# Potential of Bamboo Wall Techniques Learning from Vernacular Architecture for Post-Disaster Housing in Indonesia

インドネシアにおける災害復興住宅のための
ヴァナキュラー建築に学ぶ竹壁技術の可能性

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# Potential of Bamboo Wall Techniques Learning from Vernacular Architecture for Post-Disaster Housing in Indonesia

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*Key Words: Indonesia, Humanitarian Shelter, Bamboo Architecture*

## Background

One role of bamboo as construction material is in provision of humanitarian shelter, especially in bamboo growing regions, most of which are also world's most disaster prone regions. Including in Indonesia, resiliency are becoming more urgent, as increasing frequency of disasters is among the consequences of global climate change.

Most common use of bamboo which is temporary construction, easily applicable to temporary sheltering. However, such reconstruction strategy has drawn criticism. Durability has been the primary concern in expanding use of bamboo material beyond temporary use. Bamboo has been frequently used for construction of wall, particularly the non-structural kind. Although it is crucial for even inhabitant of simplest dwelling and used extensively in post-disaster housing, the architectural element of bamboo wall has not been much researched.

Under such urgency, this study starts by identifying the factors for using bamboo material in post-disaster housing from literature and case of transitional shelter. The term imply transition beyond temporary into durable solution, intended to address the insufficiency of temporary housing. Among the factors are the possibility to utilize self-build and available local resources, both contribute to ease of localization as one value which is also found in vernacular use of bamboo material.

In this thesis, vernacular architecture and its bamboo wall techniques are seen to embody valuable principles, potentially expanding the possibilities of bamboo use in post-disaster housing. As an exploratory type, this study aim to provide new perspectives on such potentials, gathered from vernacular cases of bamboo wall in Indonesia and Japan, which are considered less researched but relevant for post-disaster housing in the region and beyond.

## Methodology

The study is based on literature review, field study and interview in Indonesia, Japan and supplemented by questionnaire with other experts and shelter practitioner to gain lesson on cases of bamboo use in Brazil and Bangladesh, similar in Japan in ways of using bamboo grid for wall. The field study includes field observation in Japan and Indonesia, internship work in Indonesian bamboo designer and participation on informal workshop on Japanese bamboo wall construction.

Case studies are presented on two shelter phases, seen from the requirements, challenges and room for improvement in using bamboo wall techniques. For bamboo wall techniques, case studies are presented from vernacular architecture of Indonesia and Japan, where main use of bamboo has been within dry and wet-wall technique (wattle and daub) respectively.

The potential points of each wall types are based on observation on vernacular wall types linked to theory on vernacular architecture as well as multiple values of bamboo use in post-disaster housing. Afterwards qualitative description on bamboo wall types are summarized aiming to provide practical recommendation for implementing bamboo wall for post-disaster context in Indonesia.

## Results and Conclusion

It is found in selected vernacular architecture cases that bamboo has been practiced in five types of wall techniques: rounded, flattened, grid, woven wicker-work and plait-work.

The cases supported that bamboo use within the five types has different potential beyond temporary, without complete reliance on single bamboo species or skilled worker, to be considered for post-disaster housing use. Extending life-span of wall element seen to expands the role of post-disaster housing, transitioning from temporary into permanent house.

# インドネシアにおける災害復興住宅のための<br>ヴァナキュラー建築に学ぶ竹壁技術の可能性

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キーワード インドネシア、仮設住宅、竹建築

背景
竹の建築資材としての１つの大きな役割は、竹の生産地が世界で最も災害の多い地域に分布することから、災害時の仮設住宅を提供することである。インドネシアを含め、地球規模の気候変動の影響により、災害の頻度が増加していることから、災害レジリエンス機能の向上が急務となっている。

竹の用途としては、仮設建築物が最も一般的であり、一時的な避難場所として利用しやすい。しかし、このような復興戦略は批判を浴びることがあります。竹の用途を仮設住宅以外に広げるには、耐久性が重要な課題となっています。竹は壁、特に非構造部材の建築によく使われてますが、竹壁の建築的な要素についてはあまり研究が進んでいない。

そこで、本研究では、災害後の住宅に竹材を使用するための要因を、文献とトランジショナルシェルターの事例から明らかにすることから始める。トランジショナルシェルターは、仮設住宅の不足を解消するために、仮設から耐久性のある住宅への移行を意味する。その要因の中には、セルフビルドの可能性と利用可能な地域資源があり、これらは竹壁の風土的な使用にも見られる価値として、地域化の容易さに寄与している。

本論文では、風土的建築とその竹壁技術が、災害後の住宅における竹利用の可能性を広げる貴重な原則を示唆していると考えている。インドネシアと日本における竹壁の風土建築の事例を収集し、その可能性について新たな視点を提供することを目的とする。

研究方法
本研究は、日本やインドネシアでの現地調査、インタビューに加え、日本と類似しているブラジルやバングラデシュの竹利用事例からの文献調査、を基にしている。現地調査では、日本とインドネシアでの現地視察、インドネシアの竹工芸職人へのインターンシップ、日本の竹壁構造に関するワークショップへの参加などを行った。

また、2 つのシェルターフェーズについて、竹壁の技術的な要求、課題、改善の余地からケーススタディを行った。竹の壁技術については、インドネシアと日本の風土的建築の事例を紹介し、それぞれ乾式と湿式の壁技術中で竹を主に使用していることを紹介する。

また、災害後の住宅における竹の利用価値について、風土建築の理論と関連した風土建築の壁面部の観察、実測に基づき、それぞれの壁の潜在的な利用可能性を指摘した。その後、インドネシアの災害後の状況における竹の壁の実装に関する実践的な提案を行うため、竹壁に関する定性的な説明をまとめた。

結果および結論
風土的建築の事例から、竹は１、丸型：２、平型：３、グリッド型：４、籐編み型：５、編組細工型、以上 5 つのタイプの壁技法で使用されていることがわかった
災害後の住宅利用を考慮するため、この 5 つのタイプの竹の利用は、単一の竹の種類や熟練工に依存することなく、一時的利用ではない利用の可能性を持っていることを裏付けている。壁体の長寿命化は、仮設住宅から恒久住宅への移行という、災害後の住宅の役割を拡大するものと考えられる。

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# Chapter 1 Introduction

## 1.1 Background

Among the extensive role of bamboo as construction material has been for provision of humanitarian shelter, especially in bamboo growing regions, most of which are also world's most disaster prone regions (Figure 1.1) where resiliency are becoming more urgent, to address threatening increase in the number of extreme events which are among the consequences of global climate change. The vast majority of these disasters take place in tropical areas (Hebel & Heisel, 2017) and global south, also considered most vulnerable historically.

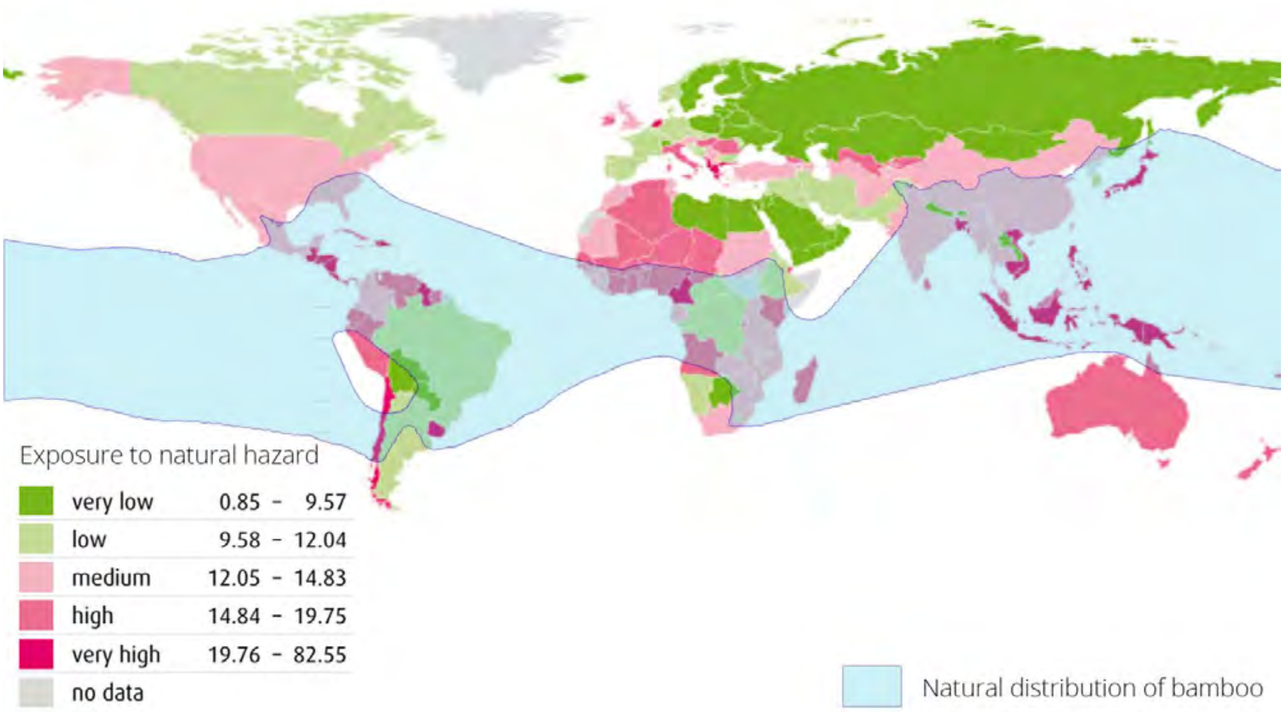



Figure 1. 1 Exposure to Natural Hazard and Natural Distribution of Bamboo
Source: Modified from World Risk Report (IFHV, 2021; El Bassam & Jakob, 1996)

While expensive and emblematic projects are often represent the bamboo material and has reintroduce it into the spotlight, use bamboo for mass housing might be considered as an exceptional case. It has been mainly through the top-down implementation of post-disaster reconstruction that bamboo material spread and contributed to the housing sector (Witte, 2018) on a wider scale.

This helped by the fact that many bamboo species potentially has faster growing rate than other plants which are cultivated for timber, thus despite reputation as 'poor man's timber' it often became an alternative helping to alleviate timber over-demand. Like timber, bamboo material has merit such as renewable and seismically very suitable. However, the use is of timber has been declining on account of forests conditions (UNIDSR, 2004) and it is only recently that new engineered timber architecture gaining momentum, but still mostly in developed countries. Various vernacular architecture often saw bamboo and wood used integrally. With the most extensive use of bamboo in construction is for walls and partitions (Jayanetti & Follett, 2008).

Both material have been used to provide lighter dwelling often desired by disaster victims, after traumatic failure of heavier construction, often made of modern material of 'prosperous city-dweller'. For this type of construction, it is often without intervention by qualified architects and engineers, thus considered as ‘non-engineered’. Such modern but heavier construction has unforgiving side due to its reliance on "complex scientific processes and theoretical analysis with differential equations "(Langenbach, 2016). Failure of such non-engineered buildings has been considered as largest threat during earthquake (UNISDR, 2004).

In various regions where bamboo grows, despite long history of use in construction and is frequently in abundant supply, it has not been extensively used in post-disaster rebuilding efforts, despite high risk often presents in such regions (Hebel & Heisel, 2017). Even where it is used extensively, it has been considered mainly for temporary shelter. Reconstruction strategy which rely on temporary shelter has continued to draw critics of using up resource needed for permanent reconstruction, especially if it has no connection to the later. For achieving permanent post-disaster housing, houses made of bamboo have not always ends up as alternative to heavier construction, despite the need for such alternative due to frequent failure of mainly heavier non-engineered buildings.

Factors hindering widespread use bamboo material could be explained common barriers (Shen et. al, 2019), including for permanent purpose. First barrier are durability and perception to it. Still related with perception, the second barrier is aesthetic bias. The other barrier to be considered in this study which is equally challenging is policy related. Seen from past studies, the barrier of durability has saw various technical solutions addressing it, while the other barriers required to be addressed beyond technical aspects.

While temporary phase after disaster easily compatible with most common use of bamboo construction, to transition toward permanent is among the most suggested key based on approaches and requirements of post disaster shelter. While there is no shortage of design proposal utilize bamboo for structure or selects few for wall element, if the various barrier not addressed, there is a chance that the bamboo shelter will face limitation such as brief post-disaster usage, at barely three months, seen for instance in Yogyakarta after the 2006 earthquake (Maly, 2013).

## 1.2 The Objective and Research Questions

The above mentioned examples suggest the challenge in post-disaster housing as well as opportunity to expand the possibilities of local vernacular knowledge and local resource of bamboo material. Seen on a new light as emerging construction material hailed for it sustainability, bamboo seen to has potential to be used more on less emblematic but much needed housing and its basic element of wall. With sustainable manner, its role is not only to provide temporary shelter but also a sustaining 'home'. The research objective is to clarify the potentials of bamboo material for post-disaster housing in Indonesia, aiming to provide practical recommendation for implementing bamboo wall in Indonesian post-disaster context. To do this research draws from extensive use of bamboo for wall in vernacular architecture.

**Research Question**

1. How bamboo material has been used for wall construction?
    a) What are the variety and examples of bamboo wall technique in vernacular architecture of Indonesia and Japan?
    b) What are the factors and ways bamboo material has been used in past cases of post-disaster housing?
2. What are the potential of bamboo wall technique from vernacular architecture for use post-disaster housing?
    a) What are the relevance of vernacular technique and its principle for the requirements of post-disaster housing?
    b) What are the potential of specific bamboo wall technique for use in post-disaster housing ?

Reflecting back to recent post-disaster housing in Indonesia, the aftermath of an earthquake near the end of 2022 in West Java Indonesia (Figure 1.2) saw another implementation of one-step policy. Among some organization involved aimed to house the beneficiary in permanent housing within less than six months. Involving alternative construction with prefabricated modular concrete structure of 'RISHA' employed, with its light characteristic and decentralized production allowed a degree of self-build. While comparing such modern concrete structure with structure from renewable bamboo material is beyond the scope of this research, further study should taken into account the structural system. When seen as non-structural element, the bamboo wall as main object of this research might be compatible with both structure. While it might be a contrasting system if used with the modern RISHA, it is one possibilities, considering the prevalence of bamboo material in hybrid construction system traditionally. To some extent, it might provide balance by improving the incorporation of local skill and resource, much suggested in post-disaster setting.


Figure 1. 2 Recent reconstruction after disaster in West Java, 2022

### 1.3 Structure of the Research Thesis

This thesis is divided into five chapters (Figure 1.3).
The Chapter 1 presents the research background, objective, question and thesis structure.

The Chapter 2 presents findings from relevant literature on the extent of bamboo use for construction particularly seen from use of wall techniques in vernacular architecture and its equally extensive use for purpose of post-disaster housing. After establishing link between the two, this chapter also define the methodology in examining vernacular architecture and post-disaster housing case studies, as the following chapters sought to extract lesson from the former towards the latter.

The Chapter 3 introduces phase and requirements of post-disaster housing and establish the emphasis of transition toward permanence. For temporary and transitional phase, the chapter examines case studies of bamboo housing in Bangladesh and Indonesia, in order to find limitation and potential of bamboo wall in post-disaster housing.

The Chapter 4 examine bamboo use and wall technique in selected cases of vernacular architecture in Indonesia and Japan. It describes lessons from five case studies followed by discussion on five wall types.

The Chapter 5 presents the discussion on use of bamboo wall for post-disaster housing, first by summarizing use of each wall type in past cases, followed by discussion on potential of each wall type for post-disaster housing in Indonesia.

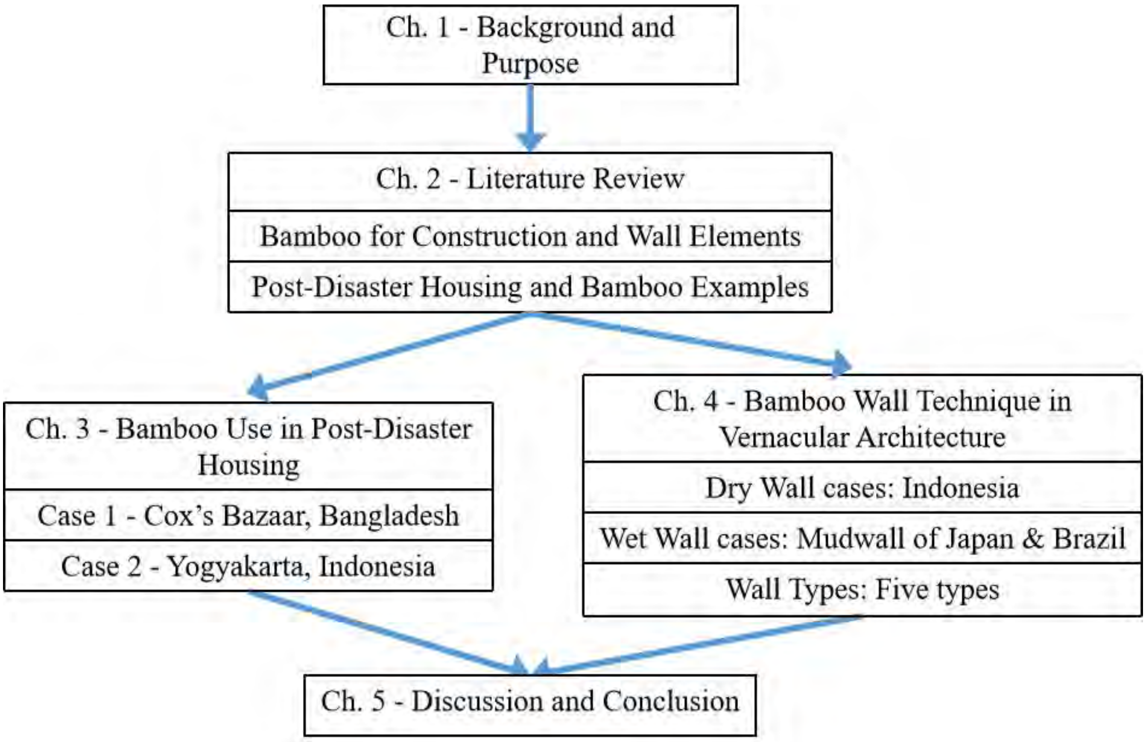



Figure 1. 3 Structure of The Master's Thesis

# Chapter 2 Literature Review

This chapter present findings from relevant literature on the extent of bamboo use for construction worldwide, its beneficial value and limiting characters of the material, then general development and technical definition regarding its use for wall construction.This chapter reviewed that some limit of bamboo material are potentially solved in vernacular architecture, particularly through use of wall technique. The aspect of life-span is seen as related with prevalent use of bamboo for temporary as well as for more permanent. As the characters factoring to utilization of bamboo material for wall in context of vernacular architecture, it then will be examined for the other extensive use of material for purpose of post-disaster housing. Considering widespread and diversity of available techniques, among the method established in this study is through reviewing past classifications of bamboo wall and proposing one. Using the classification to examine vernacular architecture and post-disaster housing case studies, it sought to extract potentials from the former towards the latter particularly concerning the life-span and other aspects identified from review on post-disaster case of Yogyakarta.

## 2.1 Bamboo as Construction Material

### 2.1.1 Introduction

Use of bamboo for construction material is extensive, with its use for simple housing still continuously prevalent. In more than 50 countries, bamboo has been used as building material traditionally. It was suggested that around the world, billions of people reside in bamboo homes (Liu et al, 2019). First example, in Bangladesh more than 70% of the homes temporarily construct their walls and roofs out of unprocessed bamboo culms (Zea Escamilla et al., 2019). The Indian Census data of 2012 found that 9% of the population live in home with wall of grass, thatch or bamboo (Dash & Gupta, 2014).

For Indonesia, of the 1250 species of bamboo in the world, 11% are native to the country. As a result, bamboo is an ubiquitous material as well as because it grows fast and in quantity, making it affordable and interchangeable for common usage by low-income populations (Larasati, 1999).

For Japan, the houses have traditionally been made from a mixture of wood, mud, bamboo, grass and paper with bamboo use in Kyoto dates far back to the Heian period around 8th-12th centuries (Tanaka et al., 1996). Long-standing practices include the usage of bamboo-reinforced structures most commonly for earthen wall base or substrate materials in form of bamboo grid, called *takekomai* for traditional wooden buildings. In addition, bamboo grid was also common used for reinforcing bars of bamboo-reinforced concrete during World War II due to a scarcity of steel, often only recently rediscovered in old buildings during demolition, works according numerous research (Terai, 2022).

### 2.1.2 Beneficial Values of Bamboo as Construction Material

Some more general characteristic of bamboo for instance are the short cycle time needed to sustainably grow bamboo and its strength compared to its weight (Vengala et al., 2008). The strength suggested to come from bamboo cell structures and technical properties which resembles wood, although it belong to the grass family of Gramineae (Dwinita, 1999).

Other notable characteristic of bamboo is it lightness as the result of its hollow form (figure 2.1) which also make it easy to handle, process, and transport with minimum effort. Coupled with its malleable character, it is simple to strip them into long horizontal strips (Dash & Gupta, 2014). Such lightly modified bamboo often only require low skill and low technology thus allows easy localization (Opoku et al., 2016; Sanchez-Morales, 2011). General benefit of bamboo material has been summarized in five perspective of large-scale (fast growth), lightweight and high strength, low-cost, environmentally friendly, and social benefits (Shen et. al, 2019). Such potentials of bamboo allow reliance on local resources not only the natural resource but also intellectual and social resource, supporting the potential of In-Situ Resource Utilization (ISRU).

While most pole of bamboo species which are used for timber is long and often not straight, it is portable and easy to transport due to its light weight and ease of processing. Like other cultivated building material such as wood, bamboo could be cut into shorter length while also comparably easier to divide or split. The split form is arguably one most important processed type in order to use bamboo for wall. Result of further processing from such splits include woven bamboo and modern laminated board. After processing the bamboo culm, it becomes easier to store and transport effectively.

Due to multiple benefits, various bamboo species has been used in Asian countries. Bamboo was once the material most commonly used to build entire dwellings in China (Shen, 2019; Stamatis, 2021). It was before bamboo was substituted, for instance with ceramic tile for roof, still in similar semi-cylindrical forms. Among the bamboo species suggested to be used for construction in China are *Phyllostachys edulis*, locally called "Moso" or "Mao Zhu" and *Bambusa Oldhamii.*

In Bangladesh, Bambusa balcooa *(Borak)* and *Melocanna bambusoides* (Muli) are among the various local species used for post-disaster housing in Cox's Bazaar, further examined in chapter 3. Other local species also used, such as *Nali, Ora, Khag* and *Talla.* For other examples in the Philippines, among bamboo species which are used for construction are *Bambusa blumeana, Bambusa vulgaris* and *dendrocalamus asper,* (Salzer et al., 2018).

