ADB

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TA-10261 REG: Supporting Innovative and Sustainable Financing

Social Impact Report on Bamboo Agroforestry

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For The Asian Development Bank

ABBREVIATIONS

ADB	–	Asian Development Bank
ASI	–	Assurance Services International
CBFT	–	Cement bamboo frame technology
CPI	–	Clean Power Indonesia
CTI	–	Circular Transition Indicator
DMC	–	developing member country
DTI	–	Department of Trade and Industry
EIV	–	environmental impact values
ESG	–	environmental, social, and governance
FSC	–	Forest Stewardship Council
GDP	–	gross domestic product
GRI	–	Global Reporting Initiative
ISO	–	International Standards Organization
LBL	–	laminated bamboo lumbar
LCA	–	life cycle assessment
MEWLAFOR	–	Maintaining and Enhancing Water Yield through Land and Forest Rehabilitation
NBM	–	National Bamboo Mission
OSB	–	oriented strand board
PRC	–	People's Republic of China
SDG	–	Sustainable Development Goal
UN	–	United Nations
WSB	–	woven strand bamboo

Note: In this publication, "$" refers to US dollars.

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EXECUTIVE SUMMARY

Bamboo, a type of woody grass that grows rapidly and is a sustainable alternative to traditional timber, has about 1,400 known species worldwide. There is an estimated 35 million hectares of bamboo resources globally, with 24.9 million hectares in Asia. A stable local market typically exists for bamboo products in countries where bamboo is indigenous, and it has long been used as a traditional housing construction material. International market is also growing for bamboo-derived products. Bamboo is a versatile fuel source, and is considered as a renewable source because new culms grow from existing clumps after harvesting, and it does not require replanting.

Bamboo can have the same tensile strength as steel, and better thermal properties than reinforced concrete. It has a shorter growth cycle and better carbon sequestration properties than timber: per hectare, bamboo sequesters 1.46 times the carbon of fir forests and 1.33 times tropical rainforests. It is more amenable than other low-cost bio-based materials for transformation into high-quality building materials through advanced production technologies.

Value-chain analyses of the bamboo sector in numerous countries point to a common theme: demand is growing for bamboo-derived products, but the bamboo sector is not well-positioned in many countries to take advantage of this opportunity. Few countries have a national or regional strategy for developing the bamboo sector, yet many of the obstacles can only be addressed with government support and intervention.

Affordable, disaster-resilient housing is one of the most pressing issues for developing countries. In the face of a chronic and growing need, views of bamboo as a building material are polarized. On one side, bamboo is viewed as a “poor man’s timber,” the housing as “shabby,” and therefore less socially valued than modern dwellings of brick, cement, and concrete. On the other there are modern, bamboo structures, such as those built using cement bamboo frame technology, an innovative construction technology that uses treated, load-bearing bamboo as its sole structural element.

Bamboo housing has a unique role in post-disaster recovery, as both temporary and long-term shelter, because it frequently grows in regions that are susceptible to hurricanes and typhoons, stands that have been flattened during storms can be repurposed immediately to construct temporary shelters. Traditional bamboo structures also have excellent seismic performance during earthquakes

Bamboo has been described as a powerful ally in the fight against climate change, land degradation, and environmental sustainability, due to its propensity for rapid growth, hardiness, remarkable carbon sequestration capacity, and as a replacement for other materials with a larger carbon footprint. Bamboo, and bamboo agroforestry in particular, can play an important role as one of a suite of options used to rapidly regenerate degraded lands and reduce soil erosion. When bamboo is used for engineered construction materials, the chemical treatments it undergoes can extend its lifespan from 2–3 years in its natural form to 30–40 years. As such, the carbon stored in natural bamboo remains there throughout the building’s lifespan.

Bamboo cultivation could potentially be used to generate carbon credits in three key ways. First, planting bamboo in degraded or deforested areas can create new carbon sinks. These projects can be certified to generate carbon credits based on the amount of carbon sequestered by the bamboo. Second, integrating bamboo into agricultural systems can enhance carbon sequestration while providing additional benefits such as soil stabilization and improved biodiversity. These integrated systems can also qualify for carbon credits. Third, projects that

promote sustainable bamboo harvesting and processing techniques can generate carbon credits by reducing emissions compared to conventional practices.

Bamboo agroforestry could be used toward a country's national determined contributions for reduction in carbon emissions. However, this will not be a short-term outcome, because 10 years of historical data is required to claim carbon credits. Generating this data in a way that is sufficiently rigorous to be recognized for carbon credit purposes is challenging, given the environments in which much of the world's bamboo is grown. Data will play a key role in addressing these challenges, such as geotagging the root of the bamboo; use of artificial intelligence or smart technologies for smart monitoring; and remote sensing, which could also be used to track, for instance, that the bamboo grows to a certain height before it is used.

The fact that bamboo is a natural, renewable resource is one of its greatest strengths, but it is also the source of one of the greatest challenges to promoting its use. The qualities of raw bamboo present a challenge to standardization, and therefore to measurement by global standards. Engineered bamboo products, especially those used in construction, are a relatively young industry. Standards by which to measure both the production processes and the products exist, but they may not be widely known or used. The International Standards Organization (ISO) has a technical committee devoted to bamboo and rattan and there are six ISO standards directly related to bamboo with more in the pipeline.

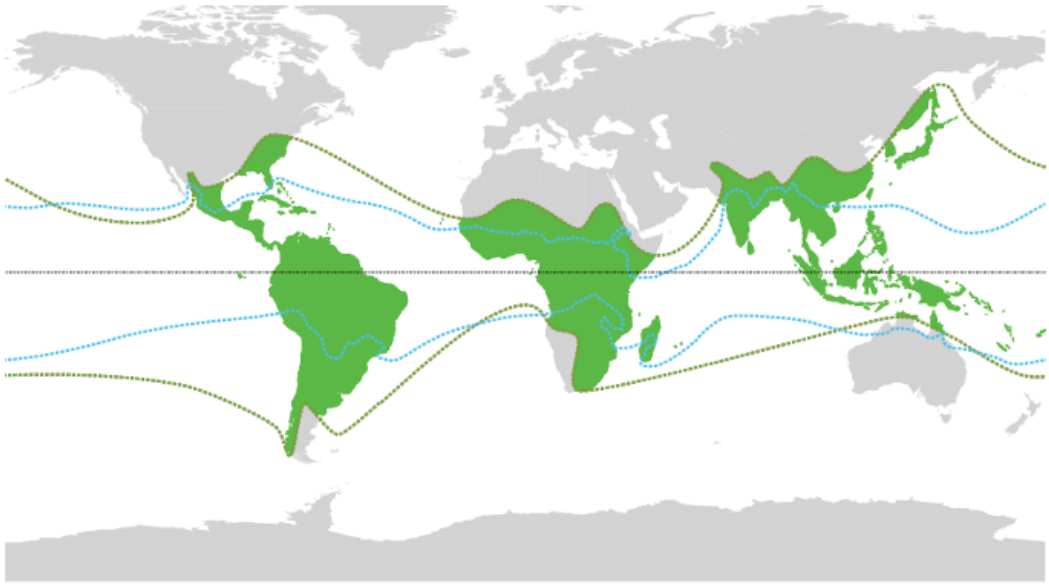
The Global Reporting Initiative Standards, widely used by organizations to report their environmental, social, and governance impacts, are highly relevant to bamboo agroforestry and associated industries. Similarly, circular economy principles, whereby materials never become waste and nature is regenerated, are especially applicable to the construction industry, because the built environment sector is one of the largest contributors to climate change. If bamboo is to fulfill its potential as a sustainable building material, and in fact as a material for other products too, its manufacture and use will have to adhere to circular economy principles. This requires effort and participation from different stakeholders, including policymakers, financial investors and developers, manufacturers, builders, waste managers, architects and engineers, as well as building occupants.

Bamboo is such a common plant across Asia and the Pacific that it is easy to overlook its transformational potential. From a social impact perspective, numerous steps can be taken to promote the bamboo agroforestry sector, and the sustainable use of high-quality bamboo materials, for both climate action and financial inclusion. This report's recommendations include ways to improve both supply and demand, including market development; education and knowledge sharing; incentivization for bamboo use in construction of affordable, resilient housing; and collaboration with other alternative materials sectors.

I. INTRODUCTION

1. Bamboo is a type of woody grass, comprising an underground rhizome system and above ground stems (culms) that range in height according to the species, from 50 centimeters (cm) to 35 meters (m) and up to 30 cm in diameter.[1] About 1,400 known species of bamboo exist worldwide, and they grow on several continents (Figure 1).

Figure 1:The World's Natural Bamboo Habitat



Note: Blue lines demarcate the world; tropical zone. The natural bamboo habitat is indicated in green.
Source: DE Hebel, F Heisel, A Javadian et al. 2015. Constructing Bamboo: Introducing an alternative for the construction industry. *FCL Magazine* Special Issue.

