

Exploring Sustainable Conservation: A Case Study on the Transformation of Knockdown Wooden Houses in Thailand

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Abstract

This research aimed to explore the local characteristics, development, and current status of knockdown wooden houses in Thailand's central and northern regions to identify effective and sustainable development methods for the design process. Knockdown wooden houses are prefabricated structures that can be quickly assembled and disassembled. They can be transported as separate elements or complete tiny houses, offering high portability and convenience for relocation. The research methodology included a literature review, observation of knockdown house construction, and semi-structured interviews with key stakeholders. The findings revealed that the current state of knockdown wooden houses can be classified into three groups based on design adaptation and resource utilization. The first group adheres to a resilience approach in a conventional manner, while the second group adopts an adaptive approach, adjusting its design for modularity. Both groups use reclaimed wood. The third group adopts a transformative approach, emphasizing both architectural design and resource utilization. This group uses plantation teak, considers the entire system from wood resource to waste wood management, and shifts from linear to circular thinking. Their design prioritizes not only the product but also the sustainable process, in particular supporting the replanting of teak stands. The common characteristics of knockdown wooden houses in the Thai context include a preference for using reclaimed wood from dismantling old wooden buildings, a kinship system among carpenter groups, and flexible modular designs to meet owner needs and accommodate the unstandardized dimensions of reclaimed wood. The construction process consists of five main steps: material selection, wood processing, design, prefabrication, and installation, with an additional stage for waste wood management. This research advocates for promoting planted trees for sustainable wooden architecture, emphasizing the importance of managed forests. Design knowledge also should incorporate content about young wood material and modularity.

Keywords

Sustainable conservation; Wooden house; Knockdown; Transformation; Resource-oriented approach; Managed forest

1. Introduction

In Thailand, the wooden building sector appears to lack a clear connection with natural and cultural resource considerations. Wood can be considered a renewable material only when sourced from forests that are responsibly and sustainably managed (United Nations Economic Commission for Europe [UNECE], 2023a). Additionally, the prohibition of cutting trees in forests for the private sector in the late 1980s led to a reduction in wood consumption in the Thai context. Since the law changed in 2019 regarding the use of trees on private land, it also has positively impacted wood construction (European Forest Institute, 2020). The knockdown wooden house in the Thai context has deep roots in Thai culture and continues to evolve into current living practices. However, there is a growing preference for concrete and steel construction over wood, primarily due to cost and maintenance factors. Furthermore, research on knockdown wooden houses in Thailand is limited, with most studies concentrating on marketing and steel knockdown structures.

Understanding knockdown wooden houses in the context of resources and sustainability is crucial for conserving associated wood knowledge and skills, directly linked to resource management. These knockdown wooden houses are vital for studying the utilization of cultural and natural resources over time, considering local characteristics and current situations. The primary objective of this research is to provide valuable insights informing decision-making and practices in the knockdown house industry, fostering a more environmentally-conscious and resource-efficient approach.

1.1 Knockdown Wooden House Principles and Situations

A knockdown house, likened to Lego, is easily movable and dismantled (Bhaskara et al., 2019). Wood construction encompasses structural and non-structural components, categorized based on industrial involvement into on-site construction and in-industry production. Techniques for knockdown houses include conventional (vernacular, semi pre-cut) and contemporary approaches (pre-cut, panel, volumetric systems), showcasing wood's adaptability (De Araujo et al., 2016a). Traditional construction involves conceptual design, detailed design, and construction phases, whereas prefabrication entails design, fabrication, and installation stages (Gunawardena & Mendis, 2022). Moradibistouni and Gjerde (2017) classify prefabrication into five types: component, panel, volume, hybrid (volume + panel), and complete building.

In Europe, there has been a noticeable shift from business as usual to bio-based construction. The most productive forests are located in Nordic countries like Sweden and Finland, as well as the DACH region which are Germany, Austria, and Switzerland (Schouten et al., 2023). Tall timber buildings also are emerging, exemplified by structures like Mjøstårnet in Norway, which utilizes cross-laminated timber (CLT) in a mixed-use 18-story building (Safarik et al., 2022). Apart from European countries, Japan is one of the developed countries that has a dense area of forest. There has been a long evolution of wood building practices. Some traditional techniques are being applied to modern architecture and these need to be integrated into the transportation system, controlling everything down to wood members in the lumber market. Japan notably imports a substantial volume of timber (Anagnostou, 2018).

Wooden houses also are part of Thailand's cultural heritage. Heritage conservation expands from tangible dimensions to intangible dimensions such as woodworking skills, forest management, and traditional construction skills (United Nations Educational, Scientific and Cultural Organization [UNESCO], 2003). To build a new wooden knockdown house, one must sometimes respect the great diversity of different regions (International Council on Monuments and Sites [ICOMOS], 2017). Additionally, craftsmanship and ecological knowledge are integral

parts of conservation (Larsen & Marstein, 2016). The intangible skills also contribute to sustainability, as traditional knowledge encompasses practices accumulated over time that have been used to make sustainable use of natural resources (UNESCO, 2015).

The sustainable conservation principles form English Heritage emphasize integrating nature, minimizing environmental impact, and building resilience to climate change (English Heritage, 2023). Timber construction poses a challenge to Sustainable Development Goals (SDGs) as the building industry accounts for 39% of global energy-related CO₂ emissions, with 11% stemming from the manufacturing of building materials and products like steel, cement, and glass (UNECE, 2023b). Resilient design principles from vernacular architecture can be applied for changes in various aspects such as element design, construction systems, and appropriate materials (Ozel et al., 2015). Changes, due to natural disturbances, are categorized into three levels: resilience, adaptation, and transformation (O'Connell et al., 2015). The ability to adapt is linked to how people use their resources, especially cultural and natural resources across various levels (Tienthavorn, 2019). Nevertheless, certain aspects of industrialization have reduced the importance of traditional knowledge concerning vernacular landscapes, despite its crucial role in nurturing a strong bond between nature and culture (Aktürk & Fluck, 2022). Sustainability in the context of wood material revolves around ensuring long-term resource availability. This is achieved through practices such as planting, harvesting, and replanting within the forest-based bioeconomy (Paper Manufacturers Association of South Africa [PAMSA], 2022).