Past research on bamboo use for construction and post-disaster housing often left out the type of bamboo species used, even though many characteristic of bamboo material are specific to its species. Among bamboo species used in Indonesia, the most commonly used for construction are the sympodial or 'clumping' type such as *Dendrocalamus Asper* and *Gigantochloa Apus*. Both has thick culm wall, with the former has among the largest culm diameter, sometimes more than 20 cm.
For species common in Japan, Moso bamboo could also reach large culm diameter, while having different rhizome structure which is *monopodial* or 'running' type that spread more easily. Other notable and much

used species in Japan is the *Phyllostachys bambusoides* or Madake. Like other running type, it has characteristically straight culm which often lend it ornamental value for its use in gardens as well as construction. Compared to Moso, the culm wall of Madake is thinner and arguably used more often for craft and construction, while Moso often cultivated for its edible shoots.

Despite different character particularly the thickness of the culm wall, splitting the bamboo culm has been common for all species mentioned above.

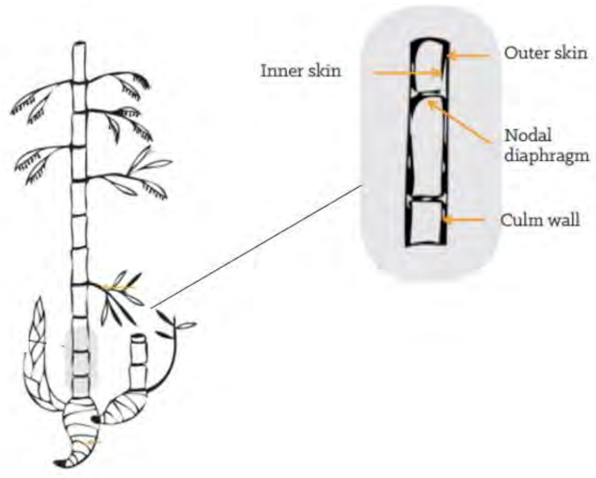



Figure 2. 1 Terminology for Parts of Bamboo Culm
(source: Humanitarian Bamboo Project (modified)

**2.2 Temporary and Permanent Life-span of Bamboo Construction**

While various benefits are factoring to extensive use of bamboo for construction, particularly for temporary construction, material limitations has hindered wider adoption of bamboo, there is always inherent limitations of the material related with its natural properties and biological imperfections (Hebel & Heisel, 2017), as well as variability in its geometric and mechanical properties (Ramage et.al, 2015).

Various past research also concern with durability as one main limitation of bamboo material, (Kaminski, 2013; Kewei et al., 2022) and prime obstacle preventing bamboo from being used in the construction industry (Shen et al., 2019). This need to be addressed if bamboo is to be used not only for temporary purpose. Seen from sustainability and as vernacular principle, the material durability also connected with the matter of life-span of building and building elements (Guillaud et.al, 2014).

**2.2.1 Temporary Bamboo Construction**

Many housing experts viewed bamboo as material with limited life-span best suited only for temporary construction (Sattar, 1996). Due to its typically thin walls and absence of natural toxins, bamboo has virtually no natural resistance, with even a tiny quantity of decay can result in a considerable loss of strength capacity (Jansen, 2000). Due to their low natural durability, difficulty in jointing, lack of structural design information, and absence from building codes, bamboo has been seen to be primarily used for temporary constructions and lower-grade buildings (D.L. Jayanetti & Follet, 2008). In case of building code in Indonesia, construction with natural material such as bamboo and timber often considered lesser than permanent (Pribadi et al., 2014). Even in various large bamboo structures in Lombok Indonesia (figure 2.3), what has been usually assessed for building code is the concrete parts, not the bamboo structure (R. Hartono, personal communication, 2021).

Temporary construction has been more widely accepted as common use for bamboo material. Such short term use is possible where durability is not required, and has been the associated where bamboo is ubiquitous, and it is used within low added value and non-processed (Zea Escamilla et al., 2019). Extensive use of bamboo for post-disaster housing has been predominantly for temporary or transitional shelter, among which are the post-disaster housing in Ecuador (Figure 2.2), Cox's bazaar, Bangladesh and Yogyakarta, Indonesia, last two cases will be examined on Chapter 3.

Figure 2. 2 Temporary Bamboo Shelter in Ecuador, designed by Shigeru Ban using flattened bamboo with diagonal arrangement for wall and structural bracing (Ban, 2021)

### 2.2.2 Permanent Bamboo Construction

Among the aspect of durability, it has been suggested that bamboo use has enabled a workable lifespan of more than 20 years (Shen et al., 2019). One example of 50-year design life for bamboo has also been suggested, achieved in engineered *bahareque* housing, making it a permanent type of housing (Kaminski et al., 2016).

Significant development of bamboo material for permanent purpose often linked to its structural role. While still considered a hybrid construction, it has fewer degree of other material mostly helping the structural role, such as concrete for foundation or steel connections. Such use for permanent structure are relatively new possibility owing to ever expanding research on engineered bamboo structure and advent of scientific preservation method. This new modern use of bamboo will be better explained through case study introducing existing practice with information form literature as well as author's experience in such projects mainly in Lombok Island Indonesia, in addition to neighboring island of Bali where many of the technique and skilled workers came from.

### 2.2.3 Case Study 1: Permanent Bamboo Development in Indonesia: Bali and Lombok Island


Figure 2. 3 Bali Island, Indonesia

Figure 2. 4 House in Panglipuran Village, Bali. Bamboo is used for wall and roof

Before the tourism boom, Balinese was considered an agricultural society benefited much from natural resource including cultivated materials. Cultivated in secondary production forest, including people's backyard or 'teba', bamboo material has been used in vernacular Balinese architecture in addition for daily necessities. Particularly in houses of Bali-aga ethnicity such as in Panglipuran village, bamboo still used intensively for wall, roof structure and roof shingle.

In autonomous village (banjar) which is still a prevalent social organization today, bamboo is still used extensively for temporary use, especially for village scale socio-religious ceremonies. Many of which has became opportunity for villagers to learn construction skills using bamboo. Among the village is Belega village in Gianyar Regency, well know for the skilled bamboo construction workers, not only for traditional temporary structure but also long-lasting and emblematic designs of contemporary bamboo architecture, including projects in neighboring island of Lombok.

Benefited from tourism development of Bali and subsequently Lombok, many of such project provide learning opportunity for local worker as well as became a test-bed for modern bamboo developments. Design of various innovative form has resulted in emblematic architecture but the basic is still related with durability of material.

Among the development are durability by design and incorporation of chemically preserved bamboo, with formula which often considered as company's secret. Both developments have allowed to extend the life-span of bamboo structure to more than twenty years, such as the case for Heart of Green School building. For durability by design, among the lesson is the role of protective roof eaves. Ranging from 80 cm at minimum to 150 cm, it reduces sunlight and rain exposure. Learning from many past cases in Bali, the damage on bamboo elements might indicate inadequate protection by the roof, particularly from windward direction during heavier rains.

Figure 2. 5 Large bamboo roof structure built by workers from Belega village, Bali.

Figure 2. 6 Protective roof protecting large structure mainly consist of *Dendrocalamus Asper*

Figure 2. 7 Workers from Belega village, Bali

Figure 2. 8 Preservation through soaking

The use of advanced engineered structure allows innovative design and has contributed to bamboo drawing attention on a global scale (Sattar, 1996) (Martens, 2019). Otherwise, full-culm bamboo architecture is not very common world-wide (Ramage et al., 2015) particularly in documented vernacular cases. However, as it has been experienced in Lombok, it often translates to high construction cost. Thus such structure might be observed more often among two of five kinds of bamboo architecture (Trujillo et al., 2013) which is luxury housing and long-span building (many also caters to luxury lifestyle). Often part of the design brief, another perceived luxury of such projects can afford is to employ architectural open plan which often eliminate the needs for wall.

### 2.2.4 Lesson From Permanent Bamboo Construction on Durability

Separating the temporary and permanent bamboo construction is the extents of its durability. To many contemporary bamboo architecture shown by the examples in Bali and Lombok Island, durability by design is one basic principle of bamboo construction, particularly owing to various principles vernacular construction.

For using bamboo beyond temporary, one important rule of thumb is 'good hats and good boots', which is still considered relevant and often used in conjunction to various preservation method. Basically, even the use of such improved element not common in vernacular setting still require a protection from the sun and rain provided by 'hat' namely a roof eaves. It is highly advised for bamboo elements not to contact the ground directly, again avoiding water as well as insects from the ground such as termite and powder post beetle (*Lyctinae* sp) as main cause of bamboo deterioration.

Beyond structural use, such principles also important for use of non-structural bamboo such as for wall. Various wall technique has been practiced for long time in vernacular setting, most of which could not rely on chemical use for extending its durability. Many record shows surprising durability of untreated bamboo for wall construction. For instance the strips inside wall using vernacular Indian technique were still in fine shape after forty years and had not been attacked by termites (Dash & Gupta, 2014).

Figure 2. 9 Himeji Castle with white plastered Ohkabe with bamboo grid

Wall technique with bamboo has been used in Japan for various buildings, particularly castles such as Himeji or Nagoya castle. Round bamboo (full-culm) substrate has been used for its plastered *Ohkabe* (big wall) technique. Dating from before Edo period, such buildings arguably symbolize the feudal era, comparable to stone fortress in Western countries, both invoke image of stability and power. Most cases in the following Chapter 4 also display use of bamboo material beyond temporary purpose.

### 2.2.5 Permanent Bamboo Wall Construction in Indonesia

Despite its temporary status in Indonesian building code, use of bamboo in permanent construction has been seen for its potential, based on past development and implementation. While plaster on woven or flattened bamboo is common in Latin American case, Indonesia examples exhibited a potential alternative which used other techniques which also resulted in long life span.

Figure 2. 10 House in Gempol, during demolition (source: Tan Tik Lam)

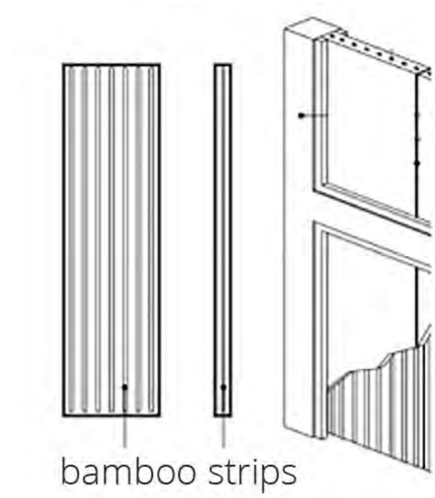



Figure 2. 11 Drawing of panel which was used for house wall in Gempol. showing vertical bamboo lath casted inside concrete (modified from Widyowijatnoko, 2006)

During the Dutch colonial era, most commonly used indigenous technique of woven bamboo wall has been the target of replacement (Ignasia, 2008; Armand et al., 2015) especially during improvement program of *kampung kota* (Indonesian type of urban settlements). Nevertheless alternative use of bamboo has been promoted to some extent by the Dutch administration, in form of bamboo-reinforced concrete for infill panel in timber framed structure (Figure 2.5). Located near proposed government center of the Dutch East-Indies and built before the Second World-War, the housing project of Kleinwoningbouw Gempol or Gempol in the

City of Bandung is still inhabited by 2023. Some houses has retained its original structure including the bamboo reinforced panel. Initially reserved to marginalized native workers, it is in much humble scale than thick walled brick houses inhabited by the Dutch ruling class. Nevertheless, the house provide an alternative case of bamboo use in early modern architecture. Although never adapted to larger extent, such type of wall using bamboo for wall of permanent house has seen recent development (Widyowijatnoko, 2008).

Different use of bamboo for permanent house in Indonesia has also been tried in 1982, using bamboo grid type which was plastered with cement mortar. Compared to the Gempol case above, the wall of trial house in the village of Panglipuran, Bali is mostly constructed in-situ.  The thin wall of seven centimeters, suggested to use common plastering method possible to do by non-professionals. Combining bamboo with cement plaster, the wall construction required form-work of wood board, dismantled after plastering process. Among of its benefit is long life-span, as a study assessed that the building has stood for more than thirty years (Muliawan, 2014).

### 2.3 The Wall: Bamboo Use for The Vernacular Architecture Element

While traditional bamboo structure utilizing full-culm was was not as durable compared to new structure treated with new preservation method, traditional bamboo use for structure include wall such as the *quincha* or *taipa* which can act as bearing wall. Particularly, in type called *bahareque encementado* on which the rigidity of the structural structure is provided by the cladding or plaster, such as that made of mud or loam (Trujillo et al., 2013).

Despite considered as interrupted tradition considering its pre-colonial origin (Stamatis, 2021), many research has studied the Latin American bamboo walls. Such hybrid bamboo wall types go so far as being adopted in national building code. Such technology also has been proposed for transfer into Asian countries (Vries, 2002; Tanuwidjaja et al., 2014; Auman et al., 2018). The Latin American bamboo wall might be more well known than its hybrid counter-part in Asia, where it was once a mainstream technique for non-structural role in Japan or India for instance and considered as uninterpreted tradition of construction.

One common but overlooked role of bamboo for construction is for non-structural role. In various vernacular cases,  bamboo used through hybrid technique supported by  timber for structure or covered by mud plaster, both are examples of relatively long-lasting material before modern material becoming available, even more so compared to bamboo. Such techniques are common in vernacular architecture around the world, among past research has studied the hybrid technique of bamboo with plaster in vernacular setting  (Jayanetti & Follett, 2008; Escamilla et al., 2019; Dash & Gupta, 2014; Lisboa & Librelotto, 2018).

Non-structural use of bamboo has been observed in Indonesia and Japan, in addition to India (Dash & Gupta, 2014). Use of non-structural bamboo wall can be found in Asian countries for comparatively different role than the Latin American case mentioned earlier. For wall which use bamboo for non-structural role, two main parts of the wall are the structural frames and so called infill between framing member, which functions are to protect against elements, for privacy, structural function, as well as related to comfort allowing light and ventilation (Jayanetti & Follett, 2008).

Luxury projects such as the case in Lombok often could afford to use open plan without any walls. However, wall function for environmental filter can be seen as more fundamental in simple shelters and most extensive role of bamboo as construction material is for building elements of wall and partition (Jayanetti & Follett (2008). Arguably such non-structural role has been brought from past tradition and still being used.

### 2.3.1 Dry and Wet (Wattle and Daub) Wall Technique of Bamboo Construction

Drawing from long continuous tradition of bamboo use for wall elements, there have been various research, proposal and implementation of wall system. One example was used in post-disaster context of Yogyakarta examined in next chapter, other examples derived from traditional bamboo wall are prefabricated mud wall (Komatsu et al, 2008) or new mud-wall '*tsuchikabe'* design (Uno, 2019) inspired by Japan tradition. Following two basic type of bamboo wall, the former is dry wall type while the latter considered as wet wall.

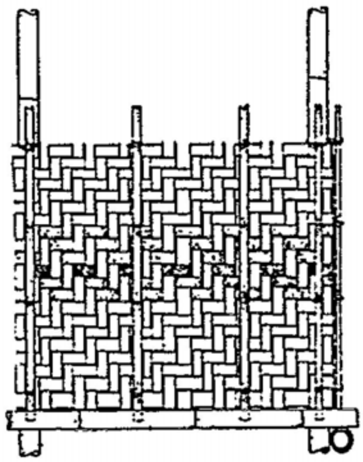


Figure 2. 12 Light weight Indonesian woven bamboo 'kepang for dry-wall (source:Stulz & Mukerji,1993)

Figure 2. 13 Light weight Indonesian woven bamboo 'bilik' for dry-wall carried by back peddler (source:tribunnews.com)

For homogeneous wall where bamboo is used with few other material, it has been considered as **'Dry' wall** (Jagadeesh & Ganapathy, 1996). In addition to dry wall of bamboo, significant number of research also develop and support hybrid use for structural as well as non-structural use which is the focus of this research. Some proposal use bamboo with plaster of other material within **wet wall technique**, often called 'wattle and daub' technique, which is considered as part of "thrown loam techniques". Such technique are suggested to be older than rammed earth and earth block techniques, have been utilized in every tropical, subtropical, and temperate climate in the world (Minke, 2006).

The daub is one terminology of earth when it is utilized as a building material. It is a mixture of clay, silt (extremely fine sand), sand, and sporadic bigger particles like gravel or stones, and is referred with scientific terms of loam (Minke, 2006). Meanwhile, wattle describe woven structure could be timber as well as bamboo, with split bamboo or lath interlaced with each other. Applied on this substrate element of wattle, is the element of 'daub' which produce less permeable wall. Otherwise when done without the daub, the interlaced element allow permeable wall, often desired in the tropics.

Covering bamboo mesh with mud has been a very popular practice from almost every part of the world (Vengala & Rao, 2020) particularly in Japan (Yokobayashi & Sato, 2015; Uno, 2019; Hijioka et al, 2013). While the practice might not be common in case of Indonesia, some case of traditional bamboo wall used plaster from lime mix or cow dung (Auman et al., 2018). Additionally, Indonesian use of mud can be observed, for instance as *pol-polan* wall in Bali (Figure 2.14).

Figure 2. 14 'Pol-polan' mud wall in Bali

Figure 2. 15 Earth wall plastered with cement plaster to cover damage in Lombok. The damage occurred despite covered by large bamboo roof

Widyowijatnoko, one Indonesian bamboo expert also argue that such wet wall type where bamboo is plastered could achieve image of permanent house in Indonesia. He also published several proposal such as pre-fabricated concrete panel with bamboo reinforcement (Widyowijatnoko, 2008) as well as proposal reusing temporary shelter into more permanent bamboo wall (by plastering).

Some of the proposal concerned with improving the durability of bamboo. For instance, through engineered *bahareque* wall used in durable form of housing, it was suggested to achieve a 50-year design life through good design and protection from fire (Kaminski et al., 2016). Easy to paint mud & cement bamboo wall also was used as respond to Haitian communities input who wanted solid looking wall for security (Architectural Association, 2016). Other proposal successfully carried technology transfer of durable bamboo wall solution from India to Ghana with life span before renovation reaching thirteen years (Paudel, 2016).

Another development on wet wall during the last century saw that mud plaster was sometime abandoned in favor of cement mortar plaster, along the preference of plastering of bamboo to make them look like concrete (Jansen, 2000). In engineered *bahareque* technique, a mixture of mud and horse dung or *cagajón* also replaced by portland cement (Vengala & Rao, 2020). Nevertheless, such engineered bahareque still potentially emit only half of the embodied carbon when compared with masonry wall (INBAR, 2016). Use of concrete plaster on bamboo (bamcrete) in contemporary concrete-framed structures was also suggested for sustainability and benefit for local economy (Dash & Gupta, 2014). Introducing wet wall type in Bali Indonesia, bamboo grid similar with Japanese wattle (Takekomai) were plastered with cement mortar (Muliawan, 2014). Alternatively, mix of cement and mud plaster also used, such as the 'Geo-beton' in Ivory Coast (Jamin, 2019) and also observed in Lombok (Figure 2.15).

While the use of more modern concrete plaster is often understood as more practical and durable, the use of loam or mud in architecture has various merits. Loam balances heat and air humidity, saves energy and reduces environmental pollution (especially compared to burnt brick), saves material and transportation costs, it embedded and preserves timber, bamboo and other organic materials (wattle and daub), as adobes loam do not become wet or lose their stability and loam is always reusable (Minke, 2006).

The last point includes the wall within hybrid bamboo technique, where loam use with bamboo has observed to allow high degree of recycling. Examined further in the chapter 4, it has been common practice in Japan to use mud from old wall, easily recycled through re-hydration. As comparison, the use of cement plaster has disadvantage as it is harder to recycle as it is not a common practice for reuse cement or concrete from old demolished project.

Alternative technique of wet wall also benefit from protection of "good hat" from roof eaves or in some case, cladding which is often made by replaceable bamboo element. The cladding protected the mud-wall and in turns, the mud protect the bamboo wattle and elongating lifespan of such substrate element which is fundamental in supporting the integrity of whole wall system.

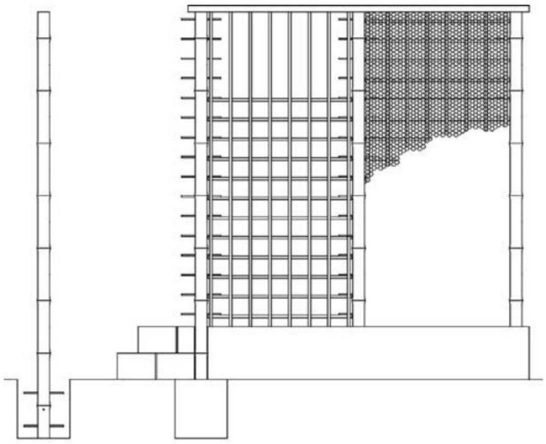



Figure 2. 16 Wet type of Bamboo Wall with Japanese wattle and daub 'tsuchikabe' technique (Source: Yao)

Figure 2. 17 Use of bamboo grid for plaster in India Jayanetti & Follett, 2008

**Vernacular solution to Bamboo Material limitation**

By guaranteeing more predictable and controllable properties —eliminating the round cross-section to create standard shape and size, while maintaining the strength of bamboo's longitudinal fiber— various techniques used traditionally for bamboo wall have addressed some natural limitation of round bamboo mentioned above, such as biological imperfections, geometric variability, mechanical properties and durability.

Such solution addressing material limitation particularly done through light modification (Ramage et.al, 2015), which explain why it has been achievable with vernacular technology. Examples of light modification are done by processing round bamboo (full culm) into sheets or lath with roughly same dimension. Among the methods are through splitting, flattening , weaving, lashing, etc. Among the product of such various methods are bamboo poles (preserved and dried), flattened bamboo (*esterilla*), woven bamboo mats and strips, all of which might fall under moderately industrialized materials (Zea Escamilla et al., 2019). Such slightly transformed components has been extensively use across different region in the world and often consists the main component for bamboo wall.