2. Bamboo grows rapidly and is a sustainable alternative to traditional timber, maturing in as little as 3 years, though more typically between 5–7 years.[2] Bamboo is well known for its versatility. It is widely used to make lightweight, economical furniture; durable, beautiful flooring; supple and hard-wearing textiles; pulp and paper; cooking and heating fuel; and even scaffolding for constructing skyscrapers. It can have the tensile strength of steel, but it can also be tender enough to eat.

3. According to a 2020 report by the Food and Agriculture Organization of the United Nations (UN), an estimated 35 million hectares of bamboo resources exist worldwide, with 24.9 million hectares in Asia.[3] Of that, over 17.87 million hectares are in Southeast Asia, and just over 7 million hectares are in East Asia. Bamboo is abundant in many Asian Development Bank (ADB) developing member countries (DMCs). The total bamboo area increased by almost 50% between

[1] International Bamboo and Rattan Organization (INBAR). Bamboo. https://www.inbar.int/why-bamboo-and-rattan/
[2] Reel. 2022. How Fast Does a Bamboo Grow in a Day? https://www.reelpaper.com/blogs/reel-talk/how-fast-does-a-bamboo-grow?srsltid=AfmBOopD9jZG8whiZaRK6Ix4oGLAIZku2aJ1Fvjqk4zaG5VoAOIhqc2a
[3] Food and Agriculture Organization of the United Nations. 2020. *Global Forest Resources Assessment 2020 Main report*. https://openknowledge.fao.org/items/d6f0df61-cb5d-4030-8814-0e466176d9a1

1990 and 2020, largely attributed to increases in India and the People's Republic of China (PRC), which, together with Indonesia, comprise the top three growers in Asia.

4. Bamboo agroforestry and associated industries have such significant potential economic and ecological benefits that they can help countries achieve several of the UN Sustainable Development Goals (SDGs), meet nationally determined contributions under the Paris Agreement, and other international development commitments such as the Aichi Biodiversity Targets.[4]

Strengths and Weaknesses of Bamboo Agroforestry

5. Bamboo agroforestry has strengths and weaknesses as a source of economic development. On the positive side, it is a versatile natural product with low environmental impact. It is fast-growing and is not susceptible to many pests and diseases. Bamboo can be grown together with other crops with commercial value, optimizing land use.

6. A stable local market for bamboo products typically exists in countries where bamboo is an indigenous plant, and the international market for bamboo-derived products, especially as an eco-friendly wood substitute, is growing. This global trend in demand for products that support environmental conservation has also created changes in energy production. Bamboo is one of the appropriate choices of plants to use for producing energy.

7. However, in most countries where bamboo is found, farmers lack the knowledge to manage a bamboo plantation, and they cannot easily access the information and research they would need to scale up commercially. Farmers often rely on middlemen to sell their bamboo, and the buyers tend to control the price. The three- to five-year time lag between planting and generating income for farmers is also a barrier.

8. New technologies are evolving to make ever more sophisticated bamboo products, notably for construction, but much of this technology is being developed in high-income countries. It is not easily accessible to potential entrepreneurs in the countries where bamboo is grown. As a result, there is little continuity in the development of bamboo industries.

9. While there is typically a government agency responsible for forest management, there is often no single agency responsible for driving the policy agenda for bamboo agroforestry.

Framing the Impact of Bamboo Cultivation and Use

10. The SDGs are a helpful way to frame the potential impact of bamboo agroforestry and related industries.

SDG 1: No poverty
Bamboo has been described as "green gold," due to its potential to alleviate poverty. Income from bamboo agroforestry, trade and transportation, and bamboo-derived product manufacturing can create new income sources, especially for grassroots communities and subsistence farmers. This can help alleviate poverty and improve livelihoods.

SDG 3: Good health and well-being

[4] Convention on Biological Diversity. Aichi Biodiversity Targets. https://www.cbd.int/sp/targets

Bamboo shoots are consumed as food in numerous Asian countries.[5] They are an essential source of nutrition, rich in protein, carbohydrates, vitamins, minerals, and fiber.[6]

SDG 5: Achieve gender equality and empower all women and girls
Because bamboo is lightweight and easy to process, it can support gender equality by providing opportunities for women to participate in farming, processing, and value-added activities, such as handicrafts.[7]

SDG 7: Ensure access to affordable, reliable, sustainable, and modern energy for all
Bamboo has excellent potential as a renewable energy source. Moreover, bamboo plantations can be established on degraded or marginal lands that cannot be used for food crops.

SDG 8: Decent work and economic growth
The bamboo sector can benefit all levels of enterprise, including micro, small, and medium-sized firms. It can help reduce rural outmigration by providing decent work in rural communities.

SDG 9: Industry, innovation, and infrastructure
As a fast-growing, eco-friendly natural resource, bamboo is attracting much attention from industries looking for an alternative to timber and plastics. It can be a material for innovative technology for both fuel and construction.

SDG 11: Sustainable cities and communities
Bamboo agroforestry can play a significant role in increasing the supply of sustainable, affordable, and disaster-resilient housing.[8]

SDG 12: Responsible consumption and production
Bamboo is an effective material and resource for waste reduction due to its potential for sustainable management, biodegradability, and effective use.

SDG 13: Climate Action
Bamboo can contribute to climate change mitigation through its carbon sequestration properties and climate adaptation through disaster-resilient housing. Bamboo's strong and flexible structure makes it resilient against earthquakes and typhoons.

SDG 15: Life on land
Bamboo agroforestry can help protect, restore, and promote sustainable use of land-based ecosystems, reverse land degradation, and halt biodiversity loss.

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[5] N Chongtham, MS Bisht. 2012. Bamboo as a functional food. IXth World Bamboo Congress. file:///Users/janeparry/Desktop/Bamboo-as-a-functional-food.pdf [xxfile cannot be openedxx]
[6] Nongdam P, Tikendra L. 2014. The Nutritional Facts of Bamboo Shoots and Their Usage as Important Traditional Foods of Northeast India. *Int Sch Res Notices*. Jul 20. 2014:679073. doi: 10.1155/2014/679073. PMID: 27433496; PMCID: PMC4897250.
[7] Gustari, A. F., Arif, M., & Nasution, M. L. I. 2024. Bamboo Crafts Business Development Model Reviewed From The Perspective Of Maslahah. Kontigensi : *Jurnal Ilmiah Manajemen*. 12(1). pp. 433–444. https://doi.org/10.56457/jimk.v12i1.555
[8] Bredenoord, J. 2024. Bamboo as a Sustainable Building Material for Innovative, Low-Cost Housing Construction. *Sustainability*. 16. 2347. https://doi.org/10.3390/su16062347

About This Report

11. This report examines the potential economic, social, and climate-positive impacts that can be gained by developing an end-to-end value chain for locally sourced bamboo. This includes its use as a building material for affordable and sustainable rural and urban housing and ancillary industries.

Data Collection and Analysis Approach

12. The information in this report was derived from an extensive literature review of peer-reviewed journals, gray literature, and interviews with key informants.

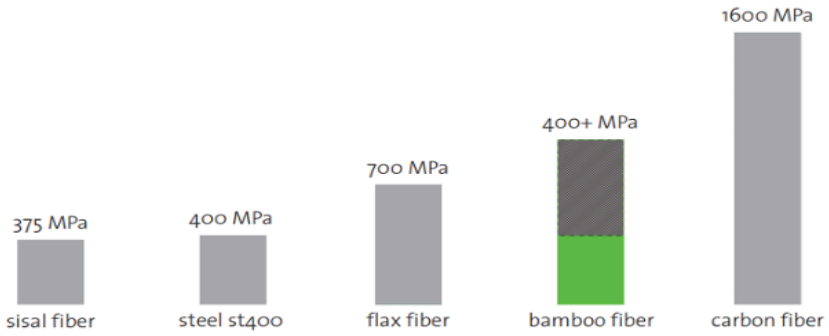
II. BAMBOO AS A BUILDING MATERIAL

13. The advantages of bamboo as a construction material can be summarized as follows:

- it can have the same tensile strength as steel,
- it has better thermal properties than reinforced concrete,
- it has a shorter growth cycle and better carbon sequestration properties than timber,
- it is more amenable than other low-cost bio-based materials for transformation into high-quality building materials through advanced production technologies. [9]

