Field Investigation of Retrofitting and Adaptive Reuse of Historic Wooden Buildings in Taiwan

Meng-Ting Tsai*1

1Assistant Professor, Department of Architecture, National Taiwan University of Science and Technology, Taiwan

Abstract
In Taiwan, most of the existing historic wooden buildings built in the Japanese colonial period have become culturally important. These properties preserve the historical atmosphere and culture of local communities. Unfortunately, some of these buildings have been abandoned or have suffered serious damage during earthquakes; and, others have not been well maintained. The conservation and retrofitting of these historic wooden buildings have recently become valued and recognized by authorities. Some of these buildings have been retrofitted, becoming exhibition galleries, restaurants, or even local landmarks. However, changes in the functions of the building have resulted in some safety issues, such as additional fire loading or demolished shear walls. In this paper, adaptive reuses of these retrofitted buildings are discussed based on a field investigation. Factors that directly influence the structural safety are emphasized, and a potential issue affecting these factors – the lack of professional education and experience – is also discussed.

Keywords: historic wooden buildings; retrofitting; structural safety; educational system; adaptive reuse

1. Introduction
Many historic wooden buildings in Taiwan have changed their functions, been damaged, abandoned or not been well maintained. However, they are important in preserving local history and culture. In 1982, the Taiwanese government passed the Cultural Heritage Conservation Law to promote the conservation of cultural properties, including historic buildings. The public has also gradually begun to appreciate these buildings, due to social development, economic growth, and advances in science and education.

The historic wooden buildings built during the Japanese colonial period that have been investigated in this study are considered some of the most important cultural properties in Taiwan. Most of these buildings have been designated as cultural properties; however, some have not been well maintained, and others have been seriously damaged through abandonment and/or earthquakes. With the advent of the Cultural Heritage Conservation Law, some of these historic wooden buildings are now valued and recognized by the public and authorities and have been retrofitted.

By the end of 2010, more than 70 different wooden building sites, including more than 100 buildings, had been designated as heritage or cultural properties by the government. However, there are still some historic buildings that need to be preserved and/or retrofitted by local authorities. For example, some of the dormitory buildings of sugar or tea companies, as shown in Fig.1., are facing abandonment or destruction to allow for other developments. A major issue is the balance between land development and conservation.

Proper retrofitting is another important concern, including structural safety, which is the focus of this study. Taiwan is located in the seismically active Ring of Fire zone and at the western edge of the Philippine Sea Plate, resulting in frequent earthquakes. The handling of the seismic forces caused by earthquakes is complex, due to their unpredictability. Appropriate reinforcement in retrofitting to ensure structural safety is, therefore, challenging.

*Contact Author: Meng-Ting Tsai, Assistant Professor, Department of Architecture, National Taiwan University of Science and Technology, No. 43, Section 4, Keelung Road, Taipei 106, Taiwan
E-mail: tsai@mail.ntust.edu.tw

(Received April 1, 2016; accepted March 10, 2017)
DOI http://doi.org/10.3130/jaabe.16.387

Fig.1. Yuchih Tea Research & Extension Station Dormitory (A-3), Located in Nantou, before Retrofitting
One major objective of this field investigation was the examination of the potential factors that jeopardize structural safety. The lack of suitable education in retrofitting for designers, including architects and engineers, is also addressed in this paper.

2. Cultural Landmarks and Landscape

Historic buildings are important spaces that help form the identity of a community and urban space. These buildings should be significant in architectural or urban design studies in cities, as they provide a cultural landscape. With effective renovations and conservation, their worth and the cultural depth of a community grow.

An appropriate example of historic wooden building conservation is the Baoan railway station, shown in Fig.2. Railway stations were largely built during the Japanese colonial period. These stations, the locations of which are shown in Fig.3. (B-1 to B-9), carried people and goods from one place to another. From a cultural perspective, the preservation of historic buildings, such as railway stations, provides history and tradition to a modern city and enriches the local culture.