## 2.4 Bamboo Material in Post-disaster Housing

**Two Approaches Related with The Design of Post-disaster Housing**

Post-disaster condition attracts attention from researcher and designers, with various designs have been proposed, one main approach is utilizing pre-fabricated shelter kits, often rely on industrial material (Figure 2.16). It could be delivered as ready made kits, providing benefits of speed and efficiency. However, it has drawn criticism because it narrows down shelter requirement to mainly protection aspect or literal function ‘to shelter’. While the former dubbed as commercial solution, the other alternative approach is ‘livelihood option’ which in principle, recognizes local skill and resource (Davis, 2006).

Figure 2. 18 Prefabricated shelter by IKEA, UNHCR, 2016

**Natural Material for Post-disaster Housing**

The alternative approach for post-disaster housing often utilizes local building material, more often from natural material (Zea Escamilla, 2018). The latter approach found supports (Pribadi et.al, 2020; Ahmed & O’Brien, 2009) as local materials had a higher potential for low environmental impact and costs (Zea Escamilla, 2018). Natural material use for post disaster housing for various countries has also been suggested (Ahmed & O'brien. 2009; Kaminski et al.,2015) including Japan’s ‘localized housing recovery’ (Maly & Iwata, 2019).

**Exceptional Bamboo Use for Post Disaster Housing**

It has been through the top-down implementation of post-disaster reconstruction, that bamboo material spread and contributed to the housing sector (Witte, 2018). Modified bamboo wall has also been used often for shelter (Kaminski et al, 2015). Extensive modern use of this non-standard building material has been confirmed when it is backed by building regulation like in Latin American countries. However, globally it can be considered as somewhat an exceptional case. Arguably there is more hesitance outside of disaster context as regulation is among barrier to use bamboo material (Shen, 2019). It has been continued to be considered as temporary material, including on Indonesian building codes (Pribadi et al., 2014).

**Proposal of Post-disaster housing Using Bamboo**

Among various development, proposing bamboo use for post-disaster housing in Indonesia, some are using bamboo for structural frame with infill wall of plait work type of woven bamboo (type 3A) (Suriansyah, 2014; Utomo et al.,2020; Dawydzik, 2021; Indrianeu, 2017; Fajrin et al.,2021). Example of nature based solution, bamboo material seen to have excellent potential as a housing system for mass housing, disaster-prone areas, and earthquake resistance (Vengala et al., 2008). Bamboo-reinforced concrete, has been proposed to contribute to earthquake-resistant buildings in Indonesia (Ditjen Cipta-karya, 2006) as well as wider Southeast Asia (Terai, 2011).

Different ways of using bamboo for post-disaster can bee seen in example from Afghanistan and Philippines. The shelter in Afghanistan (Figure 2.17) was built using bamboo culm structure as frames which are connected using plywood gusset plates and bolts. Sections of the structures were prefabricated by local carpenters in a warehouse tent within the camp. They were then passed to beneficiary assembly teams. Its use for temporary shelter was possible through fast-construction with semi-skilled labour. The design is also notable as it allowed upgraded protection for winter. It was further adopted for Pakistan after flooding in 2010. In the Philippines (Figure 2.18), the use of bamboo with timber frame for housing after cyclone Washi allowed a low-cost and light-weight shelter. It can be carried by 20 persons or easily dismantled. In addition, the design also intended to be flexibly adjusted by its inhabitant and upgraded to permanent house.

Figure 2. 19 temporary bamboo shelter in Afghanistan (source: Shelter Project 2009-2010)

Figure 2. 20 Transitional bamboo shelter in the Philippines (source: Shelter Project 2011-2012)

**2.3 Lesson on Bamboo Use for Post--Disaster Housing**

Benefits of using bamboo in post-disaster context has been reviewed from literature focusing on case of 2006 earthquake in Yogyakarta, Indonesia,  to explore how bamboo material has several value in post-disaster context.

The values of bamboo reviewed in the Yogyakarta could be seen as example of its characteristic of easy localization. Particularly the use of locally abundant and available material utilized using simple construction technique, able to involve beneficiary through self-build. Related with local character and cultural reasons, various stake-holders favored the material and saw it with affinity. Arguably, such localization and the aspect of availability also result in evidently low-cost of the housing and positive evaluation on its environmental impact (Table 2.1).

Table 2. 1 Value of Bamboo Use for Shelter in Yogyakarta Reconstruction 2006

| **Values of Bamboo Material** | **Consideration** | **Reference** |
|---|---|---|
| Availability | Availability of bamboo allow large scale use of bamboo material for construction with 180,000 units house. | Java Reconstruction Fund, 2011. Ikaputra, 2006 |
| Self-build | Around 60.000 locals had been trained in building bamboo shelter and 12.500 families had built it.<br>Such participatory construction said to be effective in mass-housing | Shelter Projects. 2009. |
| Low-cost | • Yogyakarta bamboo has been evaluated and found to be low-cost.<br>• The average T-Shelter in Jogjakarta cost USD 200–250 | Zea Escamilla, 2018<br>Macrae & Hodgkin, 2011 |
| Low environmental impact | inclusion of locally sourced local material, Yogyakarta bamboo shelter has shelter has been evaluated and found to be low impact | Zea Escamilla, 2018 |
| Life-span | Around 12.500 families had built such houses, and inhabit them from around 5 to 7 years. | Indonesian Red Cross (PMI, 2011) |
| Affinity | • Widespread use of bamboo also for cultural and environmental reasons , advocated by aid workers, local engineers architects and even the Sultan (region's monarch).<br>• Psychologically the structures provided a feeling of a safer structure than houses constructed out of concrete. | Macrae & Hodgkin, 2011<br>Java Reconstruction Fund, 2011 |

Knowledge on traditional building has been advised for post-disaster housing (UNDRO, 1982) taking into account the local skill and resource (Davis, 2006). It might be explained by one practical merits of vernacular techniques which contribute to better shelter: the techniques are more easily understood by local owners and builders, as it is based on empirical process founded on observation and experience, as opposed to complex scientific processes and theoretical analysis such as is modern materials (eg. reinforced concrete) (Langenbach, 2016). For the reinforced concrete, safe use would require communities to implement suitable seismic technology and efficient ways to distribute technical knowledge (Narafu, 2010), something which has been most challenging.

Such easier dissemination contribute to potential of owner driven construction, onward termed as 'self-build'. Together with use of cultivated material sourced locally such as bamboo it allow easy localization as one main character or vernacular architecture. Secondly, case studies on the fourth chapter illustrate the extended life-span of bamboo building elements within vernaculars technique.

Examples above illustrate potential of vernacular technique, on the aspect of self-build and extended life-time, also found on from literature review on bamboo and its use in post-disaster housing. Both aspects are suggested to be among the main principles of vernacular architecture (Guillaud et al., 2014) and both are also need to be considered for post-disaster shelter based on literature review and cases in the chapter 3.

### 2.4 Research methodology

During part of the research, the author experienced a three months internship on bamboo design company in Lombok Island, Indonesia, providing opportunity to saw the use of bamboo material within hybrid of modern and traditional technique. In addition, the use of mud material using rammed earth technique was also observed, often used in same project with bamboo. Experience in Lombok and other part of Indonesia also provided chance to examine use of bamboo in four traditional villages, in Island of Lombok, Bali, and Java with semi-structured interview in two villages in Lombok and West Java, used in chapter 4 for main case of basic type of dry bamboo wall.

In choosing the cases of bamboo wall in Japan, main consideration is the extensive but often overlooked use of the other basic type of wet bamboo wall, within hybrid method with mud plaster but different with the one observed in Lombok. In addition, the Japanese wall technique has also been found to be adapted in Yogyakarta and was more extensively adapted in Brazil, whose practice examined through interview.

The main reason of choosing post-disaster case study in Yogyakarta and Bangladesh, is the uncommonly large scale of bamboo implementation. Quantitative analysis has been possible using data on 2015 survey in Yogyakarta. The analysis provide important insight on use of bamboo beyond temporary. To analyze the use of bamboo wall in Bangladesh, literature review and online questionnaire with shelter practitioner have also been done.

Seen from literature review, post-disaster housing requirement and factors of bamboo use in post-disaster has been gathered, encompassing the bamboo material values of availability, self-build, life-span, cost, environmental-impact and affinity. Literature on bamboo material and vernacular architecture provides main method on classifying the types of bamboo wall, which then will be analyzed seen from the bamboo material values.

#### 2.4.1 Research Design

To clarify the potentials of bamboo material for post-disaster housing in Indonesia, it is hypothesized that the extensive use of the resource in vernacular architecture provides practical lessons, considering similar requirements of the two:

1. Need for extended life-span
2. Easy localization through self-build and available material

Both are considered principle of vernacular architecture and suggested for post-disaster housing.

Firstly, literature review are carried out regarding bamboo use in construction and within the material extensive use, the study established focus non-structural use of bamboo for wall and proposing a classification. Then it is followed by potential of bamboo material and its potential in post-disaster housing (PDH). As literature mostly saw short-term potential after the disaster from main case in Yogyakarta, it then compared with secondary data from survey and case study in the third chapter, including limitation.

Considering finding from PDH and how bamboo has been used for walls with lesson from each classified types, the potential of bamboo will be drawn from case studies of vernacular architecture in Indonesia and Japan.

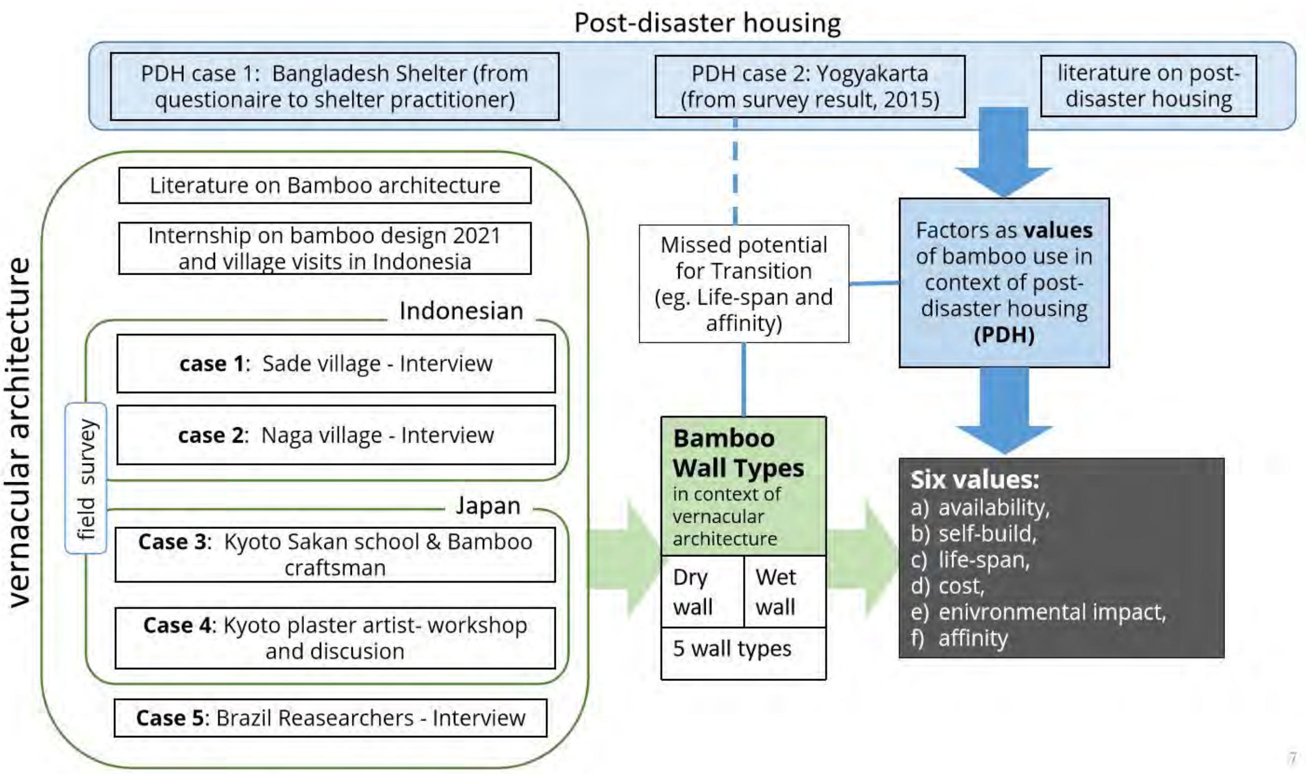



Figure 2. 21 Flow diagram of research methodology

### 2.4.2 Method to Classify Bamboo Wall

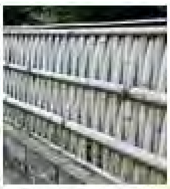
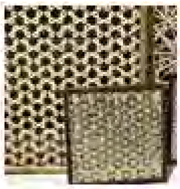
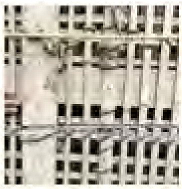
In this research, bamboo wall is acknowledged as extensive and diverse solution with a variety of species has been used for equally diverse wall types. Limited species common for construction in Japan for instance, still result in numerous bamboo wall and fence techniques. Such diversity of species and constructive traditions with complex technique, might explain why there is still limited studies on bamboo wall if compared to structural use of bamboo. Despite this, general reading of bamboo walls had been attempted, based on past studies (table 2.1). For instance, by categorizing of infill as separate from main structural frame (Jagadeesh & Ganapathy, 1996), by categorizing moderately industrialization bamboo materials form which was deemed most used for walls (Escamilla et al., 2019) or according to the processed form of the bamboo culm. (D.L. Jayanetti & P.R. Follett, 2008). Following the definition of the processed form, this study will consider bamboo wall into initial four types: rounded, flattened, woven and grid.

In architecture, the term weaving has been used by Gotfried Semper for every building works above the foundation. For bamboo, most common use of bamboo for daily life is through weaving it into various shapes and purposes. Considering this extensive use also applicable for wall, either through direct use (homogeneous) or as a base for plaster, the woven type (**type 3**) will be divided into two type of woven wicker-work **(type 3A)** and woven-plait work **(type 3B)**. The former is loose type of wall achieved by weaving split bamboo often not thinned such as used in *Ohtsu* fence in Japan, *Sasag* wall in Indonesia and in *Bahareque* wall of Latin America. ,the latter type of plait-work has tighter weave, as it often use thinner or thinned split bamboo. This type is widely used in South East Asia including in Indonesia, with patterns such as *kepang* or *mata-wali*.

Table 2. 2 Past research and Proposed classification of Bamboo Wall

| Past research | Categories | | | | | |
|---|---|---|---|---|---|---|
| Jagadeesh & Ganapathy, 1996 | ● whole culms | ● flattened and interwoven | ● half round | ● split and interwoven into mats | | |
| D.L. Jayanetti & P.R. Follett, 2008 | ● Whole or halved vertical or horizontal bamboo culms, with or without bamboo mats | ● Split or flattened bamboo, with mats and/or plaster | ● Bahareque | ● Woven bamboo, or bamboo grids, with or without plaster | ● Bamboo panels | ● wattle and daub, lath and plaster, quincha |

| | | | | | |
|---|---|---|---|---|---|
| Escamilla et al., 2019 | ● preserved and dried bamboo poles | ● flattened bamboo (e.g. esterilla) | ● strips | ● woven bamboo mats | |
| Yoshikawa, 2001 | ● Based on fence elements | ● Based on material | ● Other classification based on association with other things (e.g place or people) | | |
| Proposed Bamboo Wall Classification | Type 1<br>**Rounded** | Type 2<br>**Flattened bamboo** | Type 3<br>**A) Woven wicker-work** | **B) Woven plait-work** | Type 4<br>**Bamboo grid** |
| Notes | Whole culm or halved for vertical or horizontal arrangement | Also known as riven, used in paralel or woven | Split and woven within basket type | Split and woven into thinner bamboo mat | Main use for wet type of wattle and daub |

| | | | | |
|---|---|---|---|---|
|  |  |  |  |  |
| Modern Rounded bamboo wall, Lombok | Bamboo culm for roof and wall, Lombok | Woven wicker work-cladding, Bali | Woven plait-work wall, Lombok | Bamboo grid with cement plaster, Bali |
|  |  |  |  |  |
| Rounded bamboo wall, (Tokusa), Kyoto | Rounded bamboo wall, (Hishigi-gaki), Kyoto | Woven wicker work-(Ohtsu-gaki), Kyoto | Woven plait-work (for ceiliong use) Kyoto | Bamboo grid for mud plaster of tsuchikabe, Kyoto |

Notes:
Considering basic type, the above wall type will also seen from two basic type of wall (section 2.1.4): Regarding the use of main component and how common its use compositely with other material through wet wall techniques.

Figure 2. 22 Photographic series on five types of bamboo wall in Indonesia (above) and Japan (below) (Source: Author. Muliawan, 2014 (top right))

### 2.5 Research Limitation

The study design is an exploratory and descriptive type, with focus on wall techniques and the potential for post-disaster housing. Most techniques are from selected case of vernacular architecture in Indonesia and Japan. The quality of the research could be improved by larger sample, considering bamboo wall use around the world. However, the constraint of case selection is due to time limits (within Master's program and extra-ordinary circumstances of the Pandemic). Considering the exploratory type, the result and recommendation of this study should be considered as preliminary. Nevertheless, the awareness of this limitation should not invalidate the evaluations but instead it emphasizes the need to expand the methodological approach.

For the bamboo wall technique in Indonesia, only the design product can be observed, not the work process nor the use of tools, which can not be documented directly beyond secondary sources. For the post-disaster use of bamboo in Yogyakarta case study, it has been challenging to find bamboo use in post-disaster housing long after disaster, thus data need to be supplemented by from secondary data of past survey not by author.

# Chapter 3 Bamboo Use in Post-Disaster Housing

This chapter clarifies the past role of bamboo for post disaster housing (PDH). It starts by introducing phase and common requirements of post-disaster housing while building upon reviewed approaches and potentials of bamboo construction from previous chapter. For temporary shelter phase, case study of bamboo shelter in Cox's Bazaar is examined while another case of Yogyakarta represent transitional use. Not only various limitations, various potentials are also found from past practices and recommendations, to further examines bamboo wall techniques.

## 3.1 Post-disaster Housing: Phases and Need for Transition

### 3.1.1. Introduction

High difficulties of shelter provision (Opdyke et al., 2020) might be explained by already multiple requirements of suitable housing, with variety of functions. Recognizing all of the function of housing beyond physical protection together with participation of community for opportunity to use vernacular skill and knowledge has been advised in order to reconstruct built environment which is meaningful and rooted in tradition and place (Davis, 2006).

However, adding to the complexity in emergency circumstances are specific requirements of each shelter phase, often with overlapping definitions and need (Figure 3.1) particularly for temporary and transitional shelter. Between temporary and durable housing is the transitional shelter (Sphere, 2018) which is often complex in the way it refers sheltering process which restores normal way of living.

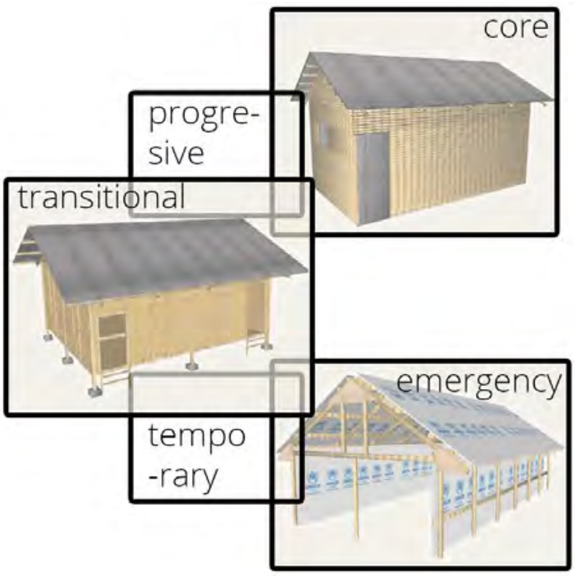



Figure 3. 1 Overlapping definition of shelter phases (source: UNHCR, 2016; modified from SPHERE, 2018)

There are various phases of shelter provision after disaster and differing view regarding it. Commonly it has been distinguished by duration of occupancy and permanence or stability of the structure. It consists of emergency shelters, temporary shelters, temporary housing, and permanent housing (Cole, 2003; Quarantelli, 1995). Starting from temporary housing, the difference between housing and shelter is that the former is more long term and may also become permanent it is decided by the disaster victims to continue to occupy the unit.

### 3.1.2. Post-disaster Housing Phases and Transition from Temporary into Permanent

As part of the post-disaster rehabilitation effort, temporary housing is a term used to describe structures which is used to house people in the aftermath of a disaster until they could be relocated to permanent housing. Such temporal limitation generally criticized for using up resource needed for permanent reconstruction (Johnson, 2007). Its cost effectiveness depend on its lifespan (UNDRO, 1982) which also relate to its environmental impact, as temporary use tend to produce increased emission (Seike et.al, 2019). Temporary dwelling found to be not preferred especially if located far from the original house (Davis, 2006). On the other hand it is often times necessary and end up permanent (Askar et.el, 2019) with instances of victims used temporary housing for extended period of time (Seike et.al, 2019; Kaminski, 2018).

Improvement to limitations and concern against purely temporary solutions is the Transitional Shelters (T-Shelter). The concept of Transitional Shelter Approach (TSA) has been introduced by The Shelter Centre to the United Nations High Commissioner for Refugees(UNHCR) following the Indian Ocean tsunami in December 2004 (Shelter Centre, 2012). T-shelter breaches the division between emergency, temporary, and permanent shelter, and it is suggested to link relief, rehabilitation and development (UNHCR 2022). It has also been defined by considering materials and its possibility for upgrade, re-used or relocated. When defined by its role, it bridge the interim period between being forced to leave home and achieving a durable shelter solution (Sphere, 2018) particularly through facilitating transition process (IFRC, 2011).

### 3.1.3 Requirements of Transitional Shelter

When seen as a construction (building) and a construction process, transitional shelter possess some requirements which are advocated by guidelines from UNHCR, IFRC, SPHERE, in addition to various past research. Focusing on the role of construction material for addressing the transitional shelter requirements, it will be analyzed how several value afforded by bamboo material construction could correspond to requirements of transitional shelter has been summarized for this study (table 3.1).

**Availability & Cost**

Reality in the field often saw reduced cost (project and material) for post-disaster housing, thus it requires wise use of locally available material which often more available and affordable. More than cost, availability also take into account local skill and resource, in a way corresponding to 'livelihood' approach of sheltering (Davis, 2006).