1.2 Development of Wooden Houses in the Thai Context

Once abundant with diverse tropical forests, including evergreen and deciduous varieties, Thailand's forest cover has decreased from 53.5% in 1961 to 31.57% in 2022 due to rapid economic growth and agricultural expansion. The reforestation goal is now approximately 40% (Royal Forest Department, 2009). These statistics imply a decline in resource availability for wood buildings and there has been a corresponding increase in the price of wood. In the past, Thai houses typically were constructed using bamboo and wood. These houses often were relocated and reassembled, which is characteristic of a knockdown system (Punpairoj, 2010). Both houses and landscapes are dynamic, capable of adapting to changing circumstances. Socio-cultural identities play a crucial role in reducing vulnerabilities and strengthening the resilience of communities and their environments (Dipasquale et al., 2014). However, compared to western countries, high-rise wooden buildings are not prevalent in Thailand due to regulations and technological constraints.

The development of Thai timber architecture can be divided into three periods, based on ways of resource utilization (Figure 1). In the initial traditional phase, wooden houses first appeared during the Dvaravati period, as evidenced by pictorial evidence from the 8th century. Subsequently, depictions from Simon De la Loubere's records illustrate wooden houses from the late Ayutthaya period (Thunwiwatkul, 2016). Traditional wooden houses were crafted using locally sourced materials such as wood and bamboo, employing regional craftsmen (Tienthavorn, 2024). The second period, the standardize period, roughly during the Rattanakosin Rama VI-V era in the 1850s, marked the introduction of the wood processing industry, leading to standardized construction methods influenced by external factors. This transformation was triggered by the Treaty of Friendship and Commerce between the British Empire and the Kingdom of Siam, resulting in the establishment of sawmills in the central and northern parts of Thailand (Makka, 2020). The wood's size and length were standardized during this period. In the third period, the Forest Industry Organization (FIO) was established in 1947, marking the start of forestry management in a more commercial manner. In 1989, the government canceled all forest concessions. However, in 2019, it revised its policies to permit the use and cutting of trees on private land.

Certain old wooden houses are associated with specific tree species and local techniques, which may vary across Thailand's four regions: central, north, south, and northeast. For example, the typical Thai house, "fa pakon," constructed using rabbet joints without nails, exemplifies this practice. Presently, knockdown wooden houses have become a thriving local business, commonly observed along roads from Bangkok to destinations like Ang Thong and Ayutthaya. Additionally, this industry is influenced by factors such as purchasing power, material costs, and labor prices, which may also vary across regions.

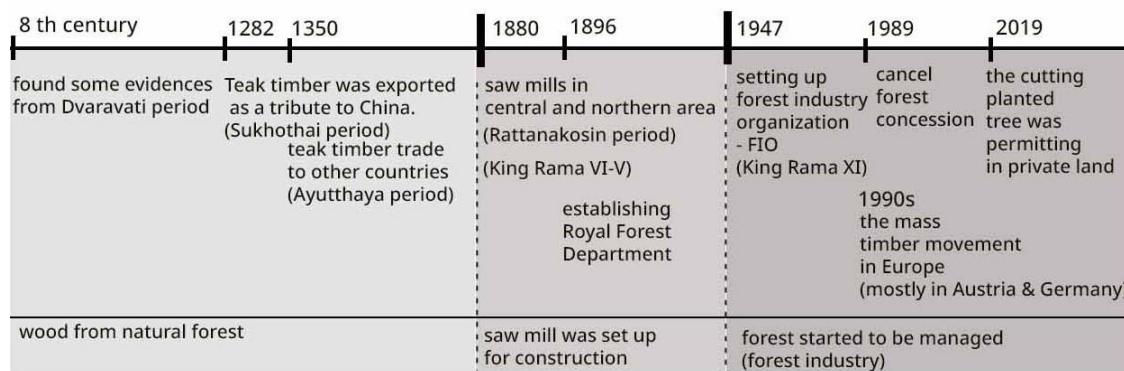


Figure 1. Timeline of transformation from natural forest to plantation forest in the Thai context

2. Research Methods

2.1 Data Collection Method and Instrument

This study employed qualitative methods, including literature reviews, observations, and face-to-face interviews with knockdown wooden house business owners, to gather data on various aspects of this sector. The interviews explored attitudes, resource utilization, construction processes, limitations, and opportunities of the knockdown industry. Methodologies encompassed comprehensive reviews of existing literature, direct observations to gather firsthand insights into the construction processes, and in-depth interviews conducted on general and specific topics related to location. Records and notes were taken during the interview process. This research received IRB approval with Certificate of Approval (COA) No. 101/67.

Criteria were established for case selection:

- 1) Material:** Houses had to be constructed with real timber.
- 2) Building type:** Cases focused on the residential sector.
- 3) Construction process:** Houses had to be built using the knockdown system.
- 4) Location:** Cases were selected from the central and northern regions of Thailand, known for their extensive history and data on the wood industry as per the literature review.

The research utilized purposive sampling, selecting at least 3 cases from central and northern Thailand, excluding Bangkok. Bangkok, due to its rich and complex nature, was excluded from the study but might be considered in future research. The southern and northeast regions were excluded from this study due to a lack of historical data. Literature reviews revealed that most records of saw mills during King Rama V's reign were found in the central and northern regions (Makka, 2020). However, the southern and northeast regions should be considered in future studies.