3. Research Methods

The research methodology of this study was based on field investigation. A total of 34 sites, including dormitories, residential houses, and railway stations, were surveyed and investigated. These buildings were retrofitted before 2010, and their adaptive reuse has subsequently improved the usability of their interior spaces. They are considered as models to demonstrate the advantages and examples of how a proper adaptive reused historical wooden building can retrieve its good old times. The locations of these sites are summarized and illustrated in Fig.3. Table 1. also lists their functions.

More buildings need to be visited; however, this preliminary study is expected to provide fundamental information for future studies. Generally, these historic wooden buildings can be clustered into 3 types based on their original function: residential houses, railway stations, and public/multifunctional spaces.

Section 4 addresses the educational issues and problems that affect the retrofitting of historic wooden buildings in Taiwan. This section also discusses the importance of these historic wooden buildings, their cultural landscapes, and the possibility of their conservation. The status and adaptive reuse of these buildings after retrofitting are presented in Section 5; and, the potential factors that can harm the structural safety of these buildings are examined in Section 6.

4. Education System that Affects Retrofitting of Historic Wooden Buildings

Most of the university training programs for architects or engineers do not offer specific courses on the retrofitting of these historic wooden buildings, such as wood science, their structural mechanisms, and design of wooden construction. Moreover, retrofitting experience with these types of wooden buildings is not easily found in Taiwan. To fill this gap, more efforts are required by researchers and authorities in spreading relevant knowledge to both professionals and the public.

4.1 University Education – Accumulation of Fundamental Experience

Unlike concrete and steel construction, which are common courses in most universities, wooden construction is rarely discussed. The historic wooden buildings that have been studied in this paper were built according to Japanese construction standards. The application of appropriate local materials and construction methods in combination with the Japanese construction standards with which these buildings were constructed are issues in the retrofitting of these historic wooden buildings.
For example, a standard wall ratio of a mud wall or other structural wooden panels is used for seismic design in Japan, which has been standardized based on various experimental research data. However, materials such as mud plaster or wood species that have been applied in retrofitting in Taiwan today are different from those in Japanese standards, such as Japanese Industrial Standards (JIS) or Japanese Agricultural Standards (JAS). Comprehensive studies and experiments are essential to accumulate fundamental data and experience locally to ensure retrofitting is adaptable and fulfills safety requirements. There are only a few fundamental research studies and publications that address retrofitting and structural behavior of these historic wooden buildings.

Chen (2007) described the structural behaviors of Japanese style bamboo mud walls under horizontal cyclic loading based on experimental results. Lin (2013) compared earthquake damage and performance for two types of historic wooden buildings. Kuo (2015) proposed seismic evaluation for these kinds of historic wooden buildings.

Retrofitting activities, however, require that researchers and authorities work together and educate professionals, especially architects and engineers.

5. Original Function and Adaptive Reuse of Historic Wooden Buildings

The conservation of historic wooden buildings is very complex, must be closely linked to the building itself, and also needs to sustain the cultural and historic environment for current and future generations. When it comes to conservation activities and approaches in Taiwan, most of the historic wooden buildings are no longer used for their original functions. Consequently, adaptive reuse has become a popular strategy, with these buildings being reused and adapted to new functions. Industrial type buildings, churches, government buildings, agriculture buildings and even residential houses have been converted for use in meeting current needs, but still preserve the historic architectural style. Some of the buildings have retained their original functions, such as railway stations, because their