**Life-Span**

Beyond temporary solution, sheltering process should also take long term perspective, considering the life-span of the shelter as possible permanent house or the better, a home. With this requirement of transitioning it to be more durable, toward permanent structures and also community (Kennedy et. Al, 2008; Barakat, 2003) with also need for better connecting path toward durable solution (Kennedy et. Al, 2008). Temporary solution often used longer than intended, thus durability is advised even in temporary shelter (Kaminski, 2018; Ban et.al, 2009). Considering this, transition should aim for improved dwelling which is more durable, sustainable, and likable (Sanderson et al, 2012). Among useful strategies for transitioning are by improving durability, adaptability (Sanderson et al., 2012; Kennedy et. al, 2008) and flexibility (Ashmore et al., 2003; Davis, Thompson, Krimgold & IFRC, 2015). Other path to transition are by being reusable, resell-able, recyclable (Félix et al, 2013). If a construction also easy to upgrade and/or reused in more permanent structure it can be considered as potential in facilitating transition

**Self-build**

Given that up to 80% of people who require shelter after a disaster do so without outside aid (Flinn, 2013), it is important to consider measures like self-building or auto construction as families and communities drive their own recovery (Clinton, 2006). Self-building especially supported with adequate training also supports building back better (Maynard & Batchelor, 2011), especially though improvement of safety and possibility to link this issues with livelihood (Kennedy et al, 2008).

As in any other major post-disaster situation, challenge on the logistic often relats to appropriate construction material and availability of skilled worker will always be an issue to be solved, considering the very high spike in demand of materials and skilled labour for rebuilding need. The way self building address this can also be seen through the concept of in-situ resource Utilization (ISRU). Beyond building material, the urgently needed social and intellectual resource particularly labor might be provided from inside their community. Considering local construction skill, post-disaster reconstruction has suggested to involve labor intensive construction, recognizing local potential before looking for outside reliance, beside providing marketable skill as result of self-build training (Davis, 2006). It also allow personalization by people who build and will inhabit the house.

**Environmental Impacts**

Environmental consideration is crucial considering often massive scale of post-disaster housing provision, which might cause adverse consequences locally such as depletion of resource or globally, with high carbon emission. Use of construction material for shelter with extended life-span optimizes resource use.

**Affinity**

Under affinity, the house suppose to contributes in providing safety for inhabitants, their belongings, property rights, privacy and emotional security etc. It will also better received if it is appropriate with its inhabitants normal pattern of life, cultural context and reflect their identity. In addition, lighter shelter often desired in post disaster settings, after collapse of conventional non-engineered, often made of heavier confined masonry house (Pribadi et.al, 2020; JRF, 2011).

Table 3. 1 Summary on Transitional Shelter Requirements

| **Requirement of Transitional Shelter** | | | | Relevant values of bamboo use (Summary from Table 2.1) |
|---|---|---|---|---|
| UNHCR | SPHERE | IFRC (Transitional Shelter) | supporting literature | |
| Cost | Affordable, Local | Material availability | | Availability & low-cost |
| Life-span | - | Life-span, maintenance and upgrade | Durability (Kennedy et. Al, 2008; Barakat, 2003; Sanderson et al,2012); Permanence (Dev & Das, 2020) | Life-span |
| Labor intensive (preferred to maximize employment) | - | construction skills | personalization & complexity (Dev & Das, 2020; Clinton, 2006; Flinn, 2013) | Self-build |
| Environmental consideration | - | - | (Sanderson et al,2012; Pribadi et.al, 2020; Ahmed & O'Brien, 2009) | Low environmental impact |
| cultural appropriateness, hazard risk, privacy | culture, safety, privacy | - | Identity (Dev & Das, 2020). Likeability (Sanderson et al,2012) | Affinity |

## 3.2 Bamboo Use for Post-disaster Housing

### 3.2.1 Worldwide case of Bamboo Use for Post-disaster Housing

Last chapter has reviewed literature for factors in considering bamboo material use for post-disaster housing (Table 2.1), this is considered as one overlooked role of this material in world's most disaster prone regions. The vast scale and tight time-frame often uncommon outside of emergency circumstances resulted in exceptional use of bamboo construction. While not all instance of post-disaster housing built with bamboo has been recorded, even among notable cases recorded by the UNHABITAT's Shelter-Project publication, shows bamboo use in more than thirty projects. Among which, in only two cases of disaster in Indonesia & Bangladesh, hundred of thousand house has been built using bamboo. The case in Cox's bazaar, Bangladesh and Yogyakarta, Indonesia, will be examined later in this chapter.


Figure 3. 2 Cases of countries with bamboo used for Post-disaster housing (Data source: Shelter Projects 2008-2021)

### 3.2.2 Bamboo and Other Material for Post-disaster Housing in Indonesia

Indonesian case in Yogyakarta saw use of bamboo for construction of transitional shelter, predominantly in form of Roof Structure Unit (RSU). Seen from the material use and type of bamboo wall according to classification defined in chapter 2, the RSU use woven-plait-work wall directly, in a manner of dry wall technique without plaster. Subsequent post-disaster housing in Indonesia, continue to use similar type of wall afterward such as in West-Java (2009), West Sumatra (Figure 3.4) and Lombok (2018). While both used similar wall, the later also saw cases which used different structure of timber. The wall and structure of RIKA house in Lombok (Figure 3.4), bear some similarity type with vernacular dwelling of Sasak ethnicity, such as in Sade village, further examined in Chapter 4.

Use of bamboo wall restricted to dry technique such as plait-work type, might allow some extent of reuse, extended use and transition. However, the case of RSU in Yogyakarta, has been suggested to be extremely temporary, as short as three month until the inhabitants moving out (Maly, 2013), despite its design intention for transitional shelter. Based on the case of similar woven wall (*amakan*) in Philippines, there was concern that the woven-bamboo wall panels do not offer sufficient protection against water during heavy rains and such concern suggested to results in less usage of some shelter (Shelter project, 2016).

Figure 3. 3 Bamboo wall with timber frame for post-disaster housing in West Sumatra, 2009
Source: Ochiai

Figure 3. 4 Timber and Bamboo house of RIKA , Lombok
Source: www.suarantb.com

Figure 3. 5 *Amakan* sheets (source: Shelter Project, 2016)

**Alternative to Bamboo in Yogyakarta Post-disaster Housing**

While lighter dwelling was desired after earthquake, moving away from the initial use of bamboo reconstructed house is still a tendency. For example, in Flores island Indonesia, the change post-disaster was associated with many social factor (Edwards & Doing, 1996).

Alternatively, one possible reconstruction path toward permanent house for many victim has been reverting to construction method of its previous house, most often involve conventional material such as confined masonry or reinforced concrete. Such house often have insufficient quality and safety before disaster (Ohno & Rachma, 2006; Boen, 2006) and even on some houses reconstructed post-disaster (Pribadi et al., 2014).

Ideally, use of such conventional construction should follow strict technical standard such as the case of core-house (Ikaputra, 2008). Otherwise, it is remain risky and difficult to ensure safety for heavy construction of brick and concrete. This especially difficult if it is mostly self-build by the owner, with absence of expertise and structural design. Even when done by building contractor, as past research in Yogyakarta found, low-quality materials were often chosen, risking safety for profit (Pribadi et al., 2014).

**Timber Alternative to Bamboo**

Other possibility which has been documented is the use of localized reconstruction using natural material. The architect Eko Prawoto designed timber houses in Yogyakarta which is built by local craftsman, many of whom also lost their houses because of the earthquake. The use of timber structure (Figure 3.6) is done with various non-structural wall particularly timber plank and plastered brick (Figure 3.7). Both material still saw use in main houses by 2015 and more or less could be considered permanent. On such relatively limited case, the use of timber construction in Yogyakarta after disaster fulfilled the role of emergency housing as well as able to transition to permanent, despite being considered a semi-permanent construction, like bamboo in Indonesia.

Figure 3. 6 Timber structure construction, 2006 (Source: Armand et al., 2015)

Figure 3. 7 House with timber structure and timber wall in 2015 (Source: Armand et al., 2015)

**Addressing The Issue of Affinity**

Use of brick, concrete and timber material could be assumed to be generally liked, accommodating permanent use or allows change from temporary into permanent. The same cannot be said for the usage of particular bamboo wall in Yogyakarta case. Past research has linked the aspect of affinity with aesthetic of bamboo material. Aesthetic is among the limitation for the material use and at worst, bamboo frequently dubbed as 'poor man's timber'.

Past study suggest that after disaster, western-style concrete structures were sometimes requested as being representative of 'development' and 'progress' (Kennedy et. Al, 2008). Including in Yogyakarta reconstruction, individual beneficiary prefers more cement, sand and reinforcing steel compared to woven bamboo (Macrae & Hodgkin, 2011).

As compromise for such beneficiary expectation, use of plastered bamboo wall proposed to aesthetically provide permanent looking and impervious wall, not unlike many Indonesia houses, including in Yogyakarta. Among such plastered bamboo wall which was proposed for Indonesia (Tanuwidjaja, 2014; Auman, Widyowijatnoko & Wonorahardjo, 2018) were derived from Latin American technique of bahareque, also used in the Philippines.

In addition to extensive use of woven bamboo for transtitional shelter, one proposed building was also completed in Kasongan, Yogyakarta which used hybrid technique. With wet wall type, it followed trial in Japan (Fujiwara et al., 2009). Its research and development concerned with shoddy image or perception of bamboo material, affecting its use limited to annexes and temporary buildings. One aim of the technology is to provide durability while resulting in an image of modern architecture. While not adopted widely, the building end up with fitting function (considering earthen material) as a ceramics visitor center.

### 3.2.3 Lesson from Literature on Post-disaster housing

The issue of choosing primarily temporary option for post-disaster housing has been considered disadvantageous if seen from resource, cost and sustainability. While Temporary shelter often considered neither cost-effective nor sustainable due to its limited durability, often times it might end up used longer and result in insufficient way of living.

Suggestions to use beyond temporary particularly through transition into durable solution, encompassed under the term of transitional shelter. It intends to address the insufficiency of temporary housing while also followed the 'build back- better' approach to reconstruction. This is considered to be a key point for clarifying the potential and to expand the possibilities of bamboo use for post-disaster housing. To this end, past suggestion are seen to mainly address life-span and affinity, notably using Latin American wet wall of *bahareque*.

### 3.2.3 Case Study of Bamboo Use In Post Disaster Housing

Considering overwhelming support for usingg post-disaster housing beyond temporary, it is seen as necessary to examine the past case of bamboo for transitional housing and even in temporary housing, where durability is also suggested to be relevant.

To better illustrate the phases, issues and challenges of post-disaster housing, case studies are presented on following section to covers temporary and transitional phase which use bamboo material on a large scale, sheltering tens of thousands beneficiaries.

The case study 1 examine the temporary shelter in the area of Cox's Bazaar Bangladesh. It follows temporary designation and faced various limitations, among which have been gathered from design practitioners, whose effort in the same area have been acknowledged, particularly by the Aga Kahn Award for Architecture in 2022. Many of self-build shelter also exhibited effort towards more durable dwelling.

The case study 2 in Yogyakarta, Indonesia, examines use of bamboo beyond temporary designation, precisely employing transitional approach. To do so, data on reconstruction in 2006, are first gathered from literature. Factors which supported the choice of bamboo material has been summarized in last chapter (Table 2.1), seen from its initial implementation in 2006.

While change toward permanent is the nature of any transitional design, it is still not much researched if the bamboo shelter in Yogyakarta could accommodate permanent use or fill the gap by transitioning from temporary into permanent. To clarify this, the condition of the bamboo temporary shelter in 2015 has also been examined from secondary data from survey by Dr. Chiho Ochiai.

Limitation must be admitted, as initial purpose of the survey was to examine housing change. While some change also affect the bamboo use beyond floor plan drawings, photographs are not available on majority of bamboo use and modification. Regardless, the finding from the data deemed to be representative on original use of the bamboo shelter by 2015, seen from the floor plan and dimension. While not exhaustive, it also provide examples of bamboo use after reconstruction as well as the prevalence of self-building.

### 3.2.4 Case Study 1: Bamboo Temporary Post Disaster Housing (Cox's Bazaar, Bangladesh)


Figure 3. 8 Location of Cox's Bazaar in Bangladesh (Shelter Projects, 2019)

**Introduction and Background of Shelter Provision**

The Government of Bangladesh (GoB) has outlawed the construction of permanent and semi-permanent structures in both temporary camps and refugee camps (Martin, 2017). Emergency response are mainly temporary shelter, among which is the emergency shelter kits (ESK). However, most agencies were initially only able to answer with an acute version of these items that excluded bamboo.

Despite the delayed progress toward achieving ESK targets, the bamboo demand was finally met since many refugees themselves brought back bamboo from surrounding forests or bought in marketplaces, which the refugee families self-purchased. One of the used species, bamboo Mulli (*Melocanna bambusoides*) has been considered less costly than timber for families to build their house, at only one-third of timber cost. Availability also supported with most vendor sold bamboo, instead of timber (Martin, 2017).

**Design of The House**

For the emergency response, emergency shelter kits (ESK) made of rope, bamboo, and tarpaulin are created by the shelter industry. For the follow up, shelter upgrade kit (USK) as part of second phase aims to improve living conditions, with the design included bamboo, tarps, repairs, tools, and technical support. Without guideline for typical design, the commonly used material are the full culm bamboo structure supporting bamboo split with grid arrangement for wall, covered with shelter-grade tarpaulin sheets.

**Construction worker**

There have been many builders involved in the sheltering process. Coming from Rohingya community as well as Bangladesh nationals, main contribution came from non-skilled and semi-skilled worker. It mainly utilized simple tools, occasionally supported with only light machinery. Among construction process which was stated more difficult is in making woven bamboo. To address this, alternative bamboo grid arrangement has been used for wall (Figure 3.10).

**Life-span and Consideration for Transition**

While the Bangladesh government did not allowed the shelters to be permanent, durability has been also considered an important aspect. It was one aspect criticized for the bamboo shelter in case of Cox's bazar, as life-span has been predicted as little as 3 months - 4 year, due to concern on bamboo structure's treatment & connection with the ground (Kaminski, 2018).

While extending life-span of bamboo through preservation process has been considered difficult (Kaminski, 2018), architect R suggested that treatment has been don for extending life span in some case some case using chemical process. In addition, durability by design also contributed mainly through roof overhang for shading and protection from rain.

Possible technique has also been proposed to improve life-span and design in general, such as hybrid use with material such as wood and metal. Also use of easy to replace bamboo covering, protecting less disposable structural column (Figure 3.10). Also other possible solution is use of mud plaster also considered (Kaminski, 2018).

Figure 3. 9 Use of bamboo for pier, wall and roof (source: Kaminski, 2018)

Figure 3. 10 Use of bamboo grid and cladding of bamboo column (source: Kaminski, 2018)

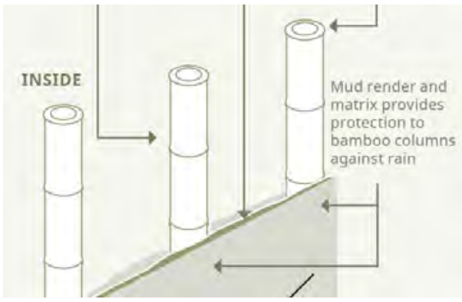



Figure 3. 11 Mud as recommended
solution improving bamboo durability
when preservation not viable.
(Source: Kaminski, 2018)

### 3.2.5 Case Study 2: Bamboo Transitional Shelter (Yogyakarta, Indonesia)


Figure 3. 12 Yogyakarta Earthquake, 2006( source: http://news.bbc.co.uk)

**Introduction and Background of Shelter Provision**

Indonesia is one of the most disaster prone country, but many houses are not built to resist earthquake despite its frequency. As the consequence, vulnerability quite high among other developing countries (Okazaki, 2018). Such vulnerability surfaced after 2006 earthquake in Yogyakarta, with around 7.4% of housing stock destroyed (BAPPENAS, 2018).

The 6.3 Richter scale earthquake struck Yogyakarta and surrounding areas on 27 May 2006. The fatalities are 5,700 people dead and more than 20,000 injured. Material damage consisted of more than 600,000, with around half of the number were destroyed.

Learning from many critique on Aceh Tsunami case in 2004, defensive stance of Government of Indonesia (GoI) are by prioritizing one step policy. It opted to went directly from tents and tarpaulins into permanent housing (Macrae & Hodgkin, 2011). Within a year of the earthquake, the GoI Permanent Housing Program was able to provide the earthquake-affected people with 150,000 permanent houses (Worldbank, 2008), with the term almost exclusively translated as building with confined masonry.

In addition to the government, among the largest response was from within the country, with diversity of private actors and organization. They are also backed up by international response, with improved preparedness due to anticipation of the eruption of nearby Mount Merapi (JRF,2011). Many organization responded in phases: initial distribution of emergency items, followed by a transitional shelter which was implemented by the organization using cash grants, either to individuals or to local organization.

Many non government organizations (NGOs) considered emergency shelter still necessary, thus some of them such as the Java Reconstruction fund (JRF), IRFC and PMI decided to integrate transitional shelter, despite initial reluctance and differing policy of the GoI. Its adoption increasingly urgent with the closing of rainy season as a sheltering roof become quintessential, especially addressed through the 'roof-first' strategy.

Potential disadvantages arise as those who would accept transitional shelter would not get subsidy from the government for reconstruction. Artificial distinction had been done in order to avoid this, by dubbing the shelter as roof structure unit (RSU). It was done for sake of beneficiary's eligibility, in the eye of the government. Receipt of the RSU or the transitional shelter kits in the end did not impact the eligibility of beneficiaries to qualify for permanent housing assistance. The provision of the RSU was racing with the provision of the permanent houses by government (Worldbank, 2008) and during its development, the need for RSU depleted as a result of rapid permanent house reconstruction, by the government.

**Design of The House**

The initial design of bamboo transitional shelter (RSU) follow common guidelines based on traditional bamboo frame construction, considered as engineered versions of the simple buildings (Macrae & Hodgkin, 2011). It follows the 'roof-first' strategy and also dubbed as roof structure unit (RSU), which typically consisted of a wind and weatherproof bamboo structure. The 6-by-4-meter rectangular bamboo frame building features a hipped roof, a door at the front, and two windows on each side. The wall made use of woven bamboo. Various patterns were proposed, but main use is woven plait-work, with 'kepang' pattern. The bamboo wall was usually non-rendered. but with some instance of paint. Also to note are pre-cutting of wall panels, with woven bamboo and split bamboo frame components which were manufactured on locally set manufacturing facilities.

**Construction Worker**

Considering effectiveness of participatory construction in mass-housing. the program saw around 60.000 locals trained in building earthquake resistant bamboo shelter, as a result around 12.500 families had built it (Shelter projects, 2017).

**Life-span and Consideration for Transition**

By separating the frame from the foundations, the structure may be transported and re-used. While the components can be recycled for use in long-term home construction. Upgrading the shelter walls with masonry or other very heavy materials to a high level is not recommended. According to technical review by structural consultant (ARUP, 2010), such upgrade might attracts even greater seismic loads causing the frame of the structure to perform poorly in an earthquake. To this end, durability is important consideration which depends on the quality of the bamboo material, its treatment, and the condition of the matting. Some recommendation on durability suggested that bamboo should be treated before casting into concrete and the frame members should also be treated to prevent rot and insect attack.

Figure 3. 13 Early model of the T-Shelter
(Source: BAPPENAS, 2018)

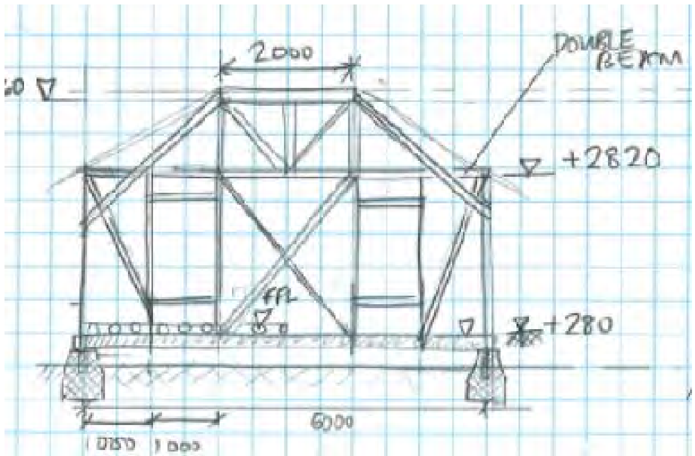



Figure 3. 14 Evaluation Drawing of the T-Shelter
(Source: ARUP, 2010)

**Revisiting Bamboo Use in Post Disaster Housing of Yogyakarta**

In this study, the use of bamboo in Yogyakarta reconstruction as roof structure unit (RSU) in 2006 has been gathered from literature. As change toward permanent is the nature of any transitional design, and it being the initial intention of the organization, the condition of the BTS in 2015 has also been examined from secondary data on two series of field surveys by Dr. Chiho Ochiai. Data of the first survey contains information on all surveyed house owner's and general house modification which are observed from 97 house in September - October 2015.

The use of the bamboo wall is identified mainly from floor plans, with some detailed measurement on houses had been gathered on the second survey, including the position of wall and room function. The use of original BTS also indicated in floor plan or could be predicted based on wall material and original space area of the BTS. The owner involvement is also examined, particularly the plan to change bamboo material as well as their participation in self-build construction.

Table 3. 2 Bamboo Use in House Samples in Serut Hamlet, Yogyakarta, 2015
(Source: Survey data by Chiho Ochiai)

| | |
|---|---|
| Survey 1 | |
| Location | Serut Hamlet |
| Surveyed house | 97 units |
| House with Bamboo Wall (Total in 2015 (A+B+C) | 31 units |
| Function of room with bamboo wall | |
| A - Other use | 17 units |
| B - (kitchen, storage) | 9 |
| C - Use of Bamboo shelter from 2006 (RSU) | 5 Units |
| Survey 2 | |
| Total house surveyed | 15 |
| Bamboo Wall Usage in 2015 | 6 |
| Plan to change bamboo part | 4 |
| Use of self-build in construction | 14 |

The use of bamboo for transitional was advocated by various NGOs, aimed towards permanent solution. However, it seems that there is no need for beneficiary to connect the transitional shelter using bamboo (RSU) to directly transitions toward permanent solution. Due to government support for more permanent type, construction of permanent housing with non-bamboo material has happened regardless of initial bamboo structure.