Eleven case studies were conducted across eight provinces in the central (Ayutthaya, Ratchaburi, Sing Buri, and Suphan Buri) and northern areas (Chiang Rai, Lampang, Nakhon Sawan, and Phrae) (Table 1), focusing on areas historically associated with wooden house settlements and carpentry. Noticeably, Nakhon Sawan could be considered part of the upper central area or the lower northern area, depending on the criteria. This research follows the criteria outlined in the National Economic and Social Development Plan, as the knockdown wooden house business is based on economic dimensions. The research targeted individuals involved in the knockdown house business, including business owners, architects, conservationists, and policymakers, all sharing an interest in promoting sustainable living practices.

Table 1. Location of case studies

	Province	Number of case studies
Central part (7 cases)		
1	Ayutthaya	3
2	Ratchaburi	2
3	Sing Buri	1
4	Suphan Buri	1
Northern part (4 cases)		
1	Chiang Rai	1
2	Lampang	1
3	Nakhon Sawan	1
4	Phrae	1

2.2 Data Analysis Method

The collected data were analyzed using thematic analysis to understand the contents or themes present in the data (Braun & Clarke, 2006) from many knockdown wooden house businesses. This methodological approach facilitates the systematic identification and interpretation of prevalent topics or themes inherent within the dataset. By discerning recurring patterns and trends, thematic analysis serves to elucidate the prevailing dynamics within the knockdown wooden house industry. Additionally, a comparative analysis of the case studies was conducted to thoroughly examine and draw conclusions from the gathered information. This process contributes to making better decisions and planning for the future, ultimately supporting the growth and sustainable conservation of building these knockdown wooden houses.

2.3 Limitation

The research focused on the central and northern regions, where Thailand's timber sources are originally located and where available data from the literature review is present. Further studies should investigate other regions such as the south and northeast. The one-year grant duration necessitated a clear and focused scope for the research.

3. Results

Three Categories of Resource Utilization for Knockdown Wooden Houses

The case studies demonstrated three ways or categories of utilizing resources that focused on: i) the design approach; ii) resource utilization methods; and iii) construction processes. The study found that there still is a presence of traditional architectural work continuing from the past, while some have adapted and changed their way of thinking in the architectural design process. Resources that traditionally were considered only for production now need to be integrated into the design process, reflecting the growing emphasis on sustainability in architectural woodwork. Sustainability appears to be the new essence in architectural practice. Some cases can be in different stages depending on situations, limitations, and owners' requirements. The resilience approach implies construction in a more conventional manner with minimal adjustments. This stage of resilience focuses on maintaining the same function without significant changes. Adaptation means the design process has to be integrated for better performance in modularity for transportation. Lastly, the transformation stage refers to the changing methods of construction concerning juvenile wood and sustainable forest ecosystems.

3.1 Category 1. Resilience Approach

a. Stakeholder and Design Approach

This category commonly is owned by small business owners, usually carpenters. These businesses typically operate with a family-oriented approach, often run by carpenters and their relatives, comprising groups of around 10 people or more. Their backgrounds partly came from carpentry and lumber sales. In the past, they were involved in selling lumber and subsequently adapted to constructing wooden houses using their materials. They are still engaged in both selling lumber and offering knockdown wooden houses. Carpenters often use patterns from traditional wooden houses that they have built in the past and adapt them for designing knockdown wooden houses. This group considered transportation for each individual part but did not address transportation for the entire system or for modularity.

The style and design of this group are closely linked to the traditional Thai style, particularly the gable roof house, with some adaptations for commuting by truck. The size usually is determined by transportation, typically around 3.00 x 6.00 meters. However, if the housing components are wider than a vehicle, the house is designed with modular or separate components to be assembled on-site. If designed for volumetric transportation, the vendors must first develop a transport methodology plan. For example, the roof structure is designed in two parts: one for the room, which can accommodate only 3.00 m due to transportation limitations, and the other for the canopy, which extends 1.00 - 1.20 m (Figure 2). The price for a house in this group, for example, one approximately the size of a truck, around 12,500 EUR (approximately 500,000 THB), excluding the foundation, electronic systems, and plumbing systems. However, the price varies based on the grade of wood, the complexity of the work, and labor costs, which can differ across various regions.

One benefit of a family-oriented approach is that carpenters can pass down their traditional knowledge and wood skills to the next generation within the family. Each family and region may possess unique woodworking skills and architectural aesthetics. Another advantage is that, as carpenters age, working off-site becomes more suitable due to their experience, and it also is more cost-effective compared to on-site work.

Here is an example of an interview from the Ratchaburi case, where the participant used to build traditional Thai-style houses and adapted these techniques to construct knockdown wooden houses:

"There is teaching for the next generation using some hand tools, not all machinery. There are two types of carpenters, the traditional Thai-style carpenter and the general carpenter. Thai-style carpenters use more traditional techniques, but not everyone can build in the Thai style. Thai-style houses are being built less this year, but there are plans to continue training the next generation. The roof of Thai-style houses in Ratchaburi is slightly higher in shape compared to those in Ayutthaya. Old wood often presents challenges related to wood scraps because when old houses are demolished, the obtained wood may not always have the desired length. Therefore, there might be more wood scraps than needed for the upcoming projects, causing an increase in wood prices. For small businesses, finding affordable sources for wood can be a challenge. To clarify, the prices of reclaimed wood from the market, predominantly sourced from the Northeastern region, have been relatively high in the past 2-3 years. (Owner, Ratchaburi case, personal communication, January 29, 2023)