| Type | Area | Name of Site/Buildings | Original Function | Function after retrofitting |
|------|------|------------------------|------------------|---------------------------|
| A-1  | Changhua | Lukang Dormitory | Residential | Exhibition |
| A-2  | Changhua | Yongjing Primary School Dormitory | Residential | Restaurant |
| A-3  | Nantou | Yuchih Tea Research & Extension Station Dormitory | Residential | Exhibition |
| A-4  | Taichung | Dim Sum Restaurant, Arts & Entertainment | Residential | Restaurant |
| A-5  | Tainan | Residential House in Tainan | Restaurant | Shop |
| A-6  | Jiayi | Residential House in Singang | Residential | Restaurant |
| A-7  | Tainan | Farming Experiment Factory Dormitory | Residential | Exhibition |
| A-8  | Taipei | Sun Yat-sen Memorial Museum | Residential | Exhibition |
| A-9  | Taipei | Tsai Rei-Yuei Dance Club | Residential | Restaurant |
| A-10 | Tainan | Zone-Ye Sugar Refinery Dormitory | Residential | Exhibition |
| A-11 | Tainan | Anping Taiwan Salt Company’s Dormitory | Residential | Tourism Sites |
| A-12 | Miaoli | Yuani Shanjiao Primary School | Residential | Tourism Sites |
| B-1  | Hsinchu | Slangshan Station | Railway Station | Railway Station |
| B-2  | Miaoli | Tainwan Station | Railway Station | Railway Station |
| B-3  | Miaoli | Dashan Station | Railway Station | Railway Station |
| B-4  | Miaoli | Sinpu Station | Railway Station | Railway Station |
| B-5  | Jiayi | Peimen Station | Railway Station | Railway Station |
| B-6  | Tainan | Houbi Station | Railway Station | Railway Station |
| B-7  | Tainan | Baoan Station | Railway Station | Railway Station |
| B-8  | Taichung | Rihnan Station | Railway Station | Railway Station |
| B-9  | Kaohsiung | Chishan Station | Railway Station | Railway Station |
| C-1  | Changhua | Erlin Primary School Auditorium | Auditorium | Chamber |
| C-2  | Changhua | Martial Art Hall (Butokuden) | Hall | Restaurant |
| C-3  | Jiayi | Chiayi Historical Document Hall | Hall | Exhibition |
| C-4  | Jiayi | Bamboo - Processing Factory | Office | Exhibition |
| C-5  | Jiayi | Alishan Train Repair Station | Office | Shop |
| C-6  | Tainan | Zone-Ye Sugar Refinery Guest House | Chamber | Exhibition |
| C-7  | Jiayi | RTI Minsyong Guest House | Chamber | Exhibition |
| C-8  | Hsinchu | Air Force Village 11 | Club | Exhibition |
| C-9  | Taipei | Beitou Flagstaff House Museum | Hotel | Exhibition |
| C-10 | Jiayi | Huang-Wu-Tong Memorial Museum | Church | Chamber |
| C-11 | Tainan | Wang Jing-He Medical Memorial Museum | Clinic | Exhibition |
| C-12 | Changhua | Fuhsing Farmers’ Association | Warehouse | Exhibition |
| C-13 | Taichung | Shihkang Farmers’ Association | Warehouse | Exhibition |
function is still in demand today. The percentages of the surveyed historic wooden buildings with original and adapted functions are shown in Fig.4., which indicates that more than two thirds of these buildings have altered their functions.

5.1 Strategy of Adaptive Reuse

The adaptive reuse of historic wooden buildings in Taiwan occurs because communities are willing to preserve the historic significance of these buildings. However, these buildings need to be adapted for new functions, in order to find a balance in the surrounding environment and accommodate current demand. Retrofitting allows these buildings to be revitalized in different forms, with many of them opening to the public as exhibition galleries or restaurants.

The results of the investigation and analysis, as illustrated in Fig.5., indicate that exhibition galleries (41.2%) and restaurants/shops (20.6%) are the most popular and efficient forms of reuse in the conservation of these historic wooden buildings. Galleries often exhibit art or historical documents, such as the displays in the Zone-Ye Sugar Refinery Guest House (C-6) in Fig.6., which offers an antique and unique environment that is open to the public. Adaptive reuse as a restaurant or shop is also a popular option for historic wooden buildings.

