: experiences of Marmara earthquake damage assessment studies in Kocaeli and Sakarya. In: *Earthquake-Safe: Lessons to be Learned from Traditional Buildings*. ICOMOS, İstanbul, Türkiye.
- Gün B, Anıktar S (2020). Çevre ve şehircilik uygulamalarında betonarme-ahşap yapı karşılaştırması. *İstanbul Sabahattin Zaim Üniversitesi Fen Bilimleri Enstitüsü Dergisi*, 2(3), 19–25.
- Guo R, Xue J, Qi L, Deng L (2021). Effect of column root connections on the dynamic behavior of Chuandou-style timber structures. *Journal of Building Engineering*, 44, 103340.
- Hıcılmaz K, Bothara JK, Stephenson M (2011). *Dhajji-Dewari*. Housing Report No. 146, World Housing Encyclopedia, Earthquake Engineering Research Institute, Oakland, CA, USA.
- Korkmaz SZ (2007). *Kırsal konutların deprem güvenliğinin artırılması*. Ph.D. dissertation, Selçuk University, Konya, Türkiye.
- Langenbach R (2007). From “Opus Craticium” to the “Chicago Frame”: earthquake-resistant traditional construction. *International Journal of Architectural Heritage*, 1(1), 29–59.
- Li T, Xu M, Cui Z, Chen F (2025). Experimental assessment of in-plane and out-of-plane seismic performance of masonry infills in a full-scaled Chuandou timber structure subjected to shaking table tests. *Journal of Building Engineering*, 112, 113736.
- Liu Y (2022). Joinery and structure: cultural and technical comparison between traditional wooden framing systems in East Asia and Western Europe. *Chinese Annals of History of Science and Technology*, 6(1), 89–118.
- Lopes M, Meireles H, Cattari S, Bento R, Lagomarsino S (2013). Pombalino constructions: description and seismic assessment. In: Costa A, Guedes JM, Varum H, editors. *Structural Rehabilitation of Old Buildings*. Springer, Berlin, Germany, pp. 187–233.
- Meireles H, Bento R, Cattari S, Lagomarsino S (2012). A hysteretic model for frontal walls in Pombalino buildings. *Bulletin of Earthquake Engineering*, 10(5), 1481–1502.
- Niglio O (2011). La casa baraccata: un prototipo di architettura antisismica in epoca borbonica. *Bioarchitettura*, 20(69), 46–49.
- Ozdemir MA (2025). Seismic performance assessment of timber-framed (hıms) structures with different infill materials. *Challenge Journal of Structural Mechanics*, 11(3), 149–159.
- Pan Y, Yi D, Khennane A, Chen J (2023). Seismic performance of a historic timber structure on a slope. *Journal of Building Engineering*, 71, 106434.
- Parlak Biçer Ö, Şahin N (2020). Geleneksel ahşap yapı sistemlerinin uygulamalar üzerinden incelenmesi. *Mimarlık ve Yaşam*, 5(2), 577–602.

- Parrotta R (2017). *Seismic vulnerability of timber framed buildings: Pombalino versus Baraccata*. M.Sc. thesis, Instituto Superior Técnico, University of Lisbon, Lisbon, Portugal.
- Perrin RWE (1960). A Fachwerk church in Wisconsin. *Wisconsin Magazine of History*, 43(4), 239–244.
- Poletti E, Vasconcelos G (2015). Seismic behaviour of traditional timber frame walls: experimental results on unreinforced walls. *Bulletin of Earthquake Engineering*, 13(3), 885–916.
- Qi L, Cao Y, Xue J, Yuan Z, Ling H, Meng R (2023). Seismic performance evaluation and engineering application of modern Chinese traditional-style buildings: the state-of-art review. *Structures*, 56, 105022.
- Qu Z, Fu X, Kishiki S, Cui Y (2020). Behavior of masonry infilled Chuandou timber frames subjected to in-plane cyclic loading. *Engineering Structures*, 211, 110449.
- Ren C, Bian R, Li S (2018). Construction of Chuandou timber houses in Southwest China: technology and community. *International Journal of Architecture and Urban Studies*, 3(1), 71–82.
- Ruggieri N, Zinno R (2014). Seismic assessment of baraccato system: constructive analysis and experimental investigations. In: *Second European Conference on Earthquake Engineering and Seismology*, İstanbul, Türkiye.
- Tan W, Zhou T, Zhu L, Zhao X, Yu W, Zhang L, Liang Z (2024). Seismic performance of a single-story timber-framed masonry structure strengthened with fiber-reinforced cement mortar. *Materials*, 17(15), 3644.
- Vasconcelos G, Poletti E, Salavessa E, Jesus AMP, Lourenço PB, Pilaon P (2013). In-plane shear behaviour of traditional timber walls. *Engineering Structures*, 56, 1028–1048.
- Vasconcelos G, Lourenço PB, Poletti E (2015). An overview on the seismic behaviour of timber frame structures. In: Ruggieri N, Tampone G, Zinno R, editors. *Historical Earthquake-Resistant Timber Frames in the Mediterranean Area*. Springer, Cham, Switzerland, pp. 119–132.
- Vieux-Champagne F, Sieffert Y, Grange S, Polastri A, Ceccotti A, Daudeville L (2014). Experimental analysis of seismic resistance of timber-framed structures with stones and earth infill. *Engineering Structures*, 69, 102–115.
- Xie Q, Wang L, Zhang L, Hu W, Zhou T (2019). Seismic behaviour of a traditional timber structure: shaking table tests, energy dissipation mechanism and damage assessment model. *Bulletin of Earthquake Engineering*, 17(3), 1689–1714.
- Yang D, Xu M, Chen Z (2021). Seismic performance of Chinese traditional timber frames. *BioResources*, 16(3), 6135–6146.
- Yılmaz Karaman Ö, Tanaç Zeren M (2015). Case study: examples of wooden vernacular architecture - Turkish houses in Western Anatolia. *YBL Journal of Built Environment*, 3(1-2), 77–87.