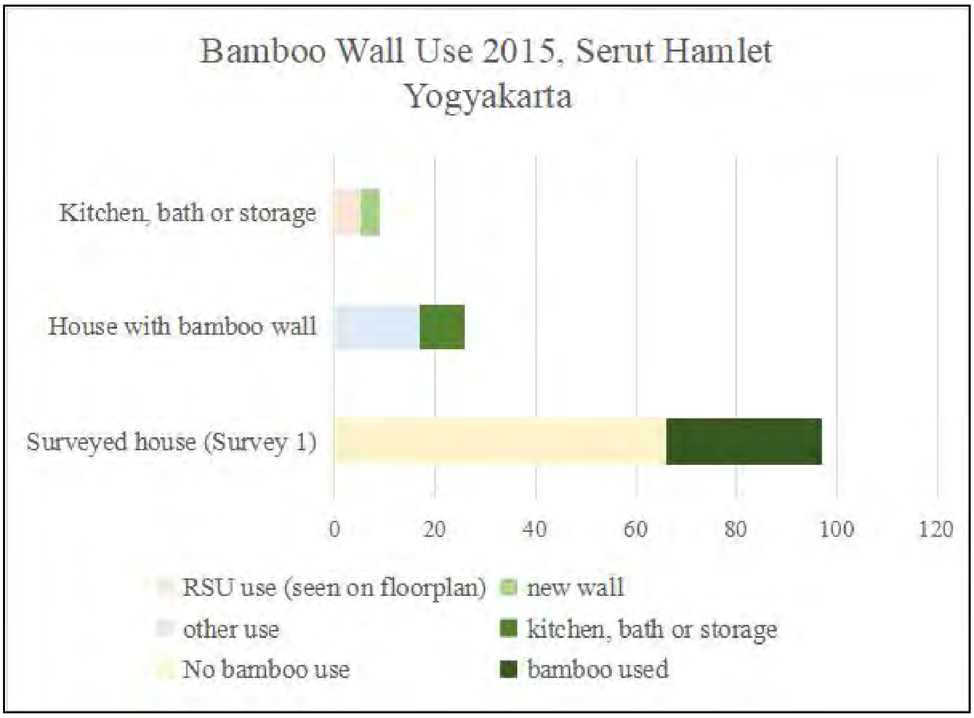



Figure 3. 15 Bamboo Wall Use in Surveyed House, 2015

In small percentage of cases, inhabitants turn the bamboo structure into annexes which has been used for service room function such as kitchen and storage. This living combination of temporary shelters and permanently restored homes saw the former has only been used for kitchen or bathroom, where comparably used briefly by inhabitants. Similar situation of such living combination has also been reported in other village (Hayashi et al., 2006).

To some extents, the RSU provided alternative to heavy non-engineered structure prevalent before the disaster. It did mainly for essential but less frequented space in a house. Further question arise whether this is also due to less preferences and affinity, to inhabit room made of bamboo.

Figure 3. 16 Reuse of Pre-cut Panel assumed from printed PMI logo (Source: Ochiai)

Figure 3. 17 plait-work bamboo wall for kitchen and shower area. The right one assumed new in 2015 from difference in floor-plan with the 2006 RSU(Source: Ochiai)

**Summary of Case Study 2: Yogyakarta**

The use of bamboo transitional shelter in Yogyakarta within the roof first strategy which was initially promoted by various NGOs might be intended to offers better alternative than temporary shelter. It tried to address the need for transitioning, which considers the inevitability of extended use towards permanent housing. At the same time, it could be seen to contribute towards 'building back better', with lighter construction and mainly with renewable material from nature, as alternative to heavy non-engineered structures which were prevalent before the disaster. Initially it promised many potential through bamboo use for post-disaster housing (table 2.2). As comparison, previous literature exhibits construction for permanent living area more oftern used reinforced concrete. Also to note is the use of timber for the transitional purpose, outside of case study (figure 3.7). With longer time elapsed after disaster in Yogyakarta, self-build has been found to be involved in majority of house modification. However, instead of lighter bamboo material, most of the surveyed self-building samples, used heavier concrete and brick material. The use of such material through self-build could be considered risky, considering them as heavy and non-engineered.

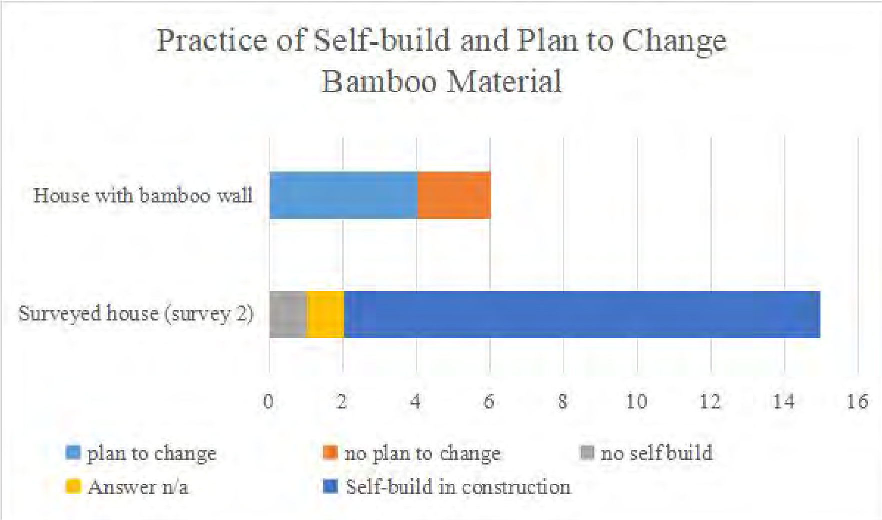



Figure 3. 18 Number of Self-build Practice and Plan to Change Material among 15 Houses

By concluding the case study with the situation in 2015, it was found that the bamboo shelter build first as RSU has been unable to achieve its aim to transition and end up being temporarily used for living, with bamboo as wall material used nominally. While it is not possible to observe change of material when seen on the floor plan, many case still using bamboo exhibited living combination of temporary shelters and permanently restored homes. The former mostly used as annexes containing kitchen and bathroom, where inhabitant only uses briefly and considered as a service function.

Despite its transitional intention, upgrading shelter walls with masonry or other very heavy materials to a high level is not recommended (ARUP, 2012). On the other hand, alternative for upgrade the wall of bamboo structure to become more permanent has not been disseminated.

**Summary of The Two Case Study**

The two presented cases study provides examples on the use of bamboo for post-disaster housing, both for temporary and transitional purpose, albeit initially. Used within the dry wall technique, the type of bamboo wall used is woven plait-work bamboo in Case 2, while the case 1 also adopted similar one, examined more for this study is the type of bamboo with grid arrangement.

Comparing to literature review on potential of bamboo for post-disaster housing (table 2.2) both case study support that among bamboo potentials are its environmental impact and easy localization, based on the aspect of cost, availability and self-build.

For the aspect of extended life-span, bamboo construction can not end up as permanent in both cases and it was different with initial intention of transitional shelter in case 1 (Yogyakarta). What has been seen instead was living combination of temporary shelters and permanently restored homes, with the former use is somewhat extended.

When seen for the affinity towards the bamboo wall type, woven plait-work wall which was used in Yogyakarta has often been considered as suitable for the tropical climate. However, its lack of use for permanent living function might signal the function of shelter not only for sheltering against climate, but also to contributes in providing safety for inhabitants, their belongings, property rights, privacy and emotional security. It might be better received if appropriate with its inhabitants normal pattern of life, not only the presumed cultural context. Past proposals on bamboo wall —often aim to extend the life-span in addition to addressing the issue of affinity— should also considered this perspective on shelter function.

Table 3. 3 Summary of post-disaster housing case study 1 and 2

| **Basic Information** | | |
|---|---|---|
| Country | Indonesia | Bangladesh |
| Disaster type | Natural disaster (earthquake) | Human induced disaster and displacement |
| Damage | | |
| Housing need | up to 600,000 houses (half of which were collapsed) | 180,000 households |
| Locale | Bantul, Yogyakarta | Cox's Bazaar |
| Shelter phase examined | Transitional Shelter | Temporary Shelter |
| Shelter strategy Involving bamboo material | Roof Structure Units (RSU) | Emergency sheltering kits (ESK)and upgraded sheltering kits (USK) |
| Material cost (per-unit) | 260CHF/ 205 USD (2006 value) | 155 USD (for USK) |
| Project cost (per-unit) | 330CHF/ 260 USD | 208 USD (for USK) |
| Support on durable housing | Government | prohibited by government, yet durability recommended by practitioner |
| **Bamboo Construction** | | |
| Hindering durability | -not possible to rely on treated bamboo (thus | -not possible to rely on treated bamboo |

| | | |
|---|---|---|
| | less durable)<br>-wall type not common to plaster | (thus less durable) |
| Bamboo species | *Dendroclamus Asper and Gigantochloa Apus* | (Borak) *Bambusa balcooa,* (Muli) *Melocanna bambusoides,* and others (in total of six species) |
| Structure and wall construction | Full culm structure with woven plait-work wall | Full culm structure and grid wall of split bamboo |
| Use of bamboo wall | **Woven plait-work** (Type 3B)<br>Other than main type, various patterns are proposed | **Bamboo Grid** (Type 4)<br>with no plaster (dry method)<br>notable as it provide easier alternative to weaving |
| Function accommodated using bamboo construction | ● transitional dwelling was no longer utilized for permanent living area<br>● Services functions → Kitchen, Life-stock, and Storage | -temporary dwelling |
| Self-build for construction | ● Construction of RSU in 2006 mainly owner driven, benefit from training and use of pre-cut wall panel<br>● From data on second survey in 2015 , most building modification is owner driven, although bamboo is much less used | main contribution came from non-skilled and semi-skilled worker. |
| Construction potential | ● -use of woven bamboo pre-cut in fabrication facilities which then supported by owner-driven<br>● -although limited in number and function, bamboo use has been extended up to 2015: reused, use in combination with brick | ● Durability improvement on structure through cladding of structural member<br>● Use of bamboo grid wall for temporary require cover of tarpaulin sheeting, however it should be possible to upgrade it for wet wall technique of plastered bamboo |
| Issue | By 2015 bamboo was less used than predominant type before disaster, which is non-engineered confined masonry | Durability improvement deemed necessary, even for temporary shelter but difficult to find bamboo with good grade and preservation |

### 3.3 Lesson from Post-disaster Housing Cases

The selected case of post-disaster housing in Bantul, Yogyakarta Indonesia and Cox's Bazaar, Bangladesh, considered the large need of housing which has been exceptionally addressed by extensive adoption of bamboo material. Lesson and issue will be seen on the aspects of extended life-span, compatibility with self-building, availability of material, low-environmental impacts and affinity.

#### a) Extended Life Span

In Cox’s bazaar, it can be learned that selectivity of the bamboo quality and reliance on its treatment were often not possible, considering the large scale and tight time-frame of post-disaster housing. Shown through both cases study, the most commonly used is local-species of bamboo without preservation.

Transition from temporary into permanent extends the material life-span, has not been observed in building element of wall in both cases. It has been suggested even in case 1, despite intended use for temporary housing. Not only technical advisors, beneficiaries also offered valuable solutions towards improvement durability to allow extended period of use, without changing the main material. Hybrid technique has also been practiced, for instance is bamboo column clad split bamboo or tarpaulin, which are easy to replace. Alternatively, use of mud plaster has also been suggested for Cox's Bazaar (Kaminski, 2018) and practiced in Yogyakarta (Fujiwara et al., 2014), all of which aim to protect bamboo elements from water action (figure 3.6), through the use of more resistant elements of wet wall technique. This is especially considering that grid bamboo wall used as infills in Cox's bazaar is more commonly wet wall technique, where it is plastered to allow semi-permeable and more permanent wall.

**b) Self-build:**

Implementation of the emergency sheltering kits (ESK) and upgraded sheltering kits (USK) in Cox's Bazaar as well as Roof Structure Units (RSU) in Yogyakarta, has relied on owner-driven construction. To some extent it has been possible because the simple construction technique and choice of slightly transformed bamboo material. Grid wall is chosen in Cox's bazaar as it is less challenging to process and to weave than woven wall, while in Yogyakarta, the woven plait-work wall panel involved remote fabrication. The grid wall type could use split bamboo directly while the plait-work often required skill for shaving and thinning the softer inside skin to make the split more flexible before it is woven, which then again, require specific skills.

**c) Low- cost and Availability**

Possibility of self-build construction and choice of slightly transformed material might also seen to address the budgetary constraint. Despite emergency context in two different location, the material and project cost is equally low (table 3.3). In the case of Cox's bazaar, the low-cost allow families to purchase or source the bamboo using their own resource, with the shelter practitioner R consider that bamboo is pretty much grows in their 'backyard' thus widely available. Such reduced cost might also the result of reduced material use. Bamboo grid wall type displayed potential to reduced material use with its gaps and spacing, compared to bamboo wall with continuous surface such as in woven wall.

**d) Environmental impacts**

Seen favorable, the environmental impact of bamboo construction is related with the above mentioned potential of extended life-span, local availability, reduced cost and material use. Use of bamboo also has potential in avoiding deforestation in both cases, compared to using slower growing timber species.

### e) Affinity

While bamboo construction shows extended use from 2006 to 2015 in case 2, it had been used as part of living combination of temporary shelters and permanently restored homes. Self-build has been found to be involved in majority of case of house modification. Such modification mostly use concrete and brick material, instead of bamboo material whose skill reportedly trained after disaster. Compared to continued use of such modern material or timber (Armand et al., 2015), the limited utilization of bamboo could be seen to imply problem of affinity. In past proposals, such problem often tackled by together problem of life-span.

## Chapter 4 Bamboo Wall Technique in Vernacular Architecture: Cases and Types Study

This chapter will clarify the use of bamboo material under the context of vernacular architecture, focusing on the scope of building elements of wall. Indonesian and Japanese cases are selected to represents two basic type of dry and wet bamboo wall technique. The vernacular cases exhibited use of bamboo with extended period not seen in post-disaster housing case in previous chapter. Following five specific types of bamboo wall suggested on chapter 2, the use of bamboo material in each case provide examples of all types. Six main potentials of availability, life-span, self-build, cost, environmental impact and affinity, are seen on each wall type provides links to previous case of use of bamboo in context of post-disaster housing.

### 4.1 Bamboo in Vernacular Architecture

**Vernacular Architecture seen From Framework of Sustainable Principle**

Prior to examining bamboo material under the context of vernaculnar architecture, the term vernacular will refer to Bernard Rudofsky (1964), Paul Oliver (1997) and Eric Mercer (1975) which mainly related to notion of popular or people architecture, architecture without architects (Oliver, 2003) and especially refer to traditional construction.

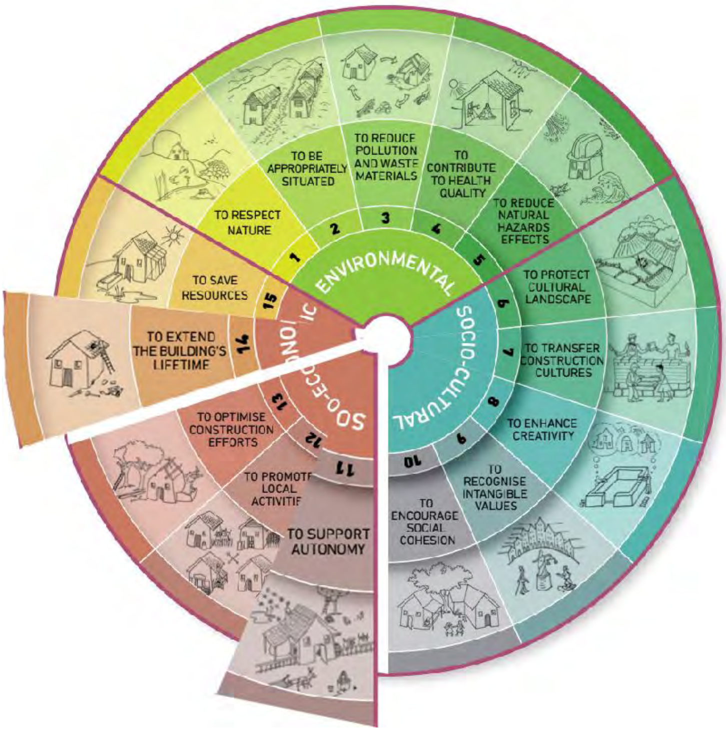



Figure 4. 1 Vernacular Sustainable (VerSus) highlights broad principles of vernacular architecture including similiar requirements with post-disaster housing: 14 (To Extend Building's Lifetime) and 11 (to Support Autonomy or Self-build) (source: modified from Guillaud et al., 2014)

Following the set definitions of vernacular architecture, principles of vernacular has been formulated (Guillaud et al., 2014) particularly through relation with its merit of sustainability and termed as Vernacular Sustainable principles (VerSus) published in 2015. As part of Culture 2007-2013 programme of The European Union, the publication visualized the wheel method which considered the environmental, socio-cultural and socio-economic sustainable principles of vernacular architecture not only in Europe. This wheel method (Figure 4.1) provides an operative approach and a clear framework to examine practices used in vernacular architecture, many of which utilize bamboo construction.

### 4.1.1 Bamboo Dry Wall Technique in  Indonesian and Japanese Vernacular Architecture

Among the 1250 species of bamboo in the world, 11% are native to Indonesia. Because it grows fast and in quantity, bamboo is an ubiquitous material which is affordable and interchangeable for common usage by low-income populations (Larasati, 1999). Most widely utilization bamboo for Indonesia is for infill wall, found in vernacular architecture such as in West Java, Bali and Lombok Island. In such examples, timber frame structure allows the use of light and non-structural bamboo wall, mostly made of woven split bamboo, with countless of patterns (Frick, 2004). Among the woven, plait work type wall can be considered more common in Indonesia, followed by looser wicker work type.

Considering the climate context, it is considered difficult to construct bamboo walls that are airtight and leak-proof. On the other hand, it made cross ventilation comes naturally. Coupled with low thermal storage of the material, incorporating ventilation has been considered the definitive use of the material in warm and humid regions, particularly where bamboo is  growing (Lara & Espinosa, 2019). However, with increasing time indoor more widespread use of window for fenestration, ventilating function of the 'breathable' wall still need more research.

Figure 4. 2 Bamboo infill walls in vernacular architecture in West Java, Bali and Lombok (L to R)(Source: author)

Alternative to direct use of bamboo through the dry wall technique, some case of traditional bamboo wall in Indonesia also plastered with lime mix or cow dung (Auman et al., 2018). Despite different climate in Indonesia, 'wet' wall construction has also been advocated for transitional shelter, allowing incremental plastering of bamboo wall as substrate which has been practiced to extend building life. For this practice however, woven plait-work bamboo seldom used in Indonesia with limited research experimented with plastering it (Idris & Lovian, 1996).

Despite various benefits, wide adoption of bamboo material in Indonesia has faced barriers, among them are related with government policy related such as ineffective action, no incentive or even direct targeting, particularly the widely used plait-work wall has been the target of replacement since Dutch era (Ignasia, 2008)(Armand et al., 2015) and New Order era (Djajadiningrat, 1995).

Even traditionally, such wall not always used prominently. As example In important building such palace, in West Sumatra's, Pagaruyung, bamboo walls is (mostly) the back of the palace. (Sabtelasari & Valentinovich, 2022).

### 4.1.2 Bamboo Wet Wall Technique in Japanese Vernacular Architecture

In Japan, homogeneous way of using bamboo as primary material has been limited to temporary building type or use in secondary element of fences or Take gaki (竹垣 ).With rich variation of intricate fences they were hardly ever constructed outside Japan and has closer relationship with Zen and the tea ceremony, originally built around and named after Zen temples (Yoshikawa, 2001) such as Kinkaku-ji or Kennin-ji.

Hybrid use of bamboo saw more use for architecture and primary elements of wall. Japanese houses have traditionally been made from a mixture of wood, mud, bamboo, grass and paper with bamboo use in Kyoto dates far back to the Heian period (8th-12th centuries) (Tanaka et al., 1996). Long-standing practices include the usage of bamboo-reinforced structures most commonly for earthen wall base or substrate materials in form of bamboo grid or *takekomai* for traditional wooden buildings. Since roughly 800 A.D., such earthen wall technique of tsuchikabe has been passed down from one generation to the next, considered established around the year 1600 and has subsequently supported the construction of homes (Yokobayashi & Sato, 2015).

*Tsuchikabe* -土壁 which literally means earthen wall is considered as part of traditional skills, techniques and knowledge for the conservation and transmission of wooden architecture in Japan according to UNESCO's Intangible Cultural Heritage of Humanity (2020). *Tsuchikabe* has also considered as part of promotion of Japanese housing by the Ministry of Land, Infrastructure, Transport and Tourism (Uno, 2019).

In case in Japan, the technique also often inseparable with bamboo as it main component, in form of Wattle of bamboo grid lashed by rope. While initial form of *tsuchikabe* has been suggested to use basketry type of woven bamboo,  the tying with rope become preferred to weaving because better grab or bonding of the mud as daub and the wattle (Reynolds, 2009).

The second and more visible main element is trowel finishing of soil mixed with straw over it to maintain a thin soil layer within the sakan （左官）plaster technique. While very high technique often reserved to tea houses, it also widely found on ordinary houses such as *minka, dozo, machi-ya* (Figure 4.3 & 4.4) etc.

Considering Japan's moderate to cold climates, 90% of people time is spent in enclosed environments, making indoor climate a critical component of wellbeing. A  recently discovered is that other building material can balance indoor humidity like the earth or loam and in a climatic chamber at 95% humidity, standing for six months, such loam do not become wet or lose their stability (Minke, 2006). Such characteristics, also applicable to hybrid bamboo wall method, where bamboo used compositely with earth including in Japan (Mizunuma et al., 2008).

Considering affinity, while Tsuchikabe in Japan are associated with practicality, health and sophistication (Hijioka et al, 2013), there also considered some negative views. For instance clay-walling was despised as it took time and money (Mizunuma, 2003) (Yokobayashi & Sato, 2015) including for its maintenance (Reynolds, 2009). Some of the concern seem understandable, considering commonly high technique involving highly skilled *Sakan-ya* or plasterer. While positive affinity might contribute to better reception of use of bamboo and mud for wall, including for Post-disaster housing, the time and cost might render it unsuitable.