14. Housing is a key component of development, and using low-cost, environmentally friendly building materials can help ensure housing needs are met sustainably. Bamboo has long been used as a traditional housing construction material in areas where it is indigenous. However, it is still not widely used as a modern, sustainable construction material and has not reached its full potential as a replacement for main structural materials like timber, concrete, and bricks.[10] One of the reasons is a widespread preference for modern materials, in the mistaken belief that buildings constructed from these modern materials are, by definition, sturdier. Yet, bamboo is a good material for affordable, climate-resilient housing because it is durable, versatile, easy to fabricate, and a sustainable resource locally available in many places.[11] It should be noted that there is extensive variation across species in terms of the tensile strength of bamboo fiber, depending on the region and climate where it is grown (Figure 2).[12]

Figure 2: Maximum Tensile Strengths of Various Materials



MPa = megapascal, a unit of pressure commonly used in engineering and science.
Source: DE Hebel, F Heisel, A Javadian et al. 2015. Constructing Bamboo. *FCL Magazine* Special Issue. https://www.research-collection.ethz.ch/handle/20.500.11850/155584

[9] Royal Institution of Chartered Surveyors. 2018. Natural Building Materials: Bamboo. https://www.rics.org/news-insights/natural-building-materials-bamboo#:~:text=Bamboo%20has%20a%20long%20tradition,Guadua%20among%20the%20most%20common; and B. Zhao, Y. Yu, Y. Xu, et al. 2023. Bamboo as a sustainable construction material for residential buildings in the cold and severe cold regions of China. *Architectural Engineering and Design Management*. 29 March. https://www.tandfonline.com/doi/full/10.1080/17452007.2023.2195614?scroll=top&needAccess=true

[10] S. Habibi. 2019. Design concepts for the integration of bamboo in contemporary vernacular architecture, *Architectural Engineering and Design Management*. 15:6. pp. 475–489, DOI: 10.1080/17452007.2019.1656596.

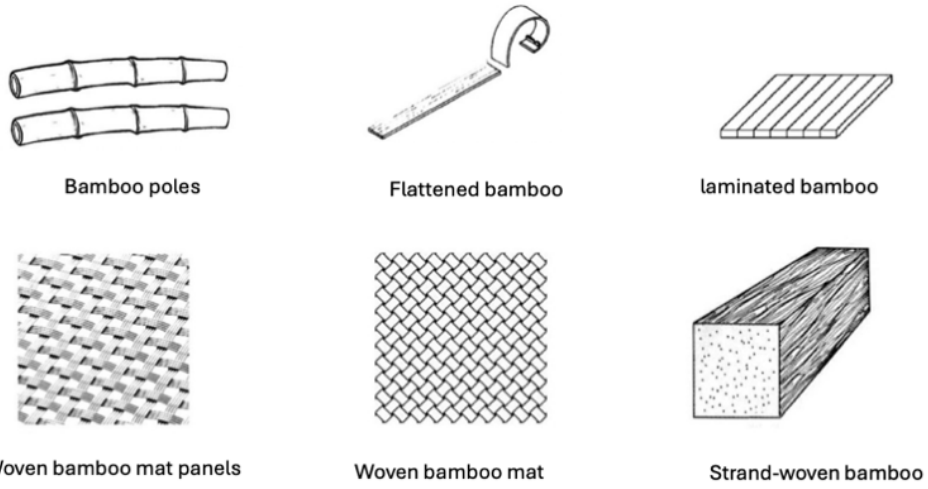
[11] A.T. Nguyen, Q.B. Tran, D.Q. Tran, et al. 2011. An investigation on climate responsive design strategies of vernacular housing in Vietnam. *Building and Environment*. 46(10). pp. 2088–2106. https://doi.org/10.1016/j.buildenv.2011.04.019.

[12] D.E. Hebel, F. Heisel, A. Javadian, et al. 2015. Constructing Bamboo: Introducing an Alternative for the Construction Industry. *FCL Magazine* Special Issue. https://www.research-collection.ethz.ch/handle/20.500.11850/155584

Construction Materials and Systems Using Bamboo

15. Various bamboo building materials are currently in use (Figure 3).

Figure 3:Types of Bamboo Building Materials



Sources: S. Habibi. 2019. Design Concepts for the Integration of Bamboo in Contemporary Vernacular Architecture. *Architectural Engineering and Design Management*. 15(6): pp. 475–489.

Unprocessed Poles

16. These can be used in construction and as scaffolding in some settings, notably in Hong Kong, China; and the People's Republic of China.[13] Because they do not have a uniform and standard shape, joining bamboo for construction is challenging (for scaffolding, they are simply lashed together).[14]

Processed Poles

17. Raw poles can be dried and chemically treated to resist mold and insects. These poles are construction grade and can be made to last 20–30 years, five times the lifespan of raw, untreated poles. Bamboo pole treatment centers are easy to set up close to the bamboo source, providing both local employment and a sustainable source of construction material.[15] Joints used in timber construction are not suitable for connecting poles. One solution is to use 3D printing technology to generate bespoke joints (footnote 14, Figure 4).

[13] Hong Kong, China, Buildings Department. *Guidelines on the Design and Construction of Bamboo Scaffolds*. https://www.bd.gov.hk/doc/en/resources/codes-and-references/code-and-design-manuals/GDCBS.pdf
[14] M. Kladeftira, M. Leschok, E. Skevaki, et al. 2022. Digital Bamboo A Study on Bamboo, 3D Printed Joints, and Digitally Fabricated Building Components for Ultralight Architectures. *Acadia*. https://www.research-collection.ethz.ch/bitstream/handle/20.500.11850/667377/acadia22_406.pdf?sequence=1&isAllowed=y
[15] Kawayan Collective. Learn more about our treatment process. https://sites.google.com/view/kawayancollective/home

Figure 4: 3D-printed Joints for Bamboo Construction

Source: M. Kladeftira, M. Leschok, E. Skevaki, et al. 2022. Digital Bamboo: A Study on Bamboo, 3D Printed Joints, and Digitally Fabricated Building Components for Ultralight Architectures. *Acadia*. https://www.research-collection.ethz.ch/bitstream/handle/20.500.11850/667377/acadia22_406.pdf?sequence=1&isAllowed=y

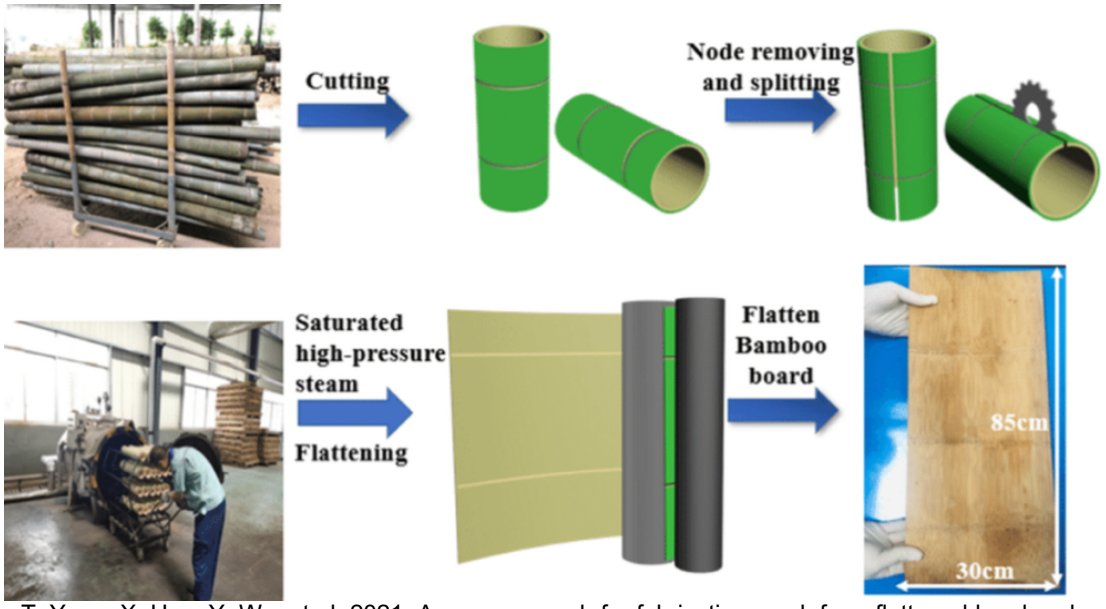
Flattened Bamboo

18. A flattened bamboo board is produced by softening bamboo tubes at high temperatures and pressing them into sheet plates (Figure 5).[16] It is used as a timber substitute in construction, making particle boards, beams, and furniture.[17]

[16] Z.C. Lou, X.Z. Wang, Y. J. Li, F. Yang, Y. H. Zhao. 2022. Production technology of flattened bamboo flooring with bamboo outer layer. *China For. Prod. Ind*. 59. pp. 49–52.

[17] T. Yuan, X. Han, Y. Wu, et al. 2021. A new approach for fabricating crack-free, flattened bamboo board and the study of its macro-/micro-properties. *European Journal of Wood and Wood Products*. 79. 10.1007/s00107-021-01734-x.