6. Structural Safety after Retrofitting

This investigation revealed that most historic wooden buildings have changed their functions after being retrofitted. Some of the new functions are very different from the original ones, frequently resulting in harm to the buildings’ structural safety. In some retrofitted historic wooden buildings, mostly those reused as restaurants, structural walls have been removed without completing an assessment of the earthquake resistance capability. Fig.7. shows a retrofitting floor plan that called for the removal of an original structural wall in order to form a continuous dining space. The interior view after retrofitting is shown in Fig.8.(a).

In other cases, air conditioning pipes have been hung directly in the roof trusses, as shown in Fig.8.(b). These pipes not only contribute additional loading to the trusses, but also add extra vibration forces to the roof. This could easily result in the loosening of bolts or a huge deformation of the wooden beam, especially in parts with connecting joints.

Structural safety issues also occur with wooden floors. Given some of the demands in the new functions of many historic wooden buildings, heavy apparatuses, such as refrigerators or box air conditioners, have been placed on the floors, as shown in Fig.8.(c). Extra loading and vibration forces are, therefore, added to the floor, again without assessment of the deformation of the wooden floor and beams.

Some historic wooden buildings that have become restaurants or coffee shops after retrofitting are successful in preserving the buildings and attracting people; however, with wood being a material that readily catches fire and burns easily, kitchens and combustible materials in the buildings increase their fire loading.

The general factors that harm structural safety after retrofitting are shown in Table 2. This investigation determined that additional loading on wooden floors was most commonly found in retrofitted buildings.
(61.8% or 21 buildings). Structural wall removal and additional loading to roof truss occurred in 50% (17 buildings) and 35.3% of the studied buildings (12 buildings), respectively.

If the factors that harm the structural safety are classified by either original or changed functions, the major factor for buildings with original functions is the removal of a structural wall. The factors for the buildings with changed functions are randomly distributed.

Structural wall removal and additional loading to wooden floors and roof trusses are just some of the issues that threaten structural safety. To ensure that each historic wooden building can be used properly and safely, attention must be paid to structural safety, especially in retrofitting. However, most architects and engineers do not have appropriate knowledge and experience to address these problems. Unfortunately, there are only a few courses related to wooden structures and construction for these professionals in the education system in Taiwan.

6.1 Major Structure Issues

The removal of a structural wall may not cause the immediate collapse of these historic wooden buildings, because the gravity load of the building is supported by columns and beams. However, given that a major structural function of these walls is the resistance of seismic loads, the removal of a structural wall may lead to collapse under earthquake shaking through two potential damage mechanisms: (1) strength deficiency against the seismic load; and, (2) asymmetric deformation, which leads to rotational movement of the building. These two mechanisms need to be carefully considered in retrofitting design.

Again, the lack of appropriate education and professional knowledge of these wooden buildings under seismic load leads to challenges in the proper consideration of these two mechanisms.

Additional loading added to floors is another issue when it comes to changing the original function from residential house to public space, such as a shop, a restaurant, or even an exhibition space. The structural components that support the floor were constructed with certain standards, with a girder on the foundation and a joist on top of the girder, supporting the floor. The spacing of each component, usually in multiples of 45 cm, indicates that the capacity of the floor is limited.
However, the examination of floor capacity was usually ignored in the cases investigated in this study. An insufficient section of these structural components may cause floor vibration, affecting serviceability and strength deficiency, which can jeopardize structural safety. Removal of a structural wall and additional loads are issues that can be solved by passing on professional knowledge to architects and engineers through improved educational systems at institutes or universities. Additional fire loading is a critical issue that is not easy to address, given the current regulations for retrofitting historic buildings. The regulations restrict distinct changes of the building in retrofitting design; however, their material properties are considered combustible.