b. Level of Resource Adaptation

Regarding natural resources, as most business owners are carpenters, they are accustomed to working with old wood. Furthermore, the interviews revealed that these carpenters typically utilize reclaimed wood, which is retrieved from old houses. The carpenters shared their opinion that old wood has low moisture, is stronger, and has a longer lifespan compared to newly harvested wood. The carpenters mentioned that old wood mostly comes from entire old houses in regions such as the northeast, with some also sourced from the central region. Using reclaimed wood is a common practice in carpentry and construction, with the wood often being chosen for its character and quality. However, some reclaimed wood is combined with imported wood, such as Shorea obtusa from Malaysia. There are various species of reclaimed wood, such as Pterocarpus macrocarpus (Burma padauk), Shorea siamensis (Burmese sal) (Owner, Ratchaburi case, personal communication, January 29, 2023). In terms of cultural resources, this group plays a vital role in transmitting cultural knowledge. Engaged mainly in carpentry, they actively pass down their knowledge to the next generation, relying minimally on external resources and ensuring the survival of unique architectural styles and techniques.

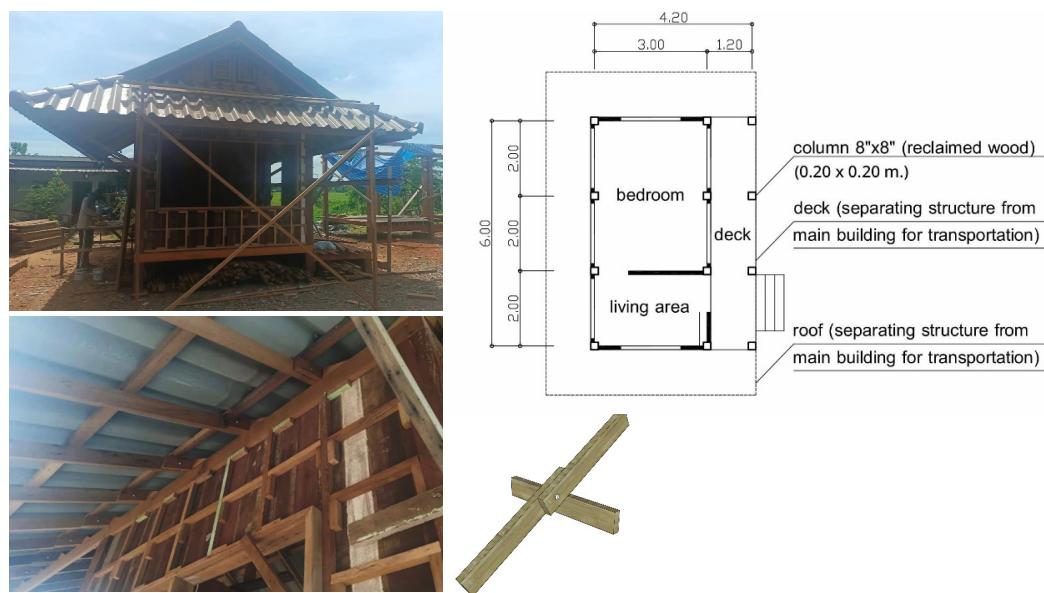


Figure 2. A traditional design house with modifications for transportation convenience (Ayutthaya case)

Photo by author

c. Process Overview of Knockdown Wooden House Construction (Figure 3).

- 1) **Material selection:** Reclaimed wood from disassembled old wooden houses.
- 2) **Wood processing:** Processing wood from reclaimed wood shops.
- 3) **Design process:** Designing for transportation on a truck of dimensions 2.50 x 5.50 meters. The modular house is approximately 3.00 x 3.00 meters but can vary according to the owners' preferences.
- 4) **Prefabrication:** Some components are panel-based, while others are volumetric for transportation.
- 5) **Installation:** Both off-site and on-site installation methods are utilized.

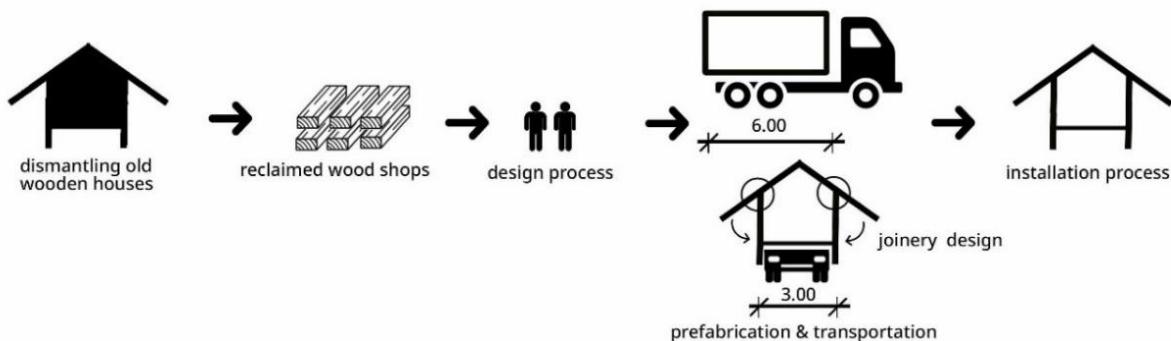


Figure 3. An overview of the construction process for knockdown wooden houses in category 1

3.2 Category 2. Adaptation Approach

a. Stakeholder and Design Approach

Many business owners in this industry either have a background in collecting old wood or have been involved in wood-related businesses before starting their own ventures. Typically, they initiate their businesses by hiring local groups of carpenters, often consisting of family members and relatives. Interestingly, it has been observed that the business owners in this group may not necessarily have a background as carpenters themselves. Instead, their involvement is driven by a passion and fondness for wood materials and wooden houses. Business owners in this group come from various professions and there is no distinct specialization as either carpenters or architects. This diversity results in a wide range of resource utilization approaches compared to the first group.