Figure 5: Flattened Bamboo Manufacturing Process



Source: T. Yuan, X. Han, Y. Wu, et al. 2021. A new approach for fabricating crack-free, flattened bamboo board and the study of its macro-/micro-properties. *European Journal of Wood and Wood Products*.79.10.1007/s00107-021-01734-x.

Laminated Bamboo Lumbar

19. Laminated bamboo lumbar (LBL) is a type of structural bamboo-based composite. It comprises several layers placed parallel to each other and bonded with durable, moisture-resistant adhesives.[18] Its size and shape can be easily controlled to suit design requirements. This makes it competitive with other commonly used building materials.[19] Studies have shown that it is a good substitute for wood, with comparable mechanical and thermal properties.[20]

Bamboo Board

20. The bamboo board is made from compressed bamboo by cutting large bamboo poles into strips and stacking them with the grain at right-angles. The stack is impregnated with a resin, then pressed and cured. Finally, the resulting board is milled and sanded to give finished panels.[21] Bamboo boards can be used as a building material in their own right and can also be made into

[18] M. Mirmehdi . 2016. *The Effects of Bamboo Species and Adhesive Type on Mechanical Properties of Laminated Bamboo Lumber (LBL)*. 10.13140/RG.2.1.2363.6881.

[19] H. Li, J. Su, Z. Xiong, et al. 2020. Evaluation on the ultimate bearing capacity for laminated bamboo lumber columns under eccentric compression. *Structures*. 28. https://www.sciencedirect.com/science/article/abs/pii/S2352012420305610#:~:text=Laminated%20bamboo%20lumber%20(LBL)%20is,other%20commonly%20used%20building%20materials.

[20] B. Zhao, Y. Yu, Y. Xu et a. 2023. Bamboo as a Sustainable Construction Material for Residential Buildings in the Cold and Severe Cold Regions of China. *Architectural Engineering and Design Management*. DOI: 10.1080/17452007.2023.2195614.

[21] *ScienceDirect*. Bamboo Board: An Overview. https://www.sciencedirect.com/topics/engineering/bamboo-board#:~:text=Bamboo%20board%20is%20made%20from,sanded%20to%20give%20finished%20panels

veneers and laminated panel products. Bamboo boards can be made into cross-ply panels either on their own or in combination with woven strand bamboo.[22]

Bamboo-Oriented Strand Board

21. Oriented strand board (OSB) is a widely used engineered wood panel building material, favored because it is versatile and similar in strength and performance to plywood, resisting deflection, warping, and distortion.[23] Bamboo has been integrated into the production of OSB and chipboard.[24]

Woven Strand Bamboo Technology

22. Natural processed bamboo is combined with an adhesive to form a water-resistant, non-swelling, and durable composite material. Strands of bamboo fiber are carbonized to eliminate all-natural sugar in the bamboo material, making it inhospitable to fungi and bacteria. The strands are then submerged into a pool of adhesive, placed into molds, and pressed into blocks. The density of woven strand bamboo (WSB) is approximately triple that of natural bamboo culm, and it is used as a flooring material (Hegel et al., Engineering Bamboo.) WSB is used to make the hardest type of bamboo flooring. It has been on the market for the past two decades and is favored as a flooring material because when it is well made, it is tough and durable, typically lasts at least 25 years, and can be resistant to termites. Its eco-friendly status is another selling point for this material. If finished correctly, it is easy to clean and has a modern look.[25] However, it can also be more susceptible to shrinkage, cracks, swelling, and warping if the raw bamboo is not properly treated and can fade or discolor over time.

Steel-Glued Laminated Bamboo

23. Steel-glued laminated bamboo (GluBam) is a two-step pressure-glued laminated bamboo lumber with a second process similar to wood-based glulam.[26] The bamboo layers can be arranged in different directions, depending on the desired mechanical properties. GluBam has excellent tensile, compressive, flexural strength, and dimensional stability. The adhesives and lamination process make GluBam resistant to humidity and degradation, as well as insects.[27]

Pinboo

24. Unlike most engineered bamboo products, pinboo comprises strips or slats of bamboo held together with sticks (Figure 6). It was pioneered by a Colombian engineer, Antonio Giraldo,

[22] Rizome. https://rizomebamboo.com/products/
[23] Naturally:Wood. Oriented strand board. https://www.naturallywood.com/products/oriented-strand-board-osb/
[24] The Bamboo project. https://www.staboo.com/en/the-bamboo-project/
[25] Impact Floors. Bamboo Flooring Pros and Cons. https://impactfloorsqld.com.au/inspiration/bamboo-flooring-pros-and-cons#:~:text=Bamboo%20grass%20easily%20absorbs%20water,%2C%20become%20marred%2C%20and%20discolour.
[26] Y. Xiao, Q. Zhou, B. Shan. 2010. Design and Construction of Modern Bamboo Bridges. *Journal of Bridge Engineering*. 15(5). pp. 533–541.
[27] V. Barrile, E. Genovese. 2024. Bamboo structures: Innovative Methods and Applications for Structural Health Monitoring and Dissemination. *Advances in Bamboo Science*. 7.

and has been used in pioneering bamboo architecture in Bali, Indonesia.[28] Research is underway to explore ways to expand its use as an alternative to timber for floors and wall panels. [29]

Figure 6: Pinboo and its Components

Credit: Better Bamboo Buildings

Bamboo Reinforcement

25. The utility of bamboo as a reinforcement material in concrete beams, slabs, and walls continues to be actively researched (Box), with some promising results for slabs. However, other forms of reinforcement still require more development.[30]

[28] Better Bamboo Buildings. The Story of Pinboo Boards. https://www.betterbamboobuildings.com/home/the-story-of-pinboo?rq=pinboo

[29] Personal communication with Luis Felipe Lopez, managing director of Base Bahay Foundation Inc.

[30] B.R. Subchan, B. A. Tayeh, E. Widayanto, et.al. Bamboo's Evolution as a Sustainable Material: A Comprehensive Exploration and Practical Integration as a Structural Element in Concrete, Bridge Frameworks, and Architectural Perspectives. *Architectural Engineering and Design Management*. 5 Mar: DOI: 10.1080/17452007.2024.2324039.

Box 1: Research into Bamboo as a Reinforcement Material in Construction

In the mid-20th century, using bamboo as a forestry product generated interest in research into its properties.[a] As early as 1914, academics were investigating the utility of bamboo as an industrialized construction material. That year, a Massachusetts Institute of Technology professor, H. K. Chow, tested small-diameter bamboo and bamboo splits as a reinforcement material for concrete applications. Similar experiments continued into the 1930s and took off again after the Second World War in 1950 as part of more elaborate and extensive research. However, in the United States, research stopped when structures built using natural bamboo as reinforcement collapsed after construction. This was due to de-bonding effects between the natural bamboo and the concrete mix. As a natural material, bamboo absorbs water from the concrete, causing the concrete matrix to swell and shrink, leading to cracking in the concrete and weakening the structure more and more over time.[b]

In the mid-1990s, research started at the Univesidade Catolica in Rio de Janeiro, but the de-bonding problems remained unresolved.

More recently, researchers successfully have addressed this issue. An experimental study on manufacturing-oriented strand boards using Indonesian bamboo showed that its physical and mechanical properties satisfied requirements under the country's building code, with good bonding properties.[c] In the 2000s, researchers at the Future Cities Laboratory in Singapore took strand woven bamboo technology as a starting point. They investigated ways in which bamboo could be treated to overcome the de-bonding issue and preserve the tensile strength of natural bamboo to develop a material that can be mass-produced and used for reinforcement.

[a]. Republic of the Philippines Department of Science and Technology. Forest Products Research and Technology Institute. Bamboo Processing and Industry Development. https://fprdi.dost.gov.ph/index.php/program-projects/forest-products-research-and-development/bamboo-processing-and-industry-development.
[b]. D.E. Hebel, F. Heisel, A. Javadian, et al. 2015. Engineering Bamboo: Composite Fiber Materials as an Alternative Reinforcement in Structural Concrete Applications. *FCL Magazine* Special Issue. https://www.research-collection.ethz.ch/bitstream/handle/20.500.11850/207297/eth-48936-01.pdf?sequence=1&isAllowed=y
[c]. M. A. Ibrahim. 2010. Properties of Oriented Strand Board (OSB) Made from Mixing Bamboo. Indonesia: Bogor Agricultural University, cited in R. Manandhar, J.H. Kim and J.T. Kim. 2019. Environmental, Social and Economic Sustainability of Bamboo and Bamboo-based Construction Materials in Buildings. *Journal of Asian Architecture and Building Engineering*, 18:2, 49–59.