Figure 4. 3 Minka in Shikoku

Figure 4. 4 Traditional town-house (Machi-ya) in Kurashiki (Source: Perez-rodriguez)

### 4.2 Introduction to Case Studies of Bamboo Wall in Vernacular Architecture

Last chapter presents two case studies on use of bamboo for post-disaster housing, specifically use the material for wall, as focus of this study. The wall element in cases of Yogyakarta and Bangladesh seen as mainly direct use of bamboo within dry wall method. Considering its transitional designation, the case of Yogyakarta has been found to have problem concerning the aspect of life-span and presumably, affinity. This urge the need to reexamine dry wall type with predominant woven plait-work wall type used in Indonesia, by taking two case as example of bamboo use in vernacular architecture, in West Java and Lombok island (case study 1 and 2) as well as in Japan (Case 3, Kyoto bamboo craftsman).

With the potential of wet wall as common suggestion found in both post-disaster case in last chapter, the Japanese case studies taken for this chapter considers wet wall as predominant wall type in Japan, with its bamboo element called *takekomai* bears some resemblance with grid bamboo used in post-disaster case of Cox's Bazaar. Such bamboo within wet technique or wattle and daub based on Asian bamboo wall provide alternative technique which is arguably more obscure than Latin American technique.

#### 4.2.1 Case Study 1 : Bamboo Dry Wall (Desa Sade, Lombok Island)

The Sade Traditional Village (*Desa Sade*), is located in Rembitan, Pujut district, on the southern flat but hilly area of Lombok Island, Indonesia, between 120 and 126 meters above sea level. Desa Sade was inhabited in a circular shape because it was perched on a hill (Subiyantoro, 2018). In Sade, just 20% of the village area is suggested to be built up, the remainder is open space. The 150 homes, two mosques, a meeting room, five public restrooms, and a rice barn make up the developed area (Wulandari, 2002).


Figure 4. 5 Sade, Lombok Island, Indonesia

Figure 4. 6 Native bamboo near Sade village area

Inhabited by Sasak ethnic group, Desa Sade is led by village head elected by the people. The kinship system in Dusun Sade is patrilineal and followed by patrilocal settlement system (Yusuf & Sukandi, 1987). When a male child is married, he will usually build a new house around his parents house, with the village customary law restricted the number of houses up to 150, as seen during survey in 2021.

Regarded as cultural heritage area (*cagar budaya*) the number of the village houses have been kept at 150 units. Around 700 inhabitants are currently living in similar type of dwelling, called *Bale Tani*. For such house, bamboo material is used for wall and roof structure. Other use of bamboo is for the public open pavilion of *Berugak*, which floor are constructed of bamboo split and currently lashed with nylon strings.

Various types of bamboo on the production forest near the village are used, with some with unique characteristic such as thick culm wall or spotted pattern etc. For wall, the woven plait-work bamboo act as infill to post and beam which has been made using timber such as teak, coconut wood. or mahogany. The bamboo wall is only thinly plastered with lime render and could be considered as dry type. Together with shading of the low thatch roof they protect the wall, thus it is not replaced as often as the roof, which is 7 or 10 years.

The preservation of bamboo has relied on natural elements of water and fire. As a result, the bamboo roof rafter can last up to 20 year and some houses has lasted up to seventy years. The cultivated bamboo poles are soaked for several months in a river and the ones with best condition are selected. In addition, the installed bamboo rafter especially in the kitchen, will be benefited from the exposure to smoke from cooking activities. The appearance of the bamboo rafter get darker and according to the villager, it gained improved bug and termite resistance to the point of extending the material life time several decades.

The average villager has good knowledge on building materials. Beyond weekly maintenance of clay and rice husk with cow dung, the know-how has been also possessed to construct their own house within community work, including the village wide renovation.

Figure 4. 7 Exterior and Interior view of the woven-plait work bamboo wall

**4.2.2 Case Study 2 : Bamboo Dry Wall (Naga Traditional Village, West Java)**

The Naga Traditional Village (Kampung Naga) is well known nationally as an example of self-sufficient community. Located in Salawu district of Tasikmalaya Regency, West Java, Indonesia, the topography of Kampung Naga Village area is a combination of hill and foothills with the west part is higher than the east where the Ciwulan river flows. Because it may be used for both residential and agricultural purposes, the land is regarded as being in an ideal location. Its forested areas can be divided into two groups: sacred forests (leuweung karamat) and protected forests (leuweung tutupan), both of them are covered by the customary law.


Figure 4. 8 Naga VIllage, Tasikmalaya, Indonesia

Figure 4. 9 Large open space in center of area with white lime plastered plait-work wall in the backgound

Sundanese ethnic group composed the residents of Kampung Naga. Two groups make up the community: one group resides inside the community and the other group resides outside, in the Sanaga settlement (Gunara, 2017). *Ki Kuncen*, who serves as both an administrator and a traditional manager, is the highest ranking leader, whose position is passed down from generation to generation (Gunara et al., 2019). The community is organized within cluster, with a large open area in the middle (Figure 4.9). Customary regulations dictate that structures as restrooms and livestock pens, must be located outside of an area of 1.5 hectare and only wood or bamboo may be used for construction, that palm fiber may only be used for roofs (Retnowati & Kurniasih, 2019).

Home construction is always guided by the teachings of the locals' ancestors. Utilizing contemporary construction tools is considered to bring misfortunes are main requirements of the house are as protection from the elements, including rain, wind, sunlight, and wild animals instead of against enemy (Hermawan, 2014). While the custom preserve building tradition, it is not static. Adaptation has been allowed to newer technique, such as case of adopting modern glass for window and skylight.

It is also suggested that bamboo technique extensively used for wall also has changed. In older houses, bamboo wall use woven wicker-work type of bamboo (*sasag*) (figure 4.4). Newer houses still use such loose woven wall, mainly for kitchen wall to prevents fire being left out in the kitchen without other people noticing. Otherwise, other kind of woven plait-work wall (*kepang*) has been used in most of the house wall. Beside kitchen wall, bamboo material has been used for house floor, also contributing to permeability and airflow. Main use of bamboo for infill wall is supported with structure of *abasia* timber for the frame. Initially timber has also been used for foundation, but replaced with stone in current condition.

Figure 4. 10 Use of woven wicker-work (kitchen-left) and plait-work type

Figure 4. 11 Larger use of wicker-work type on older house type

Figure 4. 12 Interior view of the house with plait-work type, also visible are the lime plaster and pores between the tight weave

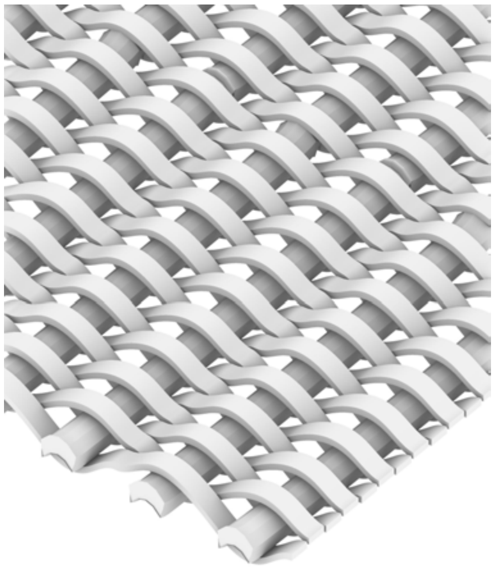


Figure 4. 13 Drawing of wicker-work used for kitchen and ventilation panel

Preservation of bamboo material done with submersion technique, with cultivated bamboo poles are soaked for several months in a river, then the ones with best condition are selected. The wall are mostly fromwoven bamboo (*kepang*) with lime render without using paint.

### 4.2.3 Case Study 3 : Bamboo Dry Wall and Wet Wall (Kyoto Bamboo Craftsman and Plasterer School)

The main information for this case study is gathered from two interview. The interview with bamboo Craftsman N provide perspective on dry type of bamboo which consist of four types established in second chapter (Type 1 to 4; Figure 4.14).

Second interview with Mud-wall plasterer S, fill the gap, as not only professional plasterer now commonly make the bamboo grid, their institution also transmit such knowledge to aspiring plasterer. From two different expertise and also two kinds of basic bamboo wall type it can be inferred key lessons: potential on aspect of extended life-span and affinity with issues on the aspect of self-build and availability.

**Potential of Extended Life-span**

Even tough it has decent life-span around ten years, the use of bamboo technique for fence is considered not permanent. The technique used for fence, also found other valuable role as it had been used for cladding (Shitami-itabari- 下見板張). Similar in appearance with fence such as *Tokusa* (figure 4.26) & *Hishigigaki* (4.28) the protective element is a special technique for reducing exposure to elements by covering mud-wall.

The Mud-wall with bamboo grid has been suggested to lasts 110 years or more. In addition the bamboo substrate could continuously reused if it is kept protected by the mud plaster, not left exposed. However if it does exposed, it can indicate a repair is needed. For such extended life-span, among important factors is in selecting suitable species for durability, especially to consider its water contents. This is among the factor for Madake (Phyllostachys bambusoides) becoming the most sought after bamboo species for some companies. Otherwise, the mud-wall also constructied wiht other species of bamboo or other plants e.g. yoshi or reed , depending on region of Japan.

If bamboo is used for take-komai, it seldom subjected to preservation (interview, mud-plasterer S) as chemically treated bamboo has been seen to crack & deteriorate easily (Reynolds, 2009). On the other hand, dry wall technique and fences making in Japan has involved various traditional technique for preservation of bamboo such as technique of abura-nuki, hi-aburi etc.

Rounded: Tokusa-gaki

Flattened: hishigigaki

Plait-work: interior ceiling use

Bamboo grid: *take-komai* as substrate for mud-wall

Figure 4. 14 Photographic series: Bamboo wall and fence made by bamboo craftsman and plasterer in Kyoto

**Affinity and Issue of Availability**

For making fence, Madake bamboo has the most desired look, especially the surface. On the opposite, Moso bamboo (*Phyllostachys edulis*) which has significant forest area in Japan has an appearance which is not as desired, considered rough and too thick. Madake is also considered most suitable for use in Kyoto style wall (*Kyo-kabe*) as it is a relatively thin type of mud-wall or *Shin-kabe* with 55mm - 60mm of total wall thickness.

High aesthetic value of both bamboo fence and mud-wall has been to to large extent decided by the use of one species of Madake. However on the issue of availability, sourcing Madake bamboo is currently difficult, often requiring supply from other region, particularly Kyushu.

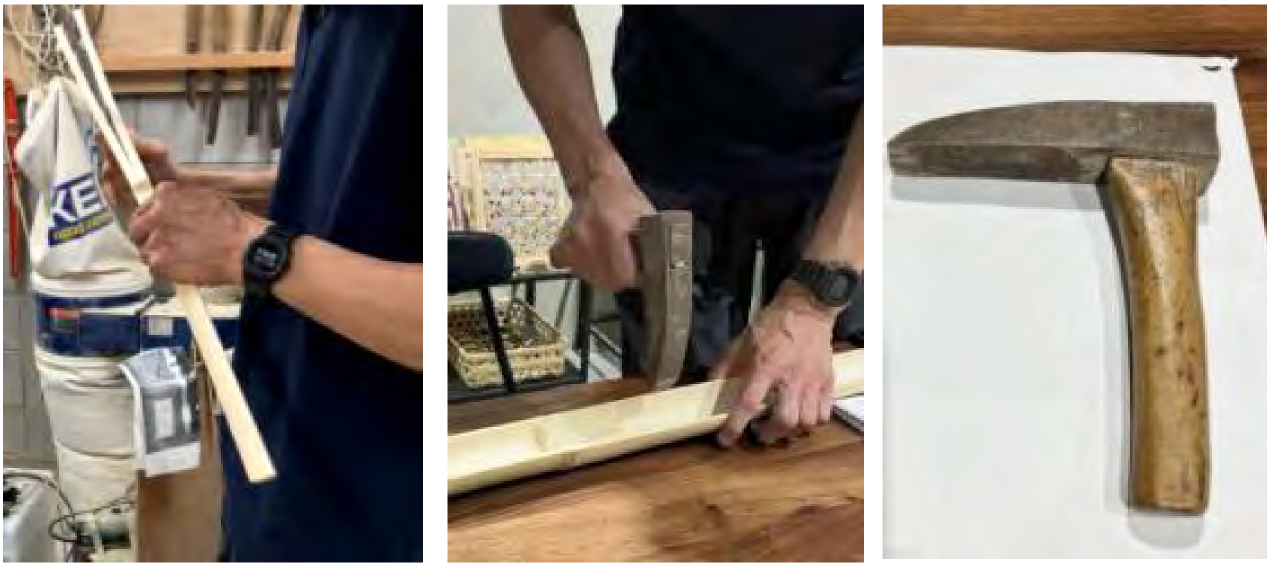


Figure 4. 15 Different methods and tools in splitting and flattening Madake bamboo.

**Issue of Self-build**

While expression of mastery is one principle of vernacular architecture (Guillaud, 2014) on the other spectrum is the more transferable technique utilizing self-build. The bamboo fence, such as Tokusa and Hishigigaki (figure 4.4) is a good example of mastery, when it is well crafted. Starting with transforming the bamboo culm, there are various technique for splitting with traditional tools (figure 4.1 & 4.4). Despite simple tools, such technique suggested to require specialized skill to split thin walled Madake bamboo. Moreover the arrangement process require even higher skill.

Traditional mud-wall most often done by professional. Up to around 30 years ago, the wattle part using bamboo for *take-komai* was made by *take-ya (bamboo craftsman*). Afterward, due to decline in demand, the number of *take-ya* also declined. Now for the Mud-wall technique, the plasterer is also expected to make the bamboo wattle. They gained the ability, despite many trial and error during the learning of the new technique. Compared to intricate technique and specification of the mud part, the bamboo wattle part might be considered more simple and shown to be possible for transfer of technique to other profession.

Different with the substrate part, traditional but specialized tools are used for the mud-plastering work (figure 4.17) namely the plasterer trowel (kotte) which comes in various size, specification and price tag, further confirming the intricacies of the plastering work.

Figure 4. 16 Bamboo craftsman tool for splitting single bamboo pole into different number of pieces possible ranging from three to nine

Figure 4. 17 Diverse tools used for Sakan plastering technique

### 4.2.4 Case Study 4: Adapted Wet Wall Technique (Renovation and Artist's Mudwall Works)

From workshop participation and visit to works by Artist I in Kyoto, Japan, unique approach in making mud-wall derived from traditional *Tsuchikabe* technique has been examined. Potential of such approach are observed during activities of mud wall repair workshop and visits to projects which involve reuse of resource in various ways.

The mud-wall repair considers various damage to the wall of Y dormitory. Formerly suggested to be a high-school building, the building was originally build using timber construction including the clap-board cladding. Beneath the cladding is wall made with traditional mud-wall technique with the interior side is plastered with lime (Shikkui). Most of the damage occur on location which the cladding are cracked, exposing the mud wall to the elements (figure 4.18).

The two days workshop main activity was repairing and reapplying the wall plaster, with the Artist I supervising as well as making a exemplary work. The work involved repair at outdoor and indoor side, with at least three and five location respectively. Not only the plaster, some location also require repair of the wall substrate built using bamboo grid (take-komai - 竹小舞; Figure 4.11).

Occurrence of water exposure (outdoor-left) with damage of wall infill

Hole in the wall to be filled

Other instance of damaged clapboard corresponding to hole on the mud wall interior side

Hole below window partially filled with ara-nuri (rough wall mud)

Figure 4. 18 Photographic Series: Mud-wall damage on two location exterior and interior sides

For take-komai (Figure 4.19) the **step 1** is to split the round culm of Moso bamboo found near the site, using hammer. In the **step 2**, the split bamboo is tried to be arranged first. The **step 3** is using the original technique of lashing the bamboo grid with rope of natural fiber, considering also old part of the mud-wall and remaining takekomai. Before plaster can be done, **step 4** requires the fixing of bamboo grid with drill and bolt in addition to the rope.

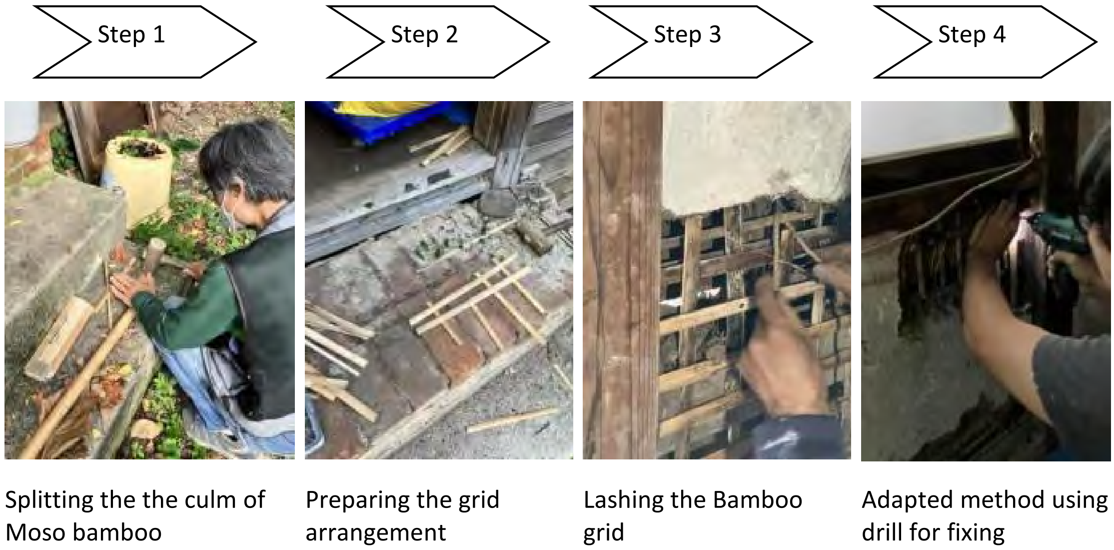



Figure 4. 19 Photographic series: Steps on replacing bamboo grid (take-komai) within adapte technique

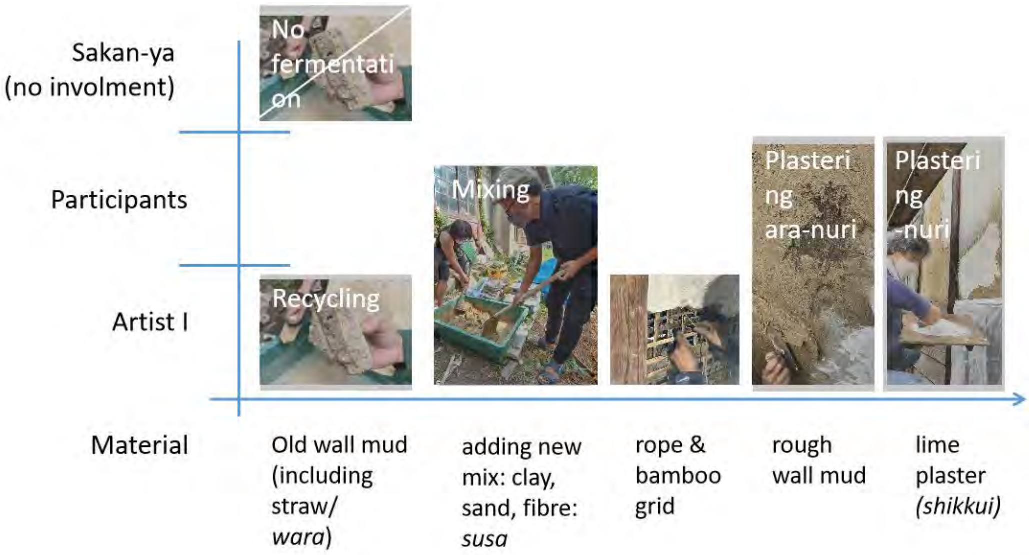



Figure 4. 20 Steps on plastering damaged wall

The workshop activities are followed with visit to artist's works in a campus of art university, west of Kyoto. Two buildings made of timber structure and bamboo mud-wall are notable for the improvisation of technique and material. The 'Tsuchi no Ie' is a circular building in plan, which was built by teams of artist and mostly art students. It used newly developed mud-wall technique that use double layer of curved bamboo grid (figure 4.21), with gap or cavity. The main intention is to make thick wall, suggested to be resembling mud wall used in traditional *Ookabe* style-wall of kura store-house, but with fewer mud used, thus lighter as well.

The other nearby building is ‘Tsuchi-ukian’, using mud-wall more resembles more wall which is built using *shin-kabe* variant of tsuchi-kabe technique, particularly in its thickness. Like in the first building, the wall is shaded by roof eaves. Different from the Tsuchi no Ie, which roof is thatched from reed (*kaya*), the latter roof was built using halved bamboo culms of Moso bamboo (*Phyllostachys edulis*) (Figure 4.22). Finised by 2018, the bamboo for the roof were treated with oil in traditional technique of *Abura-nuki*. By 2022, it has weathered but serious deterioration has not really visible, and both the roof and wall have been suggested to survive past typhoon, which is trong enough to uprooted some mature trees nearby.

Figure 4. 21 New construction method of Mud-wall with adapted technique for ‘Tsuchi-no-Ie’ (Source: Inoue, 2021)

**Adapted Tsuchikabe Technique**

The case study above will be considered as variation of original technique, as an adapted tsuchikabe technique. The repair work as well as two mud-wall buildings visited have adapted to its immediate area, using abundant species Moso bamboo (*Phyllostachys edulis*), different from main species of Madake used in traditional Japanese buildings.

Continuing the original tsuchikabe technique, the grid is arranged mainly using slightly modified split bamboo. The split could be considered a simplest type of bamboo arrangement for wattle, possible to be done by semi-skilled worker. Considered integral part of traditional tsuchikabe technique is the daub part, utilizing the reversible state of the clay matrix. This allows for seemingly infinite reuse via hydration & mix of new and old mud material from dormitory building or rammed earth wall found near the campus, from which the earth was saved from being discarded after demolition of the old wall.

One of most work intensive part is in preparing the wall-mud and plastering the wall, originally require high level of skill. As an adapted technique, the case study attempted to simplify the preparation and the application of the mud plaster, taking into account of participatory nature of the building workshop.

Further adaptation is in applying diverse solutions. While the original tsuchikabe is flat, thin and specialized work, the result of the works in this case study is wall which is curved, thick (double-layered) and a general work, undertaken by non-specialist.