Observing the variety of resource utilization, the focus is on value addition, categorized into technical improvement and meeting customer requirements. The first group prioritizes preserving traditional styles while integrating new technologies like stainless steel bolts for durability (Chaiwong, 2020). Additionally, they offer comprehensive training for carpenters through the scrutiny of elaborate architectural work and allow flexibility in size by prefabricating components. The second group adapts to owner requirements by incorporating Western or contemporary designs, with pricing reaching up to 25,000 EUR (approximately 1,000,000 THB), varying by size, location and wood quality. This price excludes the foundation, electrical systems, and water systems.

“Currently, my son is primarily responsible for the work, incorporating a blend of Western-style designs. However, he is versatile and accepts various tasks. While he excels in crafting Thai-style structures, there is another set of craftsmen specifically dedicated to Thai-style construction. (Owner, Ayutthaya case, personal communication, 2023, June 30, 2023)

b. Level of Resource Adaptation

This group is more concerned with the quality and characteristics of the wood, which directly affects the price of the house. The study found that they use a wide range of wood types, including reclaimed and imported wood. Regarding reclaimed wood, it can be classified into two groups based on management practices and wood type related to strength. The first group uses high-quality reclaimed wood from durable species, often salvaged from well-maintained structures or responsibly deconstructed buildings, such as *Pterocarpus macrocarpus* (Burma padauk), *Xylia xylocarpa* (Iron Wood), and *Afzelia xylocarpa* (Pod mahogany). The second group uses a lower grade of wood, mixing various types of reclaimed wood. In some case studies, hardwood is used for exterior parts, while lower-quality wood or non-standard-sized lumber is used for the interior or certain parts of a knockdown house. For example, wood originally intended for lumber sale, suitable for creating a 2-inch-thick floor (0.05 m), may only measure 1.8 inches (0.045 m.) in thickness when disassembled from an old house. This wood, unsuitable for sale as individual planks, is instead used in the construction of a knockdown house (Owner, Sing Buri case, personal communication, December 28, 2023)

There are both positive and negative impacts of using reclaimed wood. According to the interviews, the positive aspects of reclaimed wood include its quality and low moisture content. However, carpenters have to invest time in repairing defective wood. In contrast, new wood, which is typically teak around 30 years old, is much younger. Although there may be issues related to higher moisture content, there is no need for extensive repair time. Additionally, the size of the wood is standard in terms of length and width. Furthermore, one of the case studies in Ayutthaya used high-quality teak timber from Myanmar, sourced from natural forests with an estimated age of around 80-100 years or more. The age of these trees contributes to the wood's desirable characteristics (Owner, Ayutthaya case2, personal communication, 2023, June 30, 2023)

“Using old wood may not result in a perfectly smooth finish, as it requires filling in various imperfections, plugging holes, and sizing it uniformly. However, if new wood is used, there is no need to spend time repairing the wood. Nevertheless, concerns about moisture may still persist” (Owner, Sing Buri case, personal communication, December 28, 2023)

The business owners apply modular design for transportation, making it feasible to move larger buildings. For example, in the Nakhon Sawan case, a house larger than 3.00 x 6.00 meters can be designed in modular sections and transported in multiple rounds. A 3.00 x 6.00 meter house can be divided into three parts, requiring 3-4 rounds of transportation (Owner, Nakhon Sawan case, personal communication, January 4, 2024) (Figure 4). The pricing for houses in this group can exceed 25,000 EUR (approximately 1,000,000 THB), but it varies based on location and wood quality. This price does not cover the costs for the foundation, electrical systems, and plumbing. Factors such as location and the grade of materials contribute to the variability in house prices within this group. At this stage, the design must integrate the transportation system.

“Sometimes, the construction of knockdown houses requires more wood compared to conventional on-site types, as frames need to be made to hold them together, such as adding additional wooden posts around the structure.” (Owner, Ratchaburi Case2, personal communication, January 29, 2023)

There also is an instance in Chiang Rai that showcases a flexible modular design consisting of three primary activities: bedroom, kitchen, and toilet:

“I have recently initiated a knockdown project where customers can choose three main activities—bedroom, kitchen, and toilet—and adjust the size of the space according to the owner’s requirements. The customer can customize both the activities and the size themselves.” (Owner, Chiang Rai Case personal communication, March 30, 2024).



Figure 4. Designing house in modular system for truck transportation (Nakhon Sawan case)

Photo by author

c. Process Overview of Knockdown Wooden House Construction (Figure 5)

- 1) **Material selection:** Reclaimed wood from disassembling old wooden houses.
- 2) **Wood processing:** Wood processing at reclaimed wood shops.
- 3) **Design process:** Design for transportation on a truck (2.50 x 5.50 meters). The modular house is approximately 3.00 x 3.00 meters but can vary per owner specifications. The design must integrate modularity for transportation.
- 4) **Prefabrication:** Some components are panel-based and some are volumetric for transportation. Sometimes, the process needs to design methods for commuting elements.
- 5) **Installation:** Both off-site and on-site installation.