Barriers and Facilitators for Bamboo Agroforestry to Produce Building Materials

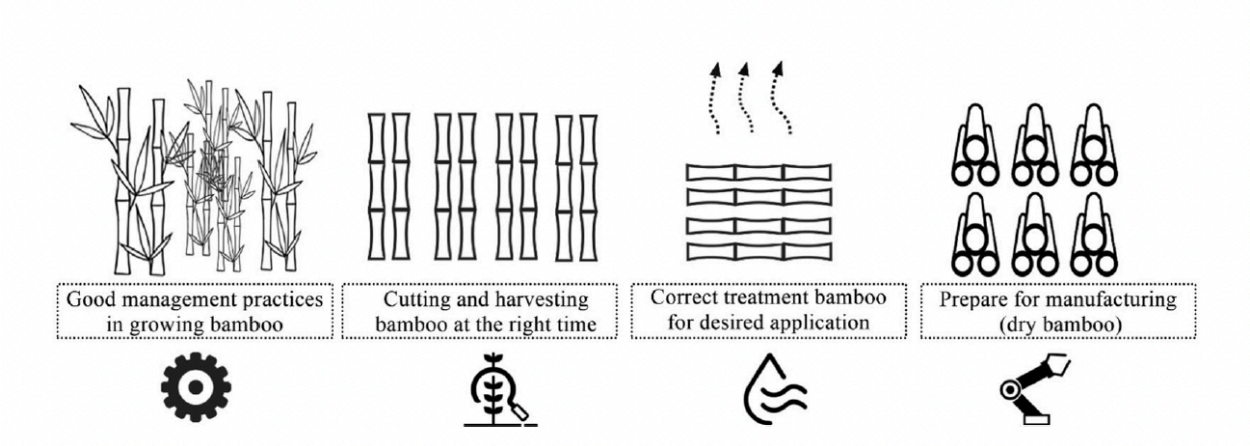
26. Despite bamboo's qualities as a strong, locally available, sustainable construction material, the bamboo industry is hampered by several constraints. Many producers do not understand the industrial potential of bamboo, and as small farmers, they find it challenging to scale sufficiently to compete with timber producers.

Technical Expertise and Data

27. A bamboo-processing industry based on sustainable approaches is needed to add value to bamboo and promote its use as a building material. Figure 7 shows the key steps to managing the harvesting and treatment of bamboo to optimize its value for manufacturing. How bamboo is dried is particularly important because of the impact the drying process has on its qualities as a construction material.[31]

[31] T.C. Yang, and T.Y. Lee. 2018. Effects of Density and Heat Treatment on the Physico-Mechanical Properties of Unidirectional Round Bamboo Stick Boards (UBSBs) Made of Makino Bamboo (Phyllostachys makinoi). *Construction and Building Materials*. 187. pp. 406–413.

Figure 7: Good Practices for Bamboo Processing into Construction Materials



Source: M. Burger, G. Oosthuizen, J. Oberholzer, P. D. Wet, and C. Ras. 2017. *Strategies to Standardize Bamboo for Manufacturing Process Chains*. Procedia Manufacturing. 8. 330–337.

28. For bamboo to be accepted as a credible alternative to other construction materials, it is necessary to demonstrate to users that it has the required qualities in terms of overall strength, tensile strength, shear strength, and elasticity. The literature shows that bamboo has strong mechanical properties compared with construction materials, but the use of bamboo for construction purposes has not been standardized, unlike other materials (footnote 10)

Supportive Policy Environment

29. The lack of relevant design and building codes covering bamboo has limited its use to small-scale, temporary, and post-disaster residential reconstruction (footnote 20). Cement bamboo frame technology (CBFT, see section 3), for example, has thus far mainly been for two-story buildings and rural areas. Bamboo must first be included in national building codes to be recognized as a suitable construction material for its use to become more mainstream.

30. The use of bamboo is also not adequately supported at policy level. Supportive public policy is key to realizing bamboo's climate change adaptation potential. This includes the integration of bamboo into national and local climate adaptation strategies that fully engage Indigenous and local communities in bamboo cultivation and management. Communities engaged in bamboo agroforestry need education and training on sustainable bamboo cultivation, processing techniques, and business management, and beyond basic training, specialized courses, and certifications to develop skilled workers and entrepreneurs in the bamboo industry.

The Need for Data and Innovation in Engineered Bamboo

31. Like other engineered bio-based materials, there is a need for more research and data on their properties and how they compare with conventional materials. There is also a pressing need for more research into “green chemistry” to develop non-toxic binders and glues.[32]

[32] United Nations Environment Programme. 2023. *Building Materials and the Climate: Constructing a New Future*.

III. THE ROLE OF BAMBOO IN ECONOMIC DEVELOPMENT

32. Bamboo can play a role in diversifying incomes for subsistence farmers, creating jobs directly in agroforestry and indirectly in ancillary and downstream industries. The cultivation of bamboo can provide an alternative income stream for subsistence farmers, and it can be grown on land that is unsuitable for farming crops. The cultivation, harvesting, and transportation of bamboo create job opportunities, especially as the location of bamboo stands in areas that cannot be reached by road, often making harvesting and transportation highly labor-intensive.

33. The manufacture of bamboo-derived products also brings job and economic development opportunities. At the most basic level, bamboo can be made by microenterprises into simple household items and handicrafts, especially in areas with tourist trade. Processing bamboo culms for industrial use close to the source can keep more of the added value in the community where the bamboo is grown. Expanding existing cottage-level bamboo industries can open new markets, including exports, and expand the scope of existing bamboo industries.

The Bamboo Value Chain

Saplings, Shoots, and Culms

34. The production inputs for cultivating bamboo saplings are the sapling, fertilizer, water, caretaking, and management of the bamboo plantation, as well as the cost of labor for pruning and digging up the stump. Production of bamboo saplings starts to generate an income for farmers in two years. Production in bamboo shoot and culm cultivation has similar inputs to those for saplings, but shoots take 3 years to start producing an income for farmers, and for culms, it takes approximately 5 years.

35. This segment of the value chain generates jobs for laborers to clear and prepare the land for sapling planting; then planting and applying fertilizer. At the two-year mark, sapling cultivation generates jobs for laborers for propagation and sapling harvest, as well as for outbound logistics, transport, and sales and marketing.

Processed Bamboo Products

36. Bamboo is processed into a wide range of products, and these are manufactured at different scales, from farmers making a few handicrafts and household utensils to supplement their farming income to mass-producers of items such as disposable chopsticks, bamboo fiber for the manufacture of paper and fabrics, and construction materials (see section 1). Bamboo charcoal can be manufactured on a small scale using quite rudimentary equipment and on a larger scale with the use of kilns. Basic bamboo construction materials such as bamboo plywood can also be made close to the source, although with a relatively high level of initial investment.

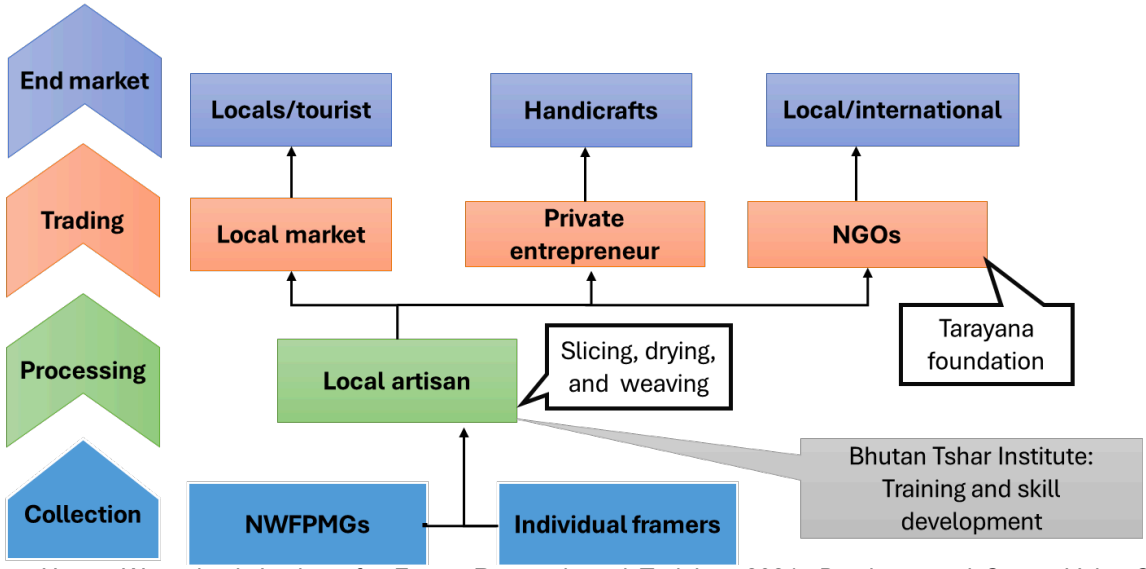
Value-Chain Analyses in Selected Asian Countries

37. Value-chain analyses of the bamboo sector have been conducted in numerous DMCs. Each country has unique advantages and challenges for developing the bamboo sector, but some common themes exist. There is growing demand for bamboo-derived products, but the bamboo sector is not well-positioned in many countries to take advantage of this opportunity. Few countries have a national or regional strategy for developing the bamboo sector, yet many of the obstacles can only be addressed with government support and intervention.