The wall repair workshop in Y dormitory exhibited a lesson for a durable and resistant wall. While it is not clear how many past repair, most damage is linked to insufficient protective element (cladding) to the mud wall and the bamboo grid, otherwise protected section show a much better condition. The life-span of adapted technique in case of 'Tsuchi no Ie' also reach around thirteen years, seems with minimal deterioration after past typhoon, despite such simple technique.

Figure 4. 22 Use of Moso Bamboo (Phyllostachys edulis) in Tsuchi-ukian

**4.2.5 Case Study 5: Brazilian Tsuchikabe**

The case study regards the technique transfer of Japanese *tsuchikabe* after the immigration of many Japanese families to Brazil. The technique saw use for the construction of their houses. The carried out interview discussed three cases: research on original Japanese immigrant house, heritage house renovation, and a Tsuchikabe workshop in 2013.

The Japanese immigrant houses in Ribeira valley, near São Paulo, Brazil utilized Japanese timber construction and mud-wall *tsuchikabe* technique for the non-structural infill. Adapting to different context, the use of material are changed from original Japanese technique by using alternative plant species of jucara (figure 4.24), as it is easier to find than bamboo. As currently it has been considered a protected species, following case of renovation and workshop had been done with alternative bamboo species, including ones uncommonly used in Japan, such as *Phyllostachys edulis* and *Bambusa Vulgaris.* The latter is not very compatible for the construction and the workshop at the university of São Paulo. For the plastering material, different with the case of original house which mainly different with used un-fermented soil, the heritage house renovation used rough wall mix has been prepared 4 months in advance. As a result, it has been suggested to form a natural polymer, which is impervious thus more durable and similar with original technique in Japan.

Figure 4. 23 Jucara plant seen from window of Japanese Immigrant house (source: Hijioka)

Figure 4. 24 Brazilian worker with *takewariki*. Split bamboo used for wall grid in the background.(source: Hijioka)

The workshop was based and supported by resulting research on the immigrant cases as well as by inviting professional plasterer (*sakan*) from Japan. (Figure 4.26). In case of construction by Japanese immigrants a century ago, the work done with limited supervision, by member of society who has some experience with mud-wall. Due to limited budget, works done by professional carpenter for timber framing followed by construction works by the families themselves, including the helping hands of the children. The preparedness suggested to made this possible, for instance was the mainly agricultural livelihood provide skill and time for such self-building. In addition, it is common for each family to bring complete toolboxes. Furthermore, learning opportunities also gained by exchange with native community, particularly in choosing good species for building material. It was suggested that using a remotely similar species found in Japan did not went well in term of durability, while in using different one such as Jucara allowed the mud-wall to last up to a century.

Figure 4. 25 Formerly one house of Japanese Immigrant in Brazil, now moved to an open air museum in Nagoya

Figure 4. 26 Japanese professional plasterer invited for workshop in Brazil (Source: Hijioka)

There is still uncertainty regarding the aspect of aesthetic and resulting affinity potential. It is suggested that there has been a new appreciation of the *Tsuchikabe* in Brazil and it also seen more favorable than native mud-wall of *Pau a pique* or *Taipa de mão*, of which well made examples getting harder to found due to displacement and security of the owner, often marginalized people. However, it was suggested that in the past Japanese immigrant living in rural area also saw tsuchikabe less favorable than concrete and brick houses found in cities.

Based on observation of Kubota house which has been moved from São Paulo and reconstructed in Nagoya, the refined quality could be seen from the appearance, particularly the white lime-plasterred (Shikkui) wall. At first glance it difficult to distinguish with any masonry plaster. It could be seen as aesthetic possibility even from such adapted technique of Tsuchikabe (Figure 4.25). Among the the repertoire of almost 500 houses in in Ribeira valley, they are considered as high quality houses, despite adversities and different nature from the origin of Tsuchikabe technique. As testament to durability of the wall in such context, are case of houses have been built more than hundred years ago and still standing. Achieved by appropriation of three resources of nature, intellect and social. This case is uniqueness allow to asses the use of mud-wall of Japanese tsuchikabe technique used in tropical context of Brazil.

### 4.3 Wall Types Observation

#### 4.3.1 Rounded Bamboo Wall - Type 1

The first classification for bamboo wall is the rounded type which is named in the way the main component still retain cylindrical character of the bamboo culm if seen in its cross section (figure 4.16). This include, whole (full-culm), halved culms or split culms. Seen from the state of its main component, this type use least transformed bamboo compared to subsequent wall types.

Arranged without weaving, some technique use nails instead such as Japanes *Tokusa* (Figure 4.27) type which use unique type of Japanese nail (wa-kugi). Alternatively, new modern tools such as nail gun also used to drive the nails, in cases found in Lombok and Kyoto. While such new tools improve the ease of construction, in both case high skill is required to select and arrange well shaped culms, in order to make a solid looking wall with less gaps.

Among various design of this type found in Japan, one type is Kennin-ji fence, named after the famous zen temple in Kyoto. While considered one of the basic type (Yoshikawa, 2001) it is also sophisticated and often done with high quality (Kawashima, 1976). While Kennin-ji fence emphasize the horizontal support poles, the Tokusa type visually dominated by verticality but similarly use a single row of vertical frets, vertical poles (*tateko*). With skilled work, well crafted and straight wall can be achieved.

Figure 4. 27 *Tokusa* type Wall

Figure 4. 28 Use of rounded bamboo for cladding the mud-wall of tea-house

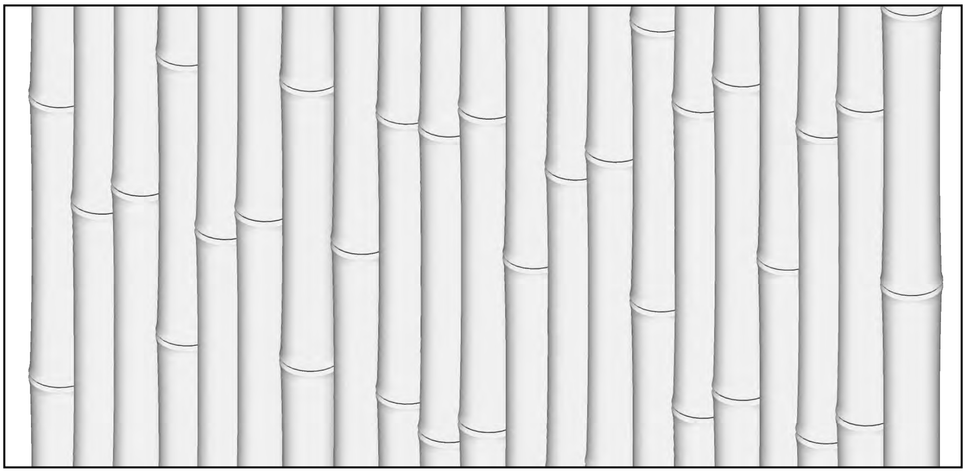


Figure 4. 29 Rounded type often use full-culm Bamboo

While not really common for main wall in Indonesia, the use of rounded type wall has been observed. In addition, use of bamboo wall with halved culm has been advised for post-disaster housing proposal (Suriansyah, 2009). In the proposal, the rounded type used for exterior side while the plait work for interior side, as the former is more weather resistant. Similar with Japanese where it protect mud-wall as a cladding. It shows the potential of this type as protective element, often easier to replace than the main wall it protects. The use of vertically arranged and tight rounded bamboo wall like *tokusa* within dry technique, less common to be plastered thus often exposed to weather.

### 4.3.2 Flattened - Type 2

The flattened bamboo, also called riven are produced modifying it from culm into flat sheets, possible using various bamboo species. One of the method is by longitudinally cutting, flattening and removing the softer interior of the bamboo culms (Vengala & Rao, 2020). Different tool and process also observed in Japan for flattening the primarily used species of *Phyllostachys bambusoide*s (Madake). While it can be done only with one tools and without removing softer interior of thinner bamboo it suggested to need higher skill especially to make a intact sheets from one culm, as seen in case study 3 (figure 4.9).

Depending on the species, skill and tools, the process might be easier. In Indonesian case with *Dendrocalamus Asper*, the job does not require high skill. Such thicker bamboo need additional process of thinning the thick culm wall, which process discarded most inner part of the bamboo thick culm.

Figure 4. 30 Simpler processing of flattened wall type in Lombok Island

Figure 4. 31 Wall sample using flattened bamboo

Figure 4. 32 Roof of small pavilion project using flattened bamboo

Figure 4. 33 Use of flattened bamboo for cladding (Shitami-itabari) in traditional Japanese house

Figure 4. 34 Drawing of flattened bamboo wall, based on Japanese hishigigaki.

In case of Latin America, example of flattened bamboo use is called *esterilla*. It often preferred as alternative to woven wicker-work type, due to no requirement of weaving process and skill, thus easier. The *esterilla* also possible to use as substrate for wet wall technique, plastered with mud or cement if using engineered bahareque method.

Similar with the type 1 (figure 4.27), flattened bamboo elements often used to clad and protect Japanese mud-wall (Figure 4.33). This is one potential of this type as protective element which is easy to replace than the main wall. Other than use for wall in Indonesia, the flattened bamboo also increasingly used for roof of bamboo project, often benefit from chemical preservation, such as in Lombok (Figure 4.32) and Bali, oftentimes the roof reach the ground vertically almost like a wall.

Figure 4. 33 Flattened bamboo wall within dry method, suggested more prevalent in Sikka, Flores, Indonesia after the 1992 earthquake (source: cendananews.com)

### 4.3.3 Woven Wicker-work - Type 3A

Using dry wall method, various usage of wicker-work bamboo could be observed in Japan and in Indonesian case of Naga village. From the case of Naga Village, it was used for most wall of the older houses, but for newer house, it is only for the kitchen wall, less used than plait-work type of woven wall.


Figure 4. 34 Ohtsu-gaki fence in Kyoto

Figure 4. 35 Wicker work for floor of Granary (*Takakura*) in Osaka

The first sub-type of woven bamboo wall is wicker work (type 3A). Among its characteristic is the use of thick split bamboo both for vertical and horizontal member, which is interwoven. In Indonesia, it is commonly known as Sasag or gedeg pattern, while in Japan one type of fence using this pattern is the Ohtsu fence. From both country it has been found diverse use of species, with mainly *Gigantochloa Apus* for the former and *Phyllostachys bambusoides* (Madake) for the latter.

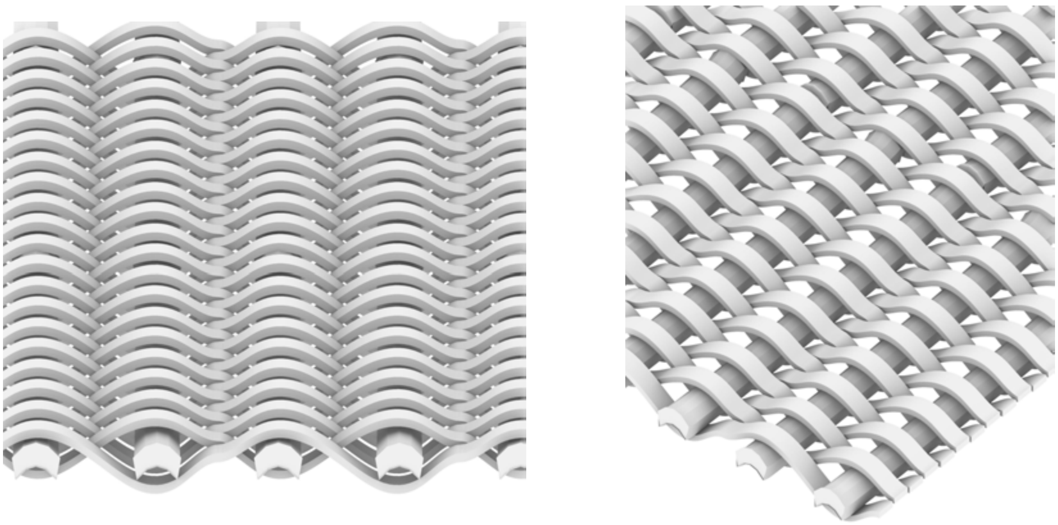


Figure 4. 36 Woven wicker work drawing based on wall and ventilation panel in Naga Village

Its use in Latin American countries, is considered common using dry technique as well as wet technique for wall such as traditional as well as engineered *bahareque*. On the other hand, its use within wet method of mud-wall is less common in Japan. It has suggested to be used for t*suchikabe* in the past*,* before mostly substituted into the bamboo grid type of *Takekomai* (Reynolds, 2009). As comparison, the use of wet wall with woven wicker work as well as bamboo grid derived from Japanese *tsuchikabe* has been suggested in Taiwan (Chang & Hsu, 2010). Use of plastered wicker work also suggested in Sumatra, Indonesia (Figure 4.24)

The wide use of this type in various countries might be contributed by its ease to weave, compared to more complicated weaving technique of type such as the plait-work. It is also suggested that the easiest and less costly of Japanese bamboo fences is using this type (*Ohtsu-gaki*). *Ohtsu-gaki* has been suggested to be less prone to deforming or disintegrating and considered to have good performance. In Indonesia, it might not be found much in studied area, but such direct use of split bamboo without thinning might lessen its difficulties compared to the woven plait work.

Figure 4. 37 Wicker work used for wattle and daub in Sumatra (source: seismico.org)

Figure 4. 38 Wicker work wall protected by roof eaves in Naga village older building

In case of Japan, the wicker-work type is now mainly used without plaster. Its life-span for exterior fence is decent but limited to around one decade before needing replacement. In Naga village case, although its use is becoming less prominent than plait-work, it has longer life-span if protected by roof eaves, such as among older building in the village (Figure 4.40).

Compared to plait-work, this type uses thicker split bamboo which irregular characteristic results in wider gap. While it might provide less privacy, it is actually encouraged to use as kitchen wall in Naga village to allow ventilation and disaster prevention, by making visible any left out stove fire.

**4.3.4 Woven Plait-work - Type 3B**

This study distinguish woven plait-work type from the previous wicker-work. The former has tighter weave as it often use thinner (or thinned) split bamboo. This type is widely used in Indonesia within the patterns called as *kepang* or *mata-wali* (Figure 4.41 & 4.42).

Extensive use of plait-work bamboo as the main wall type found in village of Sade and Naga. Similar type of woven bamboo and weaving pattern also found in Japan (Figure 4.4.1). In both Indonesian case, its use a matrix of white lime on the exterior. It was applied on outer face of the split bamboo culm, with its cortex unshaven in case of Sade, as it is considered more weather resistant. Lower elevation of roof eaves also allow more protection from water action. The technique of using lime render and roof protection can be seen as vernacular solution to the vulnerability of bamboo material when used as thin exterior wall.

The use of this wall type in two village which are thousand miles apart exhibits the widespread of this material in Indonesian archipelago, but it becoming less common. One explanation is that bamboo mat wall has been the target of replacement through government policy, since Dutch era (Ignasia, 2008; Armand et al., 2015) and New Order era (Djajadiningrat, 1995).

The two cases saw that village custom restrict the house number, type, and housing material. However both cases has a growing population, partially only able to settles outside the customary area of jurisdiction. Such outside area, displays less affinity to using bamboo material, with mainly plastered brick masonry replacing bamboo for wall. Beside for perceived status and convenient, replacing the thin bamboo plait-work wall was suggested due to safety concern as the periphery area easier to access and often less tightly-knit socially than the core village area.

Figure 4. 39 Plaitwork in Japan, resembling Indonesian pattern of mata-wali

Figure 4. 40 Thin characteristic of the woven plait-work, drawn based on kepang pattern

### 4.3.5 Bamboo Grid - Type 4

Observed in cases of vernacular architecture in Japan, the much practiced mud-wall technique of *tsuchikabe* shows that bamboo was used in a widespread manner in Japan.

While wattle and daub technique has been used in many regions, the Japan case exhibits a strong integration with mainly timber architecture. It might be possible on account of unique use of bamboo in a grid arrangement within a mainly rectangular timber frame system. Grid can basically be seen as giving an ordered arrangement even for characteristically irregular bamboo.

The main bamboo component in *Shin-kabe* technique used in Kyoto is usually split bamboo, it is relatively less transformed wit less processing requirements. In Kyoto, professional plasterer ends up learning to also made the grid arrangement of Take-komai. Supporting its potential of self-build bamboo grid assembly is suggested to be possible without weaving skill and it is considered simple and convenient way of arranging bamboo (Mud-wall artist I). For adapted tsuchikabe technique in case 4 and 5, saw the grid assembled by semi-skilled worker.

Tsuchi-kabe with adapted techniques also constructed with alternative species of bamboo, substituting Madake in original technique. This is supported by the fact that most different species could be split into more or less straight lath. In addition, bamboo grid with its spacing reduce use of material compared to the plastering whole surface of woven bamboo for instance.

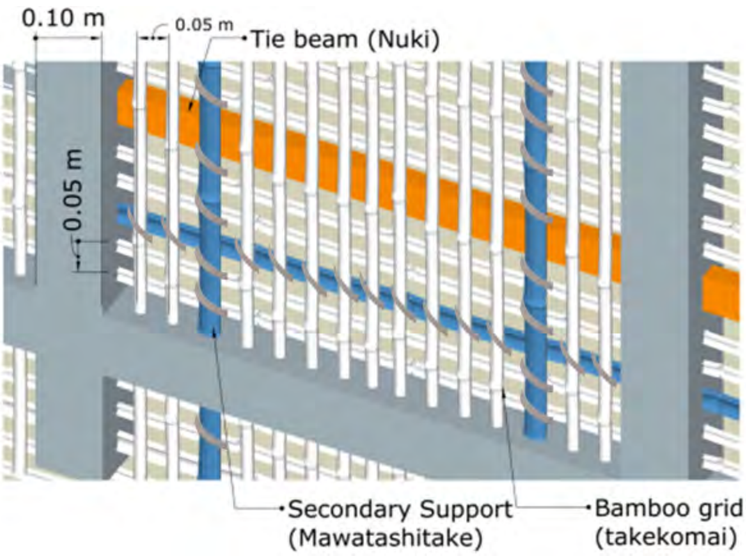



Figure 4. 41 Schematic drawing of bamboo grid use as substrate of Japanese *Tsuchikabe* technique

For lashing process of grid wall, one material considered important is the natural rope (*nawa*) which is used to tie the bamboo grid with bamboo main support (*mawashitake*) and with timber tie beam (*nuki*)(Figure

4.43). Important consideration for choosing the rope is the thickness, because if it is too thick it will become too hard to handle meanwhile if it is too thin, the rope could decompose more easily, considering the fact of it being organic material embedded in mud-wall.

Use of bamboo wattle and daub can be seen as hybrid material use in multiple scales from larger bamboo grid, rope, vegetal fibre mixed in the daub, finer fibre embedded in lime plaster (Shikkui) down to the loam particle of the daub. The nature of hybrid technique such wattle and daub means that component other than bamboo which is also important is the daub. Grid may act as net through which the daub mixture can not pass, but instead 'clawed' and bond with the grid which get stronger as the mud shrink along with drying period after moisture activates its binding strength and achieve workability (Minke, 2006).

In Japanese *tsuchikabe* technique, the mud plastering is done by the Sakan plasterer. With the complex technique seen in original technique in Kyoto, often requiring years to master. Alternatively, the case studies demonstrate the adapted technique of *tsuchikabe* made by children, family members, dormitory inhabitant, art students. In addition, mud material also sometimes substituted with cement for plastering the bamboo grid (Muliawan 2014; Vengala & Rao, 2020). While the quality might not be comparable, it is seen that adapted technique provide alternative and simplified version, more compatible with self-build.

One main design intention for Japanese mud-wall are life-span of the wall, possible as the bamboo grid as substrate is protected by **layers** primarily of mud, starting from **inner**-most towards **exterior**:
ara-nuri 荒塗,
nakanuri 中塗,
uwanuri, 上塗 - as the outer layers include the thin lime layer (Shikkui)

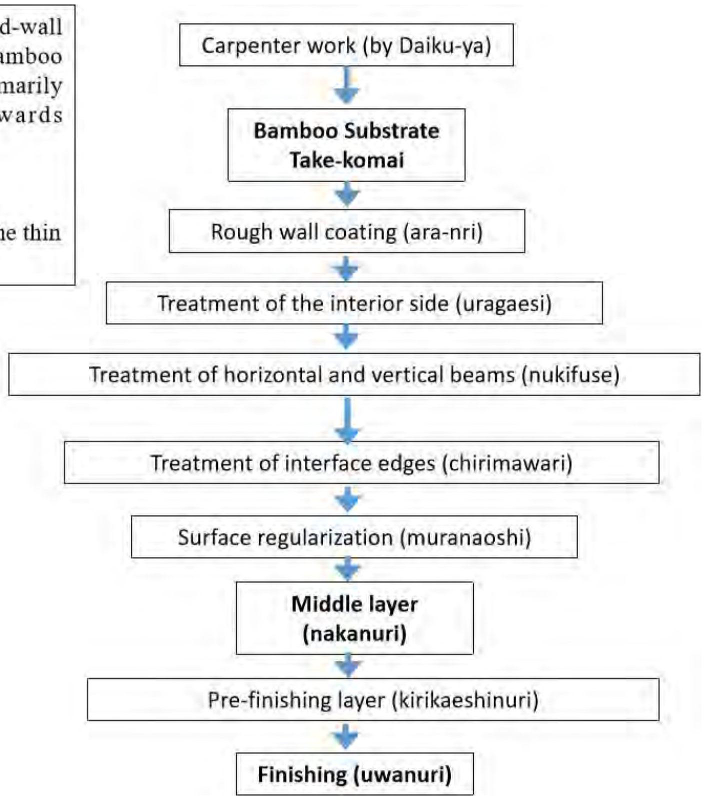



Figure 4. 42 *Tsuchikabe* Plastering within Sakan Technique (Partially modified from Hijoka, 2013)

**Protective Elements of Bamboo and Mud Wall**

Extended life-span of the wall was found in Kyoto cases as well as on transferred technique in Brazilian cases, with some of the house wall can survive up to 100 years. Even the Tsuchi-no-ie (Case Study 4) built with simplified method has stand for thirteen years in Kyoto.

In addition to the bamboo grid being protected from rain and ultra-violet by mud-plaster, use of cladding suggested to also improve the mud-wall protection, preventing water exposure and damage to the mud-wall. The cladding element has been made using similar bamboo with one used for fence such as flattened *hishigigaki* or rounded *Tokusa.* In Y dormitory, various damage to the mud-wall seen in places which clapboard for cladding is not intact. Alternative use of grid-wall with cladding also seen in cox's bazaar shelter case, with its use as dry wall clad with shelter grade tarpaulin sheeting.