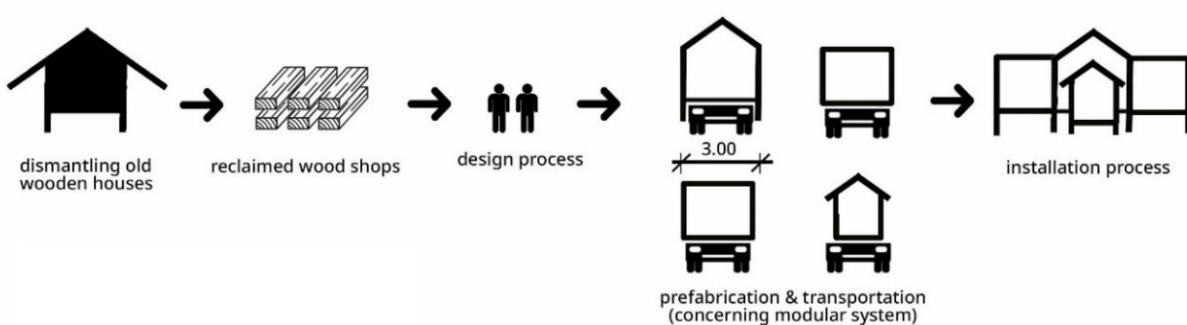


Figure 5. An overview of the construction process for knockdown wooden houses in category 2

3.3 Category 3. Transformation Approach

a. Stakeholder and Design Approach

A category 3 wooden house takes a holistic approach to resource management, considering the entire production process from timber to construction, including waste wood management. In the Phrae province

case, the owner, with an architecture background, comes from a family involved in selling teak lumber, including teak doors and windows. During the interview (Owner, Phrae case, personal communication, February 25, 2023), the concept of a knockdown house was discussed in two ways: first, focusing on the house's ability to be assembled or disassembled; second, emphasizing its capacity to be moved as a whole structure.

This case study illustrates that the price of the house is approximately 25,000 EUR (approximately 1,000,000 THB), demonstrating how the design enhances the value of new teak lumber, which is approximately 30 years old. Since the case is in Phrae province, the resources primarily benefit from the local teak plantations. There is a need for innovation in reducing moisture during the process for new wood, as moisture levels are higher in new wood compared to reclaimed wood. Consequently, the owner, along with the neighboring community, set up a wood drying machine with government subsidies to control moisture levels below 8-12%. This category involves contacting various stakeholders and requires knowledge not only in wood skills but also in architectural design and ecological considerations.

“For me, the term ‘knockdown’ potentially holds two meanings: firstly, indicating that the knockdown house can be easily disassembled and reassembled; secondly, suggesting that the knockdown wooden structure allows the entire house to be moved as a volumetric mass from one location to another. Old wood possesses two significant advantages: firstly, the maturity acquired through age, and secondly, the dryness inherent in the wood. Conversely, new wood typically contains a high moisture content, leading to the establishment of a communal wood-drying facility by the community. This initiative involves the collective effort of community members utilizing the facility. The teak wood, aged over 30 years, demonstrates a range of usability, maintaining strength, durability, and the ability for rapid replanting. The design must integrate an understanding of young wood’s qualities, such as opting for smaller columns for the 30-year-old teak instead of one large column. (Owner, Phrae case, personal communication 2023, February 25, 2023.)

b. Level of Resource Adaptation

With constraints on natural resources and forests, a case study has demonstrated a new approach to knockdown wooden house design. This evolution involves not only focusing on structural and construction aspects but also prioritizing sustainable practices and resource-efficient strategies, including replanting of trees. This category encompasses the entire process, addressing not only physical design but also the selection of sustainable materials and waste management.

Cultural resources extend beyond the physical realm to encompass intangible dimensions ingrained in the mindset of the northern or Lanna people. Firstly, individuals typically reserve wood for their offspring in the form of both wooden houses and planted forests. Secondly, there is a prevailing belief in constructing new houses with new wood rather than utilizing old wood from dismantled structures. This belief might stem from the abundance of forests in the past, as well as the consideration that old wood might have some defects.

“People here normally use new wood, as we believe it is better than using old wood sourced from various places. Old wood might not be suitable for new houses, perhaps due to the abundance of forest resources in the past. Moreover, our ancestors sometimes planted forests for their children.” (Owner, Phrae case, personal communication 2023, February 25, 2023.)

For example, in the case study of teak knockdown houses depicted in Figure 6 (Sritipasarn, 2023), the house has a total area of 18 square meters for the terrace and balcony, while the interior measures 36 square meters. The spacing between columns is set at 3.00 x 3.00 meters to optimize standing space and allow easy movement. This dimension aligns with the standard length of plantation wood from the Forest Industry

Organization (FIO), which typically ranges from approximately 3.00 to 3.50 meters. Structural parts like columns and beams, which bear the most weight, employ the more robust wood, while less weight-bearing sections like panels may use less dense or younger wood. Additionally, the design aims to be resource-efficient by using smaller-sized wood with a cross-section of 3 x 3 inches (0.075 x 0.075 m.), combining four pieces to form a column for the house's structure.



Figure 6. Planted teak knockdown house with smaller composite columns (Phrae case)

Photo by author

c. Process Overview of Knockdown Wooden House Construction (Figure 7).

- 1) **Material selection:** 30-year-old plantation teak.
- 2) **Wood processing:** Plantation wood from FIO or private land, utilizing a community wood drying machine.
- 3) **Design process:** Integration with previous stages, dividing design into structural and non-structural parts, with material quality linked to architectural aspects.
- 4) **Prefabrication:** Some panels and volumetric mass for transportation.
- 5) **Installation:** Both off-site and on-site installation.

Moreover, in this case study, leftover wood is efficiently managed by repurposing it for various uses, such as producing charcoal from different wood types and crafting knife handles from small wood scraps, maximizing resource utilization and adding value to waste materials.



Figure 7. An overview of the construction process for knockdown wooden houses in category 3

4 Discussion

4.1 Design Approach in more Ecological Thinking and Local Characteristics of Knockdown Wooden Houses

The knockdown wooden house industry shifted to using wood from planted forests around 1947, reflecting an ecosystem-focused approach. Thailand's forest concession cancellation in 1989 resulted in underutilized forests, while Europe embraced the mass timber movement in the 1990s (Lehmann & Kremer, 2023), implementing new wooden building policies. Despite Thailand amending its laws on tree cutting on private land after the 2010s, the study found only one case in Phrae using plantation teak. This indicates that the wooden house trend is more supported in Western countries. For example, in Canada, the National Building Code of Canada (NBCC) increased the allowable number of stories for mass timber buildings to six in 2015. In 2020, the NBCC raised the limit to 12 stories, demonstrating a significant policy shift supporting the forestry industry (Harp, 2022). Countries like New Zealand, Sweden, and Germany have established regulations, standards, and guidelines to support wood construction in the residential sector (De Araujo et al., 2016b).