38. There are severe information asymmetries, which means that parts of the value chain are vulnerable to exploitation and lack information about fair pricing. Human resources constraints are another common issue, as rural jobs continue to be less favored than employment in cities.

39. **Bhutan.** There are 33 species of bamboo, mostly naturally occurring in forests, with only a few species cultivated by farmers in the southern and eastern regions of the country to meet their daily needs.[33] A 2023 situational analysis of non-tree forest products-based community livelihood in the village communities of Mangling and Broksar found that they produce a diverse range of bamboo products, including baskets, drumsticks, and furniture (Figure 8). However, the local artisan community is aging, and the younger generation is not taking up the required skills to continue this tradition. Handicrafts supplement farming income and are sold informally, relying heavily on middlemen. This informal arrangement often results in inconsistent sale prices.

Figure 8: Value-Chain Analysis of Bamboo in Mangling and Broksar, Bhutan



Source: Ugyen Wangchuck Institute for Forest Research and Training. 2024. *Bamboos and Canes Value-Chain Analysis for Asian Forest Cooperation Organization Project Sites in Bhutan*. Department of Forest and Park Services. Ministry of Energy and Natural Resources.

40. The study noted that the government is also promoting the use of bamboo and cane through various supportive incentives and policies. The Department of Forests and Park Services, Handicrafts Association of Bhutan, Bhutan Tsar Institute, and Tarayana Foundation provide training programs, technical assistance, and market linkages. Demand for bamboo and cane in Bhutan is growing due to the increasing popularity of sustainable products worldwide. Bhutan can capitalize on this by producing value-added products, adopting sustainable practices, and investing in skills development.

41. **Cambodia.** Four bamboo species are known to be grown and used in Cambodia.[34] A 2019 study of the bamboo value chain in Cambodia found that handcrafted furniture and small homewares such as chopsticks, barbecue skewers, and incense sticks account for most bamboo

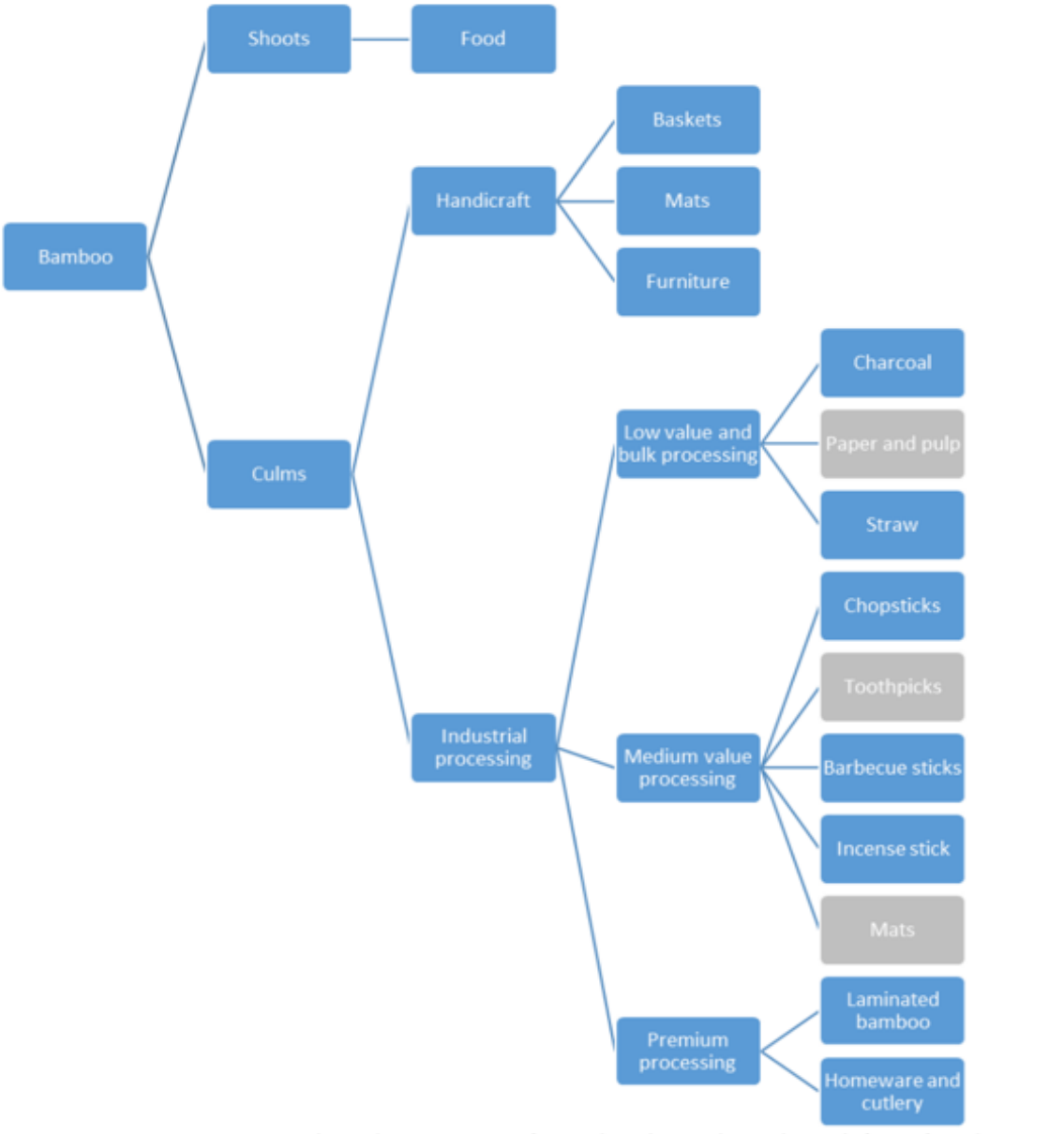
[33] Ugyen Wangchuck Institute for Forest Research and Training. 2024. *Bamboos and Canes Value Chain Analysis for Asian Forest Cooperation Organization Project Sites in Bhutan*. Department of Forest and Park Services. Ministry of Energy and Natural Resources.

[34] United States Agency for International Development. 2015. *Cambodian Bamboo Market and Value Chain Study*. https://pdf.usaid.gov/pdf_docs/PA00M3QC.pdf

product manufacturing, with only a limited amount of industrial processing of bamboo sticks and bamboo charcoal.[35] There was an emerging trend of higher-end bamboo products, such as water bottles, cutlery, and premium bags.

42. Bamboo has three main value chains: bamboo shoots, handicrafts, and industrial processing. The current processing chain in Cambodia primarily focuses on low and medium-value bamboo products (Figure 9).

Figure 9: Value-Chain Map of Cambodia's Bamboo Industry in 2019



Source: Nuppun Institute for Economic Research Report For "NTFP Value-Chain Analysis" Phase II - Value-Chain Studies. 2019.

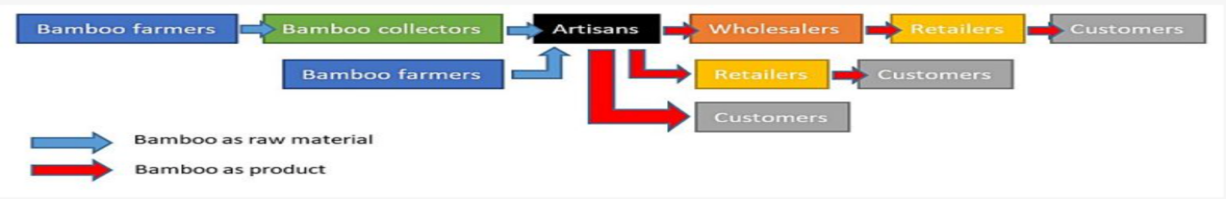
[35] Nuppun Institute for Economic Research Report For "NTFP Value Chain Analysis" Phase II - Value Chain Studies. 2019. https://www.profor.info/sites/default/files/publication/NTFP_VC_Report_Draft_Final.pdf

43. The study found that there is a large demand for bamboo-derived products such as toothpicks, barbecue sticks, chopsticks, and incense sticks. Most of the supply was imported, mainly from Viet Nam and the PRC and Thailand. The study recommended capacity building for forest communities so that they can be qualified as subcontractors of processors; fostering a favorable legal environment and infrastructure to develop bamboo value chains; promoting an enabling environment for bamboo exports; and upgrading technologies used in processing lines to improve the quality, cost, and delivery of bamboo products.