In modern wooden construction, it is suggested that gypsum board cover wooden columns and beams to protect them from direct exposure to fire. An alternative solution is to increase the size of the wooden structural component, so that the charred layer that is produced when the wooden column or beam is burned will help to protect the part of the component that is not yet burned from exposure to fire. Unfortunately, neither of these methods can be applied in the retrofitting design or process, due to the restriction of distinct changes in historical buildings. It is recommended that an additional fire extinguisher be placed near spaces with greater fire load, such as kitchens. This is only a temporary solution; and, this critical issue must be resolved, through efforts from authorities and researchers.
Threats to these historic wooden buildings are not just from inappropriate retrofitting, people's behavior can significantly influence the structural stability of historical wooden buildings. However, there are still many people who are not aware of the value of historic wooden buildings, resulting in private renovations that damage the structural safety and preservation of these buildings. Fig.9 shows a main structural wall damaged through mud plastering and a cut wooden column, indicating carelessness in making changes to these historic wooden buildings. Therefore, education of the public is also important.

6.2 Tutorial Course in Traditional Skills
Each historic wooden building left in Taiwan contains technical cultural skills, from the roof and eaves to the wooden walls and furniture. The passing on of these skills to the next generation and adoption of local elements are important issues, as Taiwan’s culture, environment and life style are different from those in Japan. However, there are still many people who are not aware of the value of historic wooden buildings, resulting in private renovations that damage structural safety and preservation of these buildings. Fig.9 shows a main structural wall damaged through mud plastering and a cut wooden column, indicating carelessness in making changes to these historic wooden buildings.

Fortunately, more and more people are becoming concerned with these cultural issues; and, university authorities recently held a series of workshops on Japanese wooden wall skills. Fig.10 shows students involved in a course offered by a skilled master, and Fig.11 shows the process of how to plaster mud on Japanese wooden walls. Activities like this workshop will draw more attention to historic wooden buildings.

7. Conclusions
To conserve these historic wooden buildings and their cultural heritage is one sustainable way to enrich the depth of a city. Despite retrofitting costs, these buildings extend the historical atmosphere and cultural traditions from one generation to the next, becoming an integral part of a community’s identity. Their conservation is very worthwhile, although special construction knowledge, techniques and materials are required.

Based on a field investigation, this paper presents results related to the factors that potentially harm structural safety after adaptive reuse of historic wooden buildings and discusses training for professionals to avoid threats to their structural safety. The study’s results indicate the issues and importance of retrofitting and a relevant education system for professionals, in order to allow architects and engineers to understand the major issues that harm structural safety and avoid inappropriate retrofitting. Moreover, the investigation shows that authorities should pay more attention to the need for education of professionals, given the current lack of training in retrofitting in Taiwan.
References
1) Wang, C. H. & Fu, C. C. (2011). The Conservation of Disappearing Sugar Industry Cultural Landscapes in Taiwan. Journal of Asian Architecture and Building Engineering, 10(1), pp.1-6.
2) Wang, C. H. & Fu, C. C. (2014). Dynamic and Diverse Conservation Approaches for an Historical Irrigation System: A Cultural Landscape in Taiwan. Journal of Asian Architecture and Building Engineering, 13(1), pp.25-32.
3) Chen, C. C., Chang, J. S. & Tsai, M. T. (2007). Structural Behaviors of Japanese Style Bamboo Mud Walls under Horizontal Cyclic Loading. Journal of Architecture, No. 62, pp.91-116.
4) Lin, Y. C., Chang, J. S. & Chen, P. L. (2013). Comparison Study of Earthquake Damage and Performance for Two Types of Historic Japanese Wooden Building – Illustrated with Two Cases in Shih-Dong Elementary School, Journal of Architecture, No. 84, pp.91-116.
5) Kuo, K. C., Sun, J.C. & Yao, G. C. (2015). Seismic Evaluation of Historic Japanese Wooden Buildings – Examples of School Offices, Journal of Architecture, No. 94, pp.1-21.