In contrast, Thailand lacks specific regulations on wood buildings. To effectively apply international policies to the Thai context, it is crucial to understand current situations and local business intricacies on a practical level. Even within Thailand, regions may vary in pricing and local resources. From the case studies, analyzing the approach, resource utilization, and process, three common characteristics were identified for the knockdown wooden house construction:

- 1) **Using reclaimed wood:** Most cases rely on reclaimed wood due to its strength and lower moisture content. However, a notable exception in Phrae in the northern region has transitioned to using plantation wood, specifically teak. The way Thai people use reclaimed wood contrasts with the practices in many European countries, which use log farms for construction. However, geographic and technological differences should be considered. Nonetheless, plantations should include more than just teak to promote diversity. Sweden also faces controversial issues with monocultures of spruce and pine, which reduce biodiversity (Stockholm Resilience Centre, 2013).
- 2) **Kinship network in labor:** Labor systems for knockdown wooden houses predominantly operate within kinship networks. Sometimes the owner is not a carpenter themselves; they hire groups of carpenters within these relative networks. This approach not only involves familial work but also ensures the transmission of woodworking skills and knowledge to the next generation.
- 3) **Flexible modular system:** The fabrication system for knockdown wooden houses primarily is designed for disassembly, assembly, and transportation, prioritizing human woodworking skills over large machinery. Adaptations may be necessary based on the specific requirements of the house owner, partly due to reclaimed wood, which sometimes does not conform to standard dimensions in size and length

However, there are some noticeable differences in regional conditions. Three issues were noted: material availability, cultural beliefs, and local techniques. Firstly, wood species may differ across regions. For instance, teak plantations are more common in the northern area, potentially influencing resource availability and the types of wood used in construction. Secondly, cultural beliefs possibly influence construction practices, as evidenced by the emphasis of the Lanna people's belief on using new wood and replanting trees for future generations. Lastly, techniques of carpenters may vary in different locations. In the Ratchaburi case, the roofs of traditional Thai-style houses are slightly higher compared to those in Ayutthaya, with the case study adapting these techniques for knockdown wooden houses.

4.2 Different ways of using Resource for Building Knockdown Wooden Houses

According to O'Connell et al. (2015), the ability to utilize resources involves absorption, adaptability, and change (see Table 2). Traditional groups in Category 1 exhibit lower adaptability, mainly focusing on traditional methods with little technical adjustment, as seen in the example of the Ratchaburi case. The adaptation group in Category 2 demonstrates a systematic approach, focusing on owner requirements and modular design to enhance building development. For instance, as observed with a case in Nakhon Sawan, modular units are integrated for transportation efficiency. Moreover, in the case of Chiang Rai, flexible key activities allow customers to customize size and function according to their needs. The transformation stage of a Phrae province case in Category 3 involves a complex and circular process that addresses various dimensions, including cultural, economic, social, and natural factors, in response to SDGs and the climate change situation. Additionally, the transformation stages correspond to Larsen & Marstein's findings (2016), indicating that conservation efforts originate from managed forests. Timber design has shifted from conventional construction to circular thinking. Similar to many Western countries like Sweden and Finland, there is a focus on planted forests for the wooden construction sector.

In Thailand, old wooden houses primarily serve as wood stock. In contrast, countries like Sweden are in the transformation stage with forest farms. However, according to UNECE (2023a), wood will be renewable only when forests are managed. Historically and culturally, Thai people used to stockpile wood for future

generations, either in the form of building wooden houses or establishing plantation forests on their lands, contributing to the hardwood stock. As mentioned by the Royal Forest Department: Ministry of Natural Resources and Environment (2009), Thailand's forested areas are decreasing, indicating a failure to build a wood stock for the next generation but rather using wood from the previous generation. Consequently, there is a need to rethink and adapt these practices for cultural heritage and environmental sustainability. Moreover, local plantation wood reduces the carbon footprint for logistics compared to imported wood. Therefore, utilizing 30 year old plantation teak can enhance the wood industry ecosystem, with more people engaging in plantation farming increasing plantation wood availability for building construction.

Previously, design priorities seemed to focus solely on physical dimensions, but now, the efficiency of resource utilization has become a crucial criterion in the design process. This consideration is particularly significant due to resource limitations and the ongoing environmental crisis. Our research illustrates that using plantation wood requires careful design considerations, not only for modularity in transportation, but also for ecological factors such as the age and species of the wood. This underscores the increasing complexity and integration required in design, emphasizing the need to incorporate ecological knowledge.

Table 2. Levels of changes in knockdown wooden houses

	Level of changes		
	resilience	adaptation	transformation
Intention	Traditional approach	Value-added approach	Resource-oriented approach
Focus	Emphasis on wooden house product	Emphasis on wooden house product	Emphasis on wooden house ecosystem; resource and process
Sustainability levels	Extending life space Reuse old wood Technical development	Extending life space Reuse old wood Technical development	Circular process from wood material to wood waste management
Methods and management	<ul style="list-style-type: none"> - Reusing old wood from disassembled houses - Emphasizing a style and technical development but is still similar to traditional styles 	<ul style="list-style-type: none"> - Reusing old wood from disassembled houses - Emphasizing improved style and technical development systematically: modular system and key activities 	<ul style="list-style-type: none"> - Supporting replanting efforts. - Integrating knowledge of planted trees for construction. - Elaborating on processes, such as drying wood thoroughly. - Managing waste wood by using small pieces, like making knives and charcoal.