44. **India.** The second-largest producer of bamboo after the PRC, India is the seventh-largest exporter.[36] Bamboo cultivation is a significant source of livelihood for half of the country's tribal population of 68 million people.[37] Major export destinations of bamboo products from India include Bhutan, Bangladesh and Nepal. There is high domestic demand for bamboo. For example, in the northeast of India, bamboo is widely used to make traditional products by experienced artisans, which are then sold locally.[38] Despite being a major bamboo producer, India imports most of the required raw materials from the PRC, which offers cheaper supplies than locally available. In 2021, India imported 88% of its bamboo raw materials (footnote 36). The country' domestic bamboo supply is dogged by lower productivity, at 1–3 tons per hectare compared with 30–40 tons/hectares (ha) in the PRC.[39] Efforts to promote the bamboo value chain have primarily focused on low-value-added products with labor-intensive work, resulting in limited profitability. The lack of mechanization in bamboo product manufacturing also results in high level of waste.

45. **Indonesia.** There are more than 140 bamboo species in Indonesia and 2.1 million hectares of bamboo forest.[40] The population has long used bamboo for construction, housing, household items, and handicrafts, and bamboo-related industries support the livelihoods of hundreds of thousands of people, particularly in rural areas. A 2018 study funded by the Australian Centre for International Agricultural Development looked at what the Government of Indonesia could do to foster the bamboo industry, focusing on bamboo value chains in Gunungkidul, Yogyakarta (Figure 10).[41]

Figure 10: Bamboo Value Chains, Gunungkidul, Yogyakarta, Indonesia



Source: L. A. G. Pieter, M. Mandira Budi Utomo. 2023. Performance and Development Challenges of Micro–Small Bamboo Enterprises in Gunungkidul, Indonesia. *Advances in Bamboo Science*. 4.

[36] INBAR. 2021. *Trade Overview 2019: Bamboo and Rattan Commodities in the International Market*. International Bamboo and Rattan Organisation. https://www.inbar. int/wp-content/uploads/2021/04/Trade-Overview-2019- China-final-1.pdf.
[37] S Jamatia. 2021. *Bamboo Regulation in India: The Need for Reforms*. Centre for Civil Society. https://ccs.in/sites/default/files/publications/viewpoint12.pdf.
[38] J. Gogoi, R. Singh, G. Barauah et al. 2022. Value chain analysis of traditional bamboo products in Meghalaya. *e-planet.* December. 20(2). pp. 115–120. https://e-planet.co.in/images/Publication/vol-20-2/value%20chain.pdf
[39] J Mathur. The Bamboo Puzzle: Why India Imports Despite Abundance? National Economic Forum.6 October 2023. https://nationaleconomicforum.in/research/f/the-bamboo-puzzle-why-india-imports-despite-abundance
[40] CGIAR Research Program on Forests, Trees and Agroforestry. 2018. Study examines bamboo value chains to support industry growth. https://www.foreststreesagroforestry.org/news-article/study-examines-bamboo-value-chains-in-order-to-grow-industry/
[41] L. A. G. Pieter, M. Mandira Budi Utomo. 2023. Performance and Development Challenges of Micro–Small Bamboo Enterprises in Gunungkidul, Indonesia. *Advances in Bamboo Science*. 4.

46. The study found that the bamboo industry in Gunungkidul contributed significantly to the rural economy and employed approximately 14,000 workers. The study looked at the value chains for durable bamboo, kitchen utensils, and handicrafts. It found that although the performance of the three bamboo value chains was good, there was room for improvement. Moreover, the economic contribution of bamboo handicrafts for farmers was minuscule due to low prices and irregular demand. Artisans, however, could gain significant income from processing bamboo, but profits were unevenly distributed. Growers were the most disadvantaged, lacking knowledge about bamboo management, and artisans lacked marketing knowledge and entrepreneurial skills. The study highlighted the lack of coordination between government bodies and limited coordination between people within value chains, which restricted the industry's growth. The study recommended the establishment of a government taskforce to operate both nationally and locally to promote the development of the bamboo industry through:

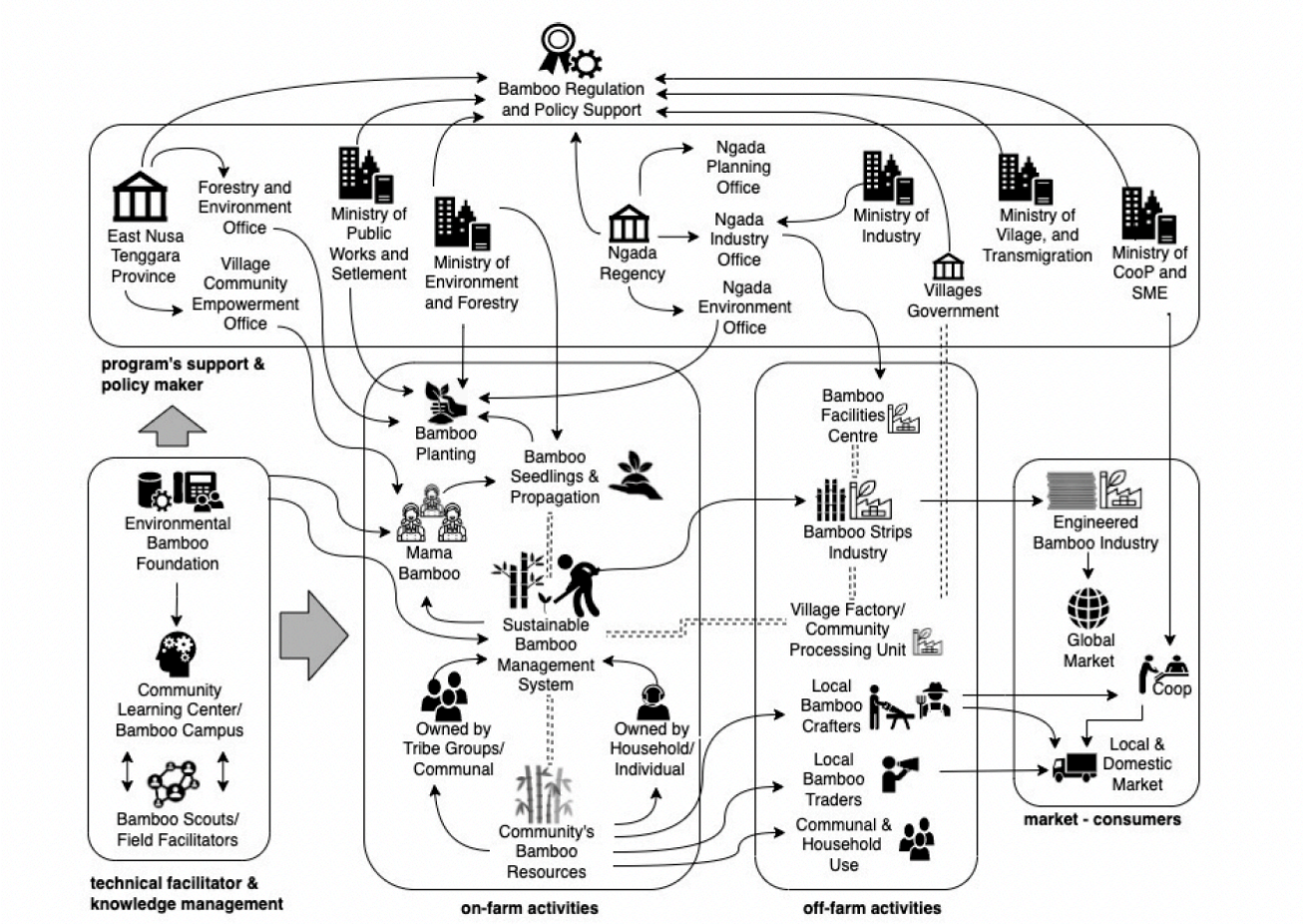
- integration of the industry within agricultural and rural development programs,
- lobbying of relevant ministries,
- collaboration with nongovernment organizations (NGOs) and research institutions,
- improved promotion of handicrafts,
- better access to microcredit,
- the formation of producer cooperatives to build capacity and enhance bargaining power.