**Aesthetic Possibilities**

In addition to protective role, interviewed experts also suggested that the use of cladding has been done for aesthetic reasons. In addition to this, tsuchikabe also has other aesthetic possibilities from use of various finishing from exposed rough mud of *Arakabe* to smooth white lime finnish of *Shikkui* (Figure 4.45).

Figure 4. 43 Artist I applying thin layer of white lime (*Shikkui*)

Based on brief workshop experience working with the grid (Case 4), straight angle of timber frame and the flatness of bamboo grid might help in achieving flat plastered surface, not unlike plaster on masonry wall. This might provide affinity points in terms of aesthetic, in adapted cases and even more so in original technique by Sakan plasterer in Kyoto. In such wall, the grid became base to a refined plastered wall, to some extents that the bamboo use is often overlooked. In addition, adapted technique by the artist I also produce thicker and curved mud-wall, with main structure using full-culm bamboo. Arguably this extends the possibilities of the use of bamboo grid.

There are many complexity in the technique contribute to refined quality shown in original case of mud-wall in Japan, particularly Kyoto.  In comparison, on the adapted case it show the potential of the flexible grid to be well adjusted with different variables of material (the frame, wattle and daub), shape (flat or curved) as well as self-build or high craftsmanship methods.

Use for curved wall in Lombok

Use for curved wall in Shikoku

Figure 4. 44 use of grid for alternative curved wall shapes

**4.4 Discussion**

Bamboo has been use for wall in extensive area and diversely, within dry and wet methods. There are five types established for this study, able to be observed from cases in Indonesia, Japan, and Brazil. Among which some commonalities have been observed, the first is related with one principle of vernacular architecture which is slightly transformed material. The least transformed form of bamboo is full culm, used in Rounded Wall (type 1) followed by split bamboo, used in Grid wall (type 4) and woven-wicker work (type 3b). Secondly, all of the case study exhibit an extended life-span, with bamboo elements commonly protected by other elements such as roof eaves, cladding, as well as other material used within hybrid technique such as mud or lime, which act as a more resistant screen against exposure to elements.

When linked to use of  in post-disaster housing, the first common principle of slightly modified material potentially fulfill the aspects of availability, cost, environmental impact and self-build. The second common principle of extended life-span is considered a mutual aspect required in both vernacular architecture and post-disaster housing. The potential of such life-span can be seen contributing to the aspect of environmental impact and affinity.

The challenges of post-disaster housing exhibited on chapter 3 are aspect life-span and affinity. In addition, other aspect which are considered for post-disaster use of bamboo wall techniques includes availability, cost, environmental impact and self-build. The vernacular techniques in this chapter shown potential of extended life-span, including in woven plait-work (Type 3b). As comparison, similar use in post-disaster housing case 2 in Yogyakarta saw limited use for semi-permanent functions. Considering affinity, there is still uncertainties especially on use of durable dry wall technique (Case 1 & 2) as the use is tied to customary law, and when new family moved out of the village, many suggested to discontinue the use of bamboo for wall. On the other hand, the use of wet wall technique in Japan show aesthetic possibilities as it can be finished smoothly as well as promote involvement. In Brazil, such adapted *tsuchikabe* case also suggested to gain more positive association compared to native wattle and daub technique.

## Chapter 5 Finding and Conclusion

Through the wall classification method proposed in Chapter 2, various bamboo wall types has been identified from cases studies of vernacular architecture. With consideration of case study of bamboo wall use for post-disaster housing in Chapter 3, the chapter will propose practical recommendation on each generic types of bamboo wall with emphasis on self-build and extended life-span, both among the value of vernacular and bamboo architecture which are also relevant with need of transitional shelter.

### 5.1 Past Cases and Considering Bamboo Wall for Post-Disaster Housing

#### 5.1.1 Past Cases of Bamboo Wall for Post-Disaster Housing

Seen from the use in past case of post-disaster housing, some bamboo wall types has not seen much utilization due to some factors identified in chapter 3 and 4. Later summarized in this chapter will be the positive and negative factor affecting the potential use of each wall type.

The rounded bamboo wall (Type 1) is considered an intricate type, needing skills to make a well crafted arrangement, as observed in *Tokusa* type in Kyoto. While it can be simple to construct a make-shift version, it might not provide much protection as a wall. The wall type was partially suggested in proposal (Suriansyah, 2014) but it saw limited use in post-disaster housing.

For other wall type particularly flattened bamboo (Type 2) and bamboo grid (Type 4), the use for post-disaster housing has been recorded, with potential when seen in the aspect of self-build and extended life span. The former saw many use with examples in Ecuador and Nepal, while the latter used in case of Cox's bazaar examined in the Chapter 3, in addition to other examples in Ethiopia. Both wall type has been considered easy to process.

The woven bamboo of Type 3A and 3B, could be considered as the most commonly used type of bamboo, although the requirement of weaving skill need to be addressed, for instance thorugh pre-fabrication of wall panel like in Yogyakarta, alternatively the woven wall saw substitution with easier type, such as the grid (type 4) used in Cox’s Bazaar case. The woven wicker work bamboo wall (Type 3A) suggested to be used in post-disaster in Latin American country, particularly the locally familiar type of plastered *bahareque*. This suggests its potential to transition into more durable wall through the compatibility of this type with wet wall method.

one drawback for using the woven wall of Type 3a is that its looser weaving has more gaps. In vernacular setting such as kampung Naga, it has been used mainly for ventilation and less for main wall compared to tighter weaved plait-work. Before it can be plastered, transitioning it from dry into wet wall, the wicker work type advised to use additional element e.g screen to provide more protection especially from disease vector e.g. mosquitoes.

Lastly, the woven plait-work type has seen extensive use for post-disaster housing, for instance in Myanmar, Philippines and Indonesia. Learning from Indonesia's Yogyakarta case in chapter 3, its use might be prolonged (2006-2015). However the wall type seems not preferred for main houses, but instead for annexes. As comparison,  the use this type is more preferred in Indonesian vernacular cases in Chapter 4, in two village in different island.

### 5.1.2 Discussion on Bamboo wall type

The first part of this section is the summary of qualitative description so far on bamboo wall types (Table 5.1). It will be followed by the summary of wall potentials which qualitative scoring will be explained further in the appendix 7. Lastly, there will be discussion of each wall types.

Seen from the aspects of low-cost and low environmental impact, all wall types have decent potential. The potential of bamboo as a material which is easy to be localized, has been achieved by utilizing its availability and possibility of self-build. Utilizing the  potential of availability is exhibited through less reliance on single bamboo species for weaving or wattle for grid type. For wet wall technique, this potential also possible through adapted method for the wall plaster (daub).

The types of woven-wicker work (type 3a), adapted grid (type 4b) and flattened (type 2) mostly utilized slightly modified forms of bamboo which allow involvement of self-building, thus valuable for post-disaster housing use.

For the aspect of life-span and affinity, some wall types addressed the limited durability and provide aesthetic possibilities, mainly due to its compatibility for hybrid use with wet wall technique (plaster). Such potentials are exhibited by the type of woven-wicker work (type 3a), grid and adapted grid (type 4b) and flattened (type 2) .

Table 5. 1 Summary of Bamboo Wall Types Potential

**1). Potential: Values of Bamboo Use in Post-disaster housing**

**d. Low-environmental impact**

**c.Low- cost** | **e. Life-span** (e=1.67) | **b. Self-build** (e=1.67)

**a.Availability** (e=1.67) | **f. Affinity** (e=1.25) | **Low-cost**

**2. Assesing bamboo wall types from cases of vernacular architecture**

| Observation Items: | Substitute material | Dry wall method | Type of Proces-sed bamboo | Reduced material use | Reuse of material | Life span (obser-ved) and past-cases | Durability by design (protected/ protecting) | Wet wall method | Both Wall Method | Challenge in processing |
|---|---|---|---|---|---|---|---|---|---|---|
| Type 1 Rounded | Fair | Good | Good | Good/fair | Fair (n/a) | Good/fair | Good/fair | Fair | Fair | Fair |
| Type 2 Flattened | Good | Good/ Fair | Good/fair | Fair (Indonesia) | Fair (n/a) | Good/ | Good | Good | Good | Good/ Fair |
| Type 3a Wicker-work | Good | Good | Good | Good | Fair (n/a) | Good | Good | Good | Good | Good |
| Type 3b Woven plait-work | Good | Good | Good/fair | Good | Fair (n/a) | Good/fair | Fair | Fair | Fair | Fair |
| Type 4 Grid | Good/Fair | Good | Good | Good | Good | Good | Good | Good | Good | Fair |
| Type 4 (adapted) | Good | Good | Good | Good | Good | Good | Good/fair | Good | Good | Good/Fair |
| Correspon-ding principle of vernacular architecture | Local resource and adapta-tion | Reduction of Material | -Slightly transfor med material -Less machine ry | Reduction of Material | -Reduction of materials - Embodied energy reduction | Extended life-span | Resistant material<br>Replaceable element | Resistant material | Diversity of solution (aesthe-tic poten-tials) | Self-build<br>Skilled labour |

1. On the first row, the description and scoring from chapter 4 identify how each wall type has potential on six values of:

- Availability (e=1.67)
- Self-build (e=1.67)
- Low-cost
- Low-environmental impact
- Life-span (e=1.67)
- Affinity (e=1.25)

In addition, equalizer (e) has been applied for adjustment as some values supported by more number of observation items (for instance, low-cost relate to more observation items than affinity)

2. For assessing bamboo wall types, the observation items are derived from the principles of vernacular architecture (Guillaud, 2014). Their availability are based on field study and interview.

Primarily for visualizing, three grade of qualitative scoring is given for each observation items, on five wall types (left-most column)

The score as follows:

- Fair: 1
- Good/Fair: 2
- Good: 3

**Type 1 - Rounded Bamboo**

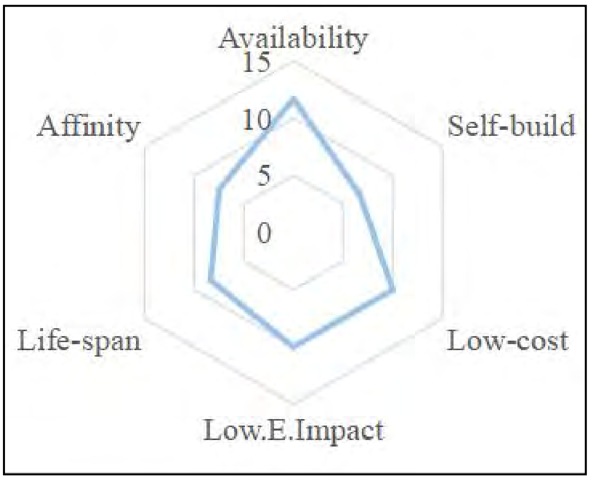



Figure 5. 1 Summary of Wall Potentials: Type 1

Use of the rounded bamboo wall (Type 1) for post-disaster context might be challenging in the aspect of self-build, cost and life-span. This type is often difficult to construct with requiring skilled labour to construct a well functioned wall.

The wall type has limited option to be used with other resistant material, such as mud plaster in wet-wall technique. However, it could offer alternative potential to extend its life-span learning from Japanese case where it saw various use for cladding elements. It might be used to protect main part of the wall from high precipitation in Indonesia, benefited by its minimal and slightly transformed form as it use most of bamboo part, reducing waste and impact to environment.

**Type 2 - Flattened Bamboo**

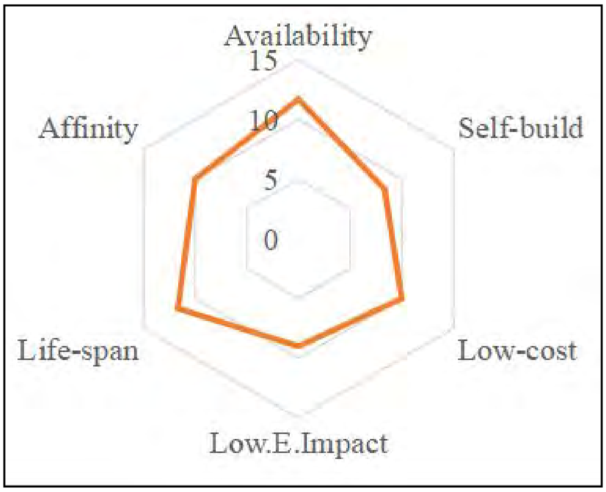



Figure 5. 2 Summary of Wall Potentials: Type 2

The type 2 saw various use for cladding elements in Japan. Its potential in Indonesia allow the type to be commonly used for roof of contemporary bamboo projects, a testimony to its good durability especially when properly preserved.

While the processing is not difficult with thick walled species e.g. *Dendrocalamus Asper* or *Guadua angustifolia 'Kunth'*, the process is still not short and it also discarded the inner part of culm wall, thus less favorable when seen from environmental impact.
Regardless, the processing ease and durability make the type 2 as an potential alternative to woven bamboo wall of type 3, with further possibility of improving the life-span by applying plaster to this wall through wet wall technique.

**Type 3A - Woven Wicker-work**

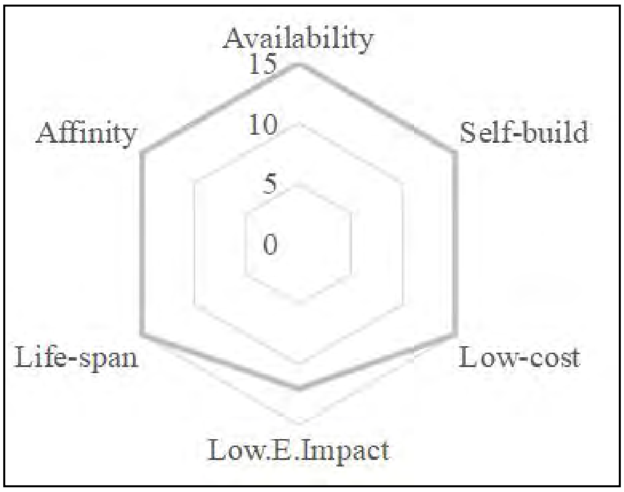



Figure 5. 3 Summary of Wall Potentials: Type 3A

The woven wall type of wicker work, might be less used for post-disaster housing in Indonesia, one drawback for using this kind of wall is the looser weaving has more gaps. In vernacular setting such as Naga village, it is used mainly for ventilation and less for main wall, if compared to tighter weaved plait-work. Before it can be plastered, transitioning it from dry into wet wall, the wicker work type advised to use additional element such as screen to fill the gaps and provide more protection especially against disease vector e.g. mosquitoes.

For it potential, it has good compatibility with wet wall method, increasing its life-span and potentially the aspect of affinity with such aesthetic possibilities. The looser weaving compared to plait work also considered easier to make involving self-build while it able to use a less transformed type of split bamboo which is also thicker and sturdier.

**Type 3B - Woven Plait-work**

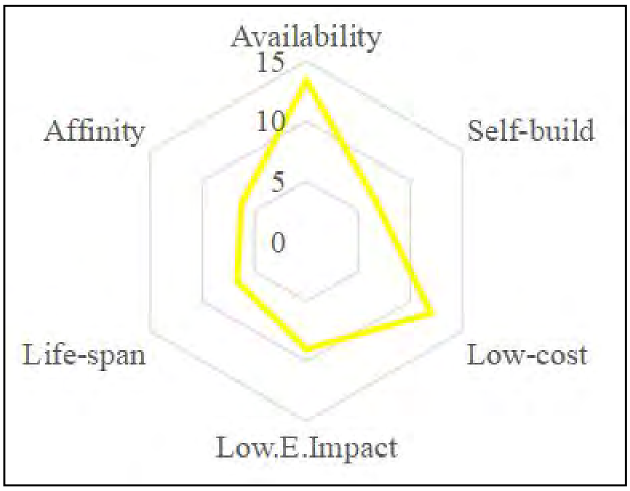



Figure 5. 4 Summary of Wall Potentials: Type 3B

Woven wall type within the so-called plait-work type has been found in all Indonesian case studies. Different with vernacular setting, the self-build aspect for using in it in post-disaster might be challenge due to requirement of weaving skill.

Improvement on the aspect of life-span and affinity for this type of wall might be limited. Different with Type 3A of woven wicker-work , this wall mainly used for dry method with no benefit or protection from plaster. Issue of its life-span was also seen on its use in Japan, which is only recommended for interior use.

High aesthetic valuation can be seen in vernacular case where this wall is rendered beautifully and well protected using lime plaster. However, the affinity which motivate the use of this wall type for permanent living function was less observed in place without customary law. The positive affinity of this wall linked with its role for ventilation in the tropic need further study, which also should consider the more prevalent use of window for role of ventilation, which has been an introduced element in vernacular architecture e.g. Kampung Naga. It is assumed that the thin characteristic (less than one centimeter) feels less safe outside of traditional community and also appear much different in thickness and surface than more familiar masonry wall.

**Type 4 - Grid and Adapted Bamboo Grid**

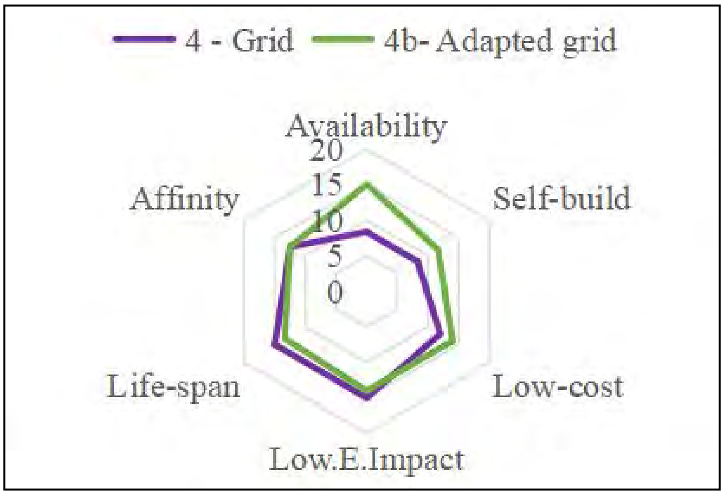



Figure 5. 5 Summary of Wall Potentials: Type 4 and 4B (adapted grid)

Bamboo grid wall could be seen as alternative to woven wall, especially for construction within wet wall technique or wattle and daub.

The issue on the aspects of availability and self-build has been found as original tsuchi-kabe often rely on use of one bamboo species of Madake and sakan technique which high skill is required for the crucial plaster layer. Regardless, the two aspect seen to be addressed in adapted technique in Brazil and Japan where the use of substitute bamboo material has seen to possible and hybrid material of loam for the plaster has been made simpler. While cement plaster has been used in Indonesia as one alternative material for this wall type, one merit was learned from Japan case using mud plaster. The use of non-industrial material of mud allow high degree of local resource usage which also suggested to be infinitely recycle-able and widely available.

The grid often made by utilizing culm from local bamboo species, directly usable after slightly transform it into bamboo lath. The grid spacing allow it to reduce the amount of bamboo raw material required and subsequently the cost. The grid arrangement is also considered simpler without weaving. It allow high-involvement of non-skilled worker and workshop, seen on adapted case in Japan and Brazil which exhibit potential of  self-build. The use of flat mud plaster and lime render with bamboo grid, contribute to its aesthetic, potentially improving affinity.

Protected by the use plaster, extended life-span has been seen in original tsuchikabe in Japan as well as in adapted cases of Brazil and Japan. Commonly durable in its original and adapted technique, the wall withstand the humidity in Japan. Alternatively, one possible substitute material for protection in emergency setting is tarpaulin, seen to be utilized in Bangladesh case.  For its life-span in Indonesia, the use of cladding (*shitami-itabari*) is a potential lesson from Japan, to protect the mud wall from rain thus improving its life-span in tropical climate, through durability by design.

The use of bamboo grid wall with dry as well as wet technique is potential for post-diaster housing in Indonesia, for use beyond temporary housing. This is concluded by taking into account the balanced potential of availability, self-build, environmental impact, affinity and past case of use in Indonesia after disaster. Learning from post-disaster case study, its use within dry method could make use of tarpaulin cladding and bamboo culm structure, afterward it could transition by using wet technique of plastered wall, allowing protection for bamboo durability and aesthetic possibility of plaster.

### 5.1.3 Discussion: Considering Bamboo Wall for Post-Disaster Housing

Considering change is often inevitable when seeing post-disaster housing as process. It is suggested for this context to use bamboo material within the wet wall technique of wattle and daub, with plaster of mud or cement plaster as alternative. The technique considered beneficial in aspect of availability, environmental impact, cost, self-build, extended life-span and affinity by providing aesthetic possibilities.

If homogeneous or dry type of bamboo wall is used, it is advised to choose one which could be plastered for the later such as Flattened bamboo culm (type 2), woven wicker-work (type 3A) or Bamboo grid wall (type 4). Use of wall type which is compatible with both technique potentially extends the life-span of wall element, which in turns, expands the role of bamboo material for post-disaster housing by allowing transitioning from temporary into permanent house.

## 5.2 General Conclusion

In the context of post-disaster housing, extensive use of bamboo has been identified. In the context of vernacular architecture, extended life-span of bamboo wall element has been exhibited by its use beyond temporary. It is possible as limited durability of bamboo has been addressed in various vernacular cases of bamboo wall. Learning from the cases, the use of bamboo wall beyond temporary should also be possible for post-disaster housing, allowing transition and use for permanent housing.

Various bamboo wall techniques exhibit easy localization of the material, possible using local material and local skill without complete reliance on single bamboo species or skilled worker. It shows the potential on the aspect of availability and self-build, which are beneficial for post-disaster housing requirements.

A material from grass family, bamboo has potential as widely available material which could support the need for post-disaster housing with extended life-span and allow people to drive their own recovery, particularly in constructing their own dwelling, in other word through a ‘grass root’ motivation.

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## Appendix


I. Appendix 1 - Notable Case of Original Bamboo Shelter Use in 2015
II. Appendix 2 - Vernacular Bamboo Use Workshop
III. Appendix 3 - reviewed benefits of bamboo use
IV. Appendix 4 - Photos of Main Interviewee
V. Appendix 5 - Questionnaire
VI. Appendix 6 -Memo of Discussion
VII. Appendix 7 -Scoring Table for Wall Type Potentials
VIII. Appendix 8 - Thesis Defence Presentation