4.3 Five Steps in Process Overview of Knockdown Wooden House Construction

Gunawardena & Mendis (2022) outlined the design process of a knockdown or prefab building, consisting of three steps: design, fabrication, and installation. However, our research proposes five stages for a knockdown wooden house, placing a stronger emphasis on comprehensive consideration of circular economy principles. The first stage involves selecting materials, followed by wood processing in the second stage. The third stage focuses on the design process, which must integrate ecological knowledge and modularity design. The fourth stage encompasses fabrication, where modularity and the size of plantation wood must be carefully considered. The last stage addresses installation. Moreover, an additional stage involves managing waste generated during construction, some of which is repurposed into wood pieces for knives and charcoal, further exemplifying the commitment to sustainable and circular practices.

Newly planted wood, approximately 30 years old, may exhibit a shorter life cycle compared to reclaimed wood. However, the advantage of newly planted wood lies in the ability to replant more frequently, contributing to a healthier environment, especially in light of reduced forest areas in Thailand. This approach establishes a sustainable ecosystem for planting and utilizing wood, particularly in timber construction. It is preferable to have a longer wood cycle for cutting and usage. However, at this stage, it is essential to initiate the process of planting and using wood rather than resorting to a complete prohibition of cutting, resulting in discontinuation of wood usage. Nevertheless, it would be better if we could extend the life cycle of trees, as was done in the past.

5. Conclusions and Recommendations

In conclusion, knockdown wooden houses have integrated sustainability by emphasizing efficient resource use. Three main characteristics of wooden knockdown houses have emerged. Firstly, reclaimed wood from dismantled wooden houses serves as a primary source for new constructions in Thailand. Nonetheless, the shortage of new plantations poses a significant concern. Teak plantation wood presents a sustainable alternative. Additionally, the kinship and family systems within carpenter groups, which have evolved over a long period, gradually integrate with business operations. The flexible modular designs, tailored to suit transportation needs, driven by owners' requirements and the unstandardized nature of reclaimed wood, create a blend of craftsmanship and industry.

Although the Thai government supports the use of plantation forests and permits tree cutting on private land, the overall forest area continues to decrease. Log farms in Thailand remain underutilized due to the younger age of teak wood, typically around 30 years old, which affects its quality in construction compared to reclaimed wood. This stands in contrast to countries like Sweden and Canada, where wooden building construction is actively supported. Reclaimed wood is suitable for construction due to its quality; however, it does not contribute to the replanting process. The design process for knockdown wooden houses has gradually shifted from linear to circular thinking, as proposed in Figure 8. These processes involve multiple stages: material selection, wood processing, material and logistics-related design, prefabrication, and installation, with an additional stage for waste wood management. Once valued solely for speed and cost-effectiveness, this approach now places greater emphasis on resource sustainability. This shift underscores the importance of carefully selecting wood materials, taking into account factors like age and species, which impact both sustainability and aesthetics. By embracing this holistic approach, construction becomes environmentally responsible, aligning with circular design principles.

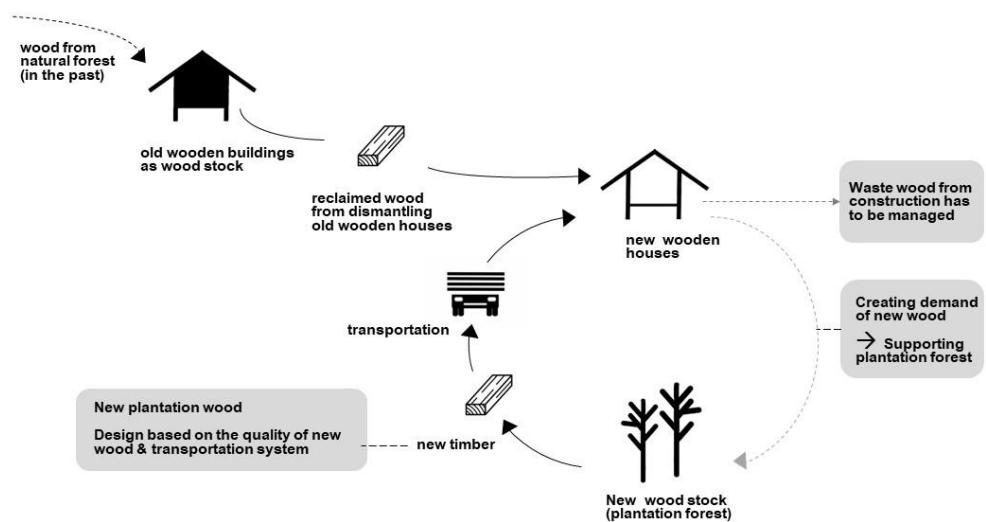


Figure 8. Knockdown wood house ecosystem in the transformation stage

In terms of recommendations for practical implementation, it is suggested to develop supportive policy frameworks for sustainable construction practices, with a focus on plantation wood and the exploration of alternative species beyond teak. Additionally, promoting integrative knowledge about young wood material and modular systems can significantly enhance sustainability in the design process. Within the academic realm, priority should be given to conducting further research aimed at enhancing understanding of the environmental impacts and long-term sustainability associated with the use of young wood in construction, particularly within the Thai context. Furthermore, considering the diverse geographical contexts, there is a pressing need for comprehensive studies focusing on knockdown wooden houses in regions beyond the current scope, such as the northeastern, southern, and Bangkok areas.

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Author Contributions

The author confirms sole responsibility for the following: conceptualization, methodology, formal analysis, investigation, data curation, interpretation of results, manuscript preparation, writing - original draft, writing - review and editing, and visualization.

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