47. Research in Ngada Regency, Flores Island, East Nusa Tenggara Province investigated how bamboo, widely grown in the area and long used in daily life and for handicrafts could be expanded for use at an industrial scale.[42] The study found that bamboo is perceived by the community as important for maintaining environmental quality and water resources; and has become part of culture and tradition, but that the potential economic benefits of bamboo had not been significant. Although a factory producing preserved split bamboo had opened in 2012 in the area, it had faced problems ensuring a consistent supply of required raw materials from community-owned bamboo resources. The three main barriers that would need to be addressed for the area to adopt modern utilization of bamboo were the absence of an established value chain, low capacity in bamboo management; and the lack of integrated regulation support. Further research in this area looking at how a more integrated the value chain could be created, highlighted how community-level bamboo production is situated within a complex ecosystem of stakeholders (Figure 11).[43]

[42] D Ekawati, L Karlinasari, R Soekmadi et al. *2022.* Drivers, Barriers, and Strategies in the Community-Based Supply of Bamboo for Industrial-Scale Bamboo Utilization in Ngada Regency, East Nusa Tenggara, Indonesia. *Sustainability.*14 (5970). https://doi.org/10.3390/su14105970.

[43] D. Ekawati, L Karlinasari, R Soekmadi, et al. 2023. A Model of Integrated Community-Based Bamboo Management for the Bamboo Industry in Ngada Regency, East Nusa Tenggara, Indonesia. *Sustainability*. 15(977). https://doi.org/10.3390/su15020977.

Figure 11: Rich Picture Situation of Community-based Bamboo Management in Ngada Regency, East Nusa Tenggara



Source: D Ekawati,, L Karlinasari, R Soekmadi, et al. 2023. A Model of Integrated Community-Based Bamboo Management for the Bamboo Industry in Ngada Regency, East Nusa Tenggara, Indonesia. *Sustainability* 15(977). https:// doi.org/10.3390/su15020977.

48. A key conclusion of the study was the role of women in the management and utilization of bamboo. At the study site, women play a role in the manufacturing and providing of bamboo seedlings, supported by both government funding and NGOs. Women drive both the on-farm and off-farm activities in bamboo, and women's role ion handicraft production there echoed findings from other parts of the country. As such, any efforts to promote the use of bamboo should take this gender dimension into account.

49. **Lao People's Democratic Republic.** Bamboo is an essential natural resource in the Lao People's Democratic Republic (Lao PDR), and there are 52 known species growing there.[44] It is abundant and accessible.[45] It is used as a house-building material, a raw material for furniture and handicrafts, and as a food. Despite its abundance, there is pressure on existing bamboo

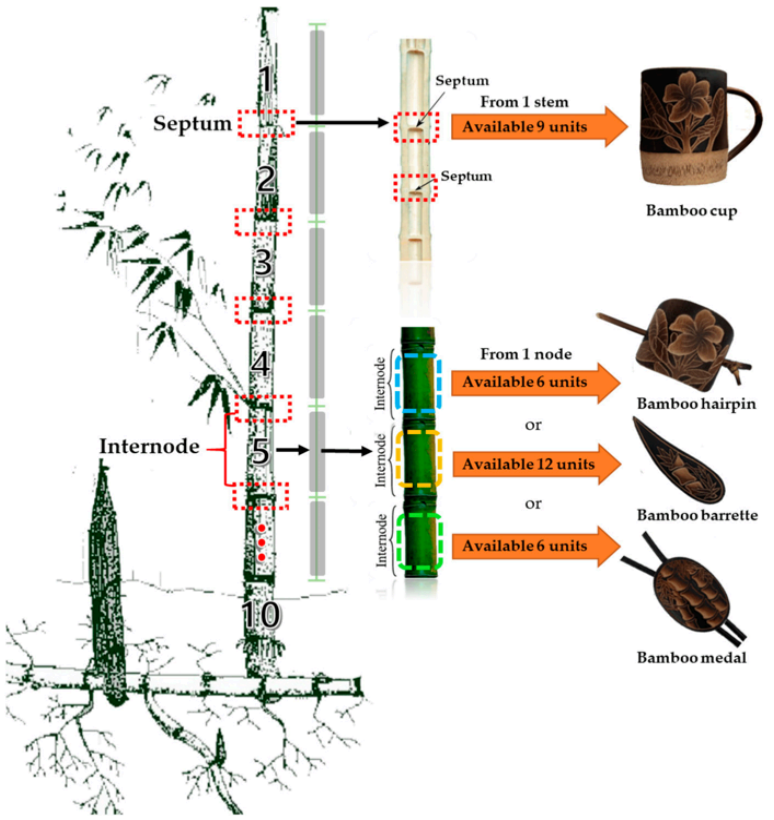
[44] V. Soydara and S. Ketphanh. 2000. Case Study on the marketing group of bitter bamboo shoots in Nam Pheng Village, Oudomxai Province. Proceedings of the BAMBOO 2000 International Symposium, 2 –4 August. Changmai, Thailand. http://lad.nafri.org.la/fulltext/3967-0.pdf

[45] World Wide Fund for Nature (WWF). Bamboo Can Become the Green Gold of Small Holders to Decrease Poverty. 2016. https://www.wwf.org.la/?271273/Launching-of-a-Lao-Bamboo-Platform-and-National-strategy

resources due to increasing demand from neighboring countries, i.e., the PRC, Thailand, and Viet Nam.[46]

50. A case study of a rural village in eastern Lao PDR compared two value chains.[47] The study found that almost two-thirds of the villagers earned cash from harvesting and selling bamboo during the five-month dry season. The highly labor-intensive work of harvesting required a minimum of three people to work efficiently, and between them, they could produce 300–350 kilograms (kg) of bamboo splits in 2 hours. The first value chain studied was the existing practice of exporting semi-processed raw materials (bamboo splits) to Viet Nam for production into bamboo chopsticks. In this scenario, villagers received less than 5% of the total value chain. In the alternative scenario, whereby local villagers were trained in handicraft production, such as cups and small decorative items (Figure 12), they could retain nearly 30% to over 40% of the total value and double the value of their labor. However, the model required training for villagers in handicrafts and lacked a stable sales route. Both issues would require external support to address.

Figure 12: Bamboo Parts Used for the New Bamboo Handicraft Model



Source: B. Lee, H. Rhee, S. Kim, et al. 2021. Assessing Sustainable Bamboo-Based Income Generation Using a Value-Chain Approach: Case Study of Nongboua Village in Lao PDR. *Forests*. 12(2). p.153.

[46] L. Phounvisouk, T. Zuo, N.C. Kiat 2013. Non-timber forest products marketing: Trading network of trader and market chain in Luang Namtha Province, Lao PDR. *J. Humanit. Soc. Sci*. 18. pp. 48–57.
[47] B. Lee, H. Rhee, S. Kim, et al. 2021. Assessing Sustainable Bamboo-Based Income Generation Using a Value Chain Approach: Case Study of Nongboua Village in Lao PDR. *Forests*. 12(2). p. 153.

51. **Nepal.** More than 50 species of bamboo can be found in Nepal, covering an estimated 63,000 hectares of private land, public land, riverbanks, and national forests. Most bamboo products, from hundreds of small producers and traders, are consumed domestically, but Nepal has also been marketing bamboo products internationally for more than two decades. Bamboo-related exports include bamboo painting materials, wood charcoal, bamboo plywood and laminated products, bamboo baskets, and bamboo furniture. Bamboo has the potential to provide jobs and economic growth prospects for Nepal's rural and urban populations, and over 25,000 households are involved in producing bamboo products.[48]

52. **Pakistan.** In the 1980s, various bamboo species from Bangladesh, the PRC, Sri Lanka, and Thailand were introduced into Pakistan, with estimates of the actual number of species introduced ranging from 13 to 25, in addition to the 3 native species.[49] Almost all bamboo resources have been grown on private farms in the Punjab region in recent decades. Most bamboo produced in Pakistan is consumed domestically, and the relatively poor quality of the bamboo grown makes it difficult for it to compete in the international market. There is local demand for high-finish, value-added bamboo products in Pakistan, but the local industry cannot supply them.

53. A 2024 study of the bamboo value chain in Pakistan found several issues holding back the bamboo industry in Pakistan.[50] The local bamboo-derived product manufacturing sector is almost nonexistent. Research and data on bamboo resources are lacking, and relevant government agriculture departments have little interest, leading to little or no policy supporting the bamboo sector. There is also a lack of interest from research institutions and academia, which deprives bamboo growers of technical guidance and stops the development of the required human resources.

54. **The People's Republic of China.** With more than 590 bamboo species, more than any other country, the PRC also has the largest bamboo industry in the world.[51] There are more than 10,000 bamboo-processing enterprises in the PRC, with a combined output value of $56.8 billion in 2022. With an average 30% annual growth rate, the country's bamboo industry output has grown from $11.52 billion in 2010. The PRC's bamboo exports account for 75% of the global total.[52] The Government of the PRC has invested heavily in research and development on bamboo-related technologies such as high-yield plantations, and new processing and product development. The country's bamboo industry benefits from favorable policies and regulations at central and local government level. The country's bamboo value chain is well-developed. However, data on all aspects of the industry is still lacking, and the country is facing increasing competition in the global market from neighboring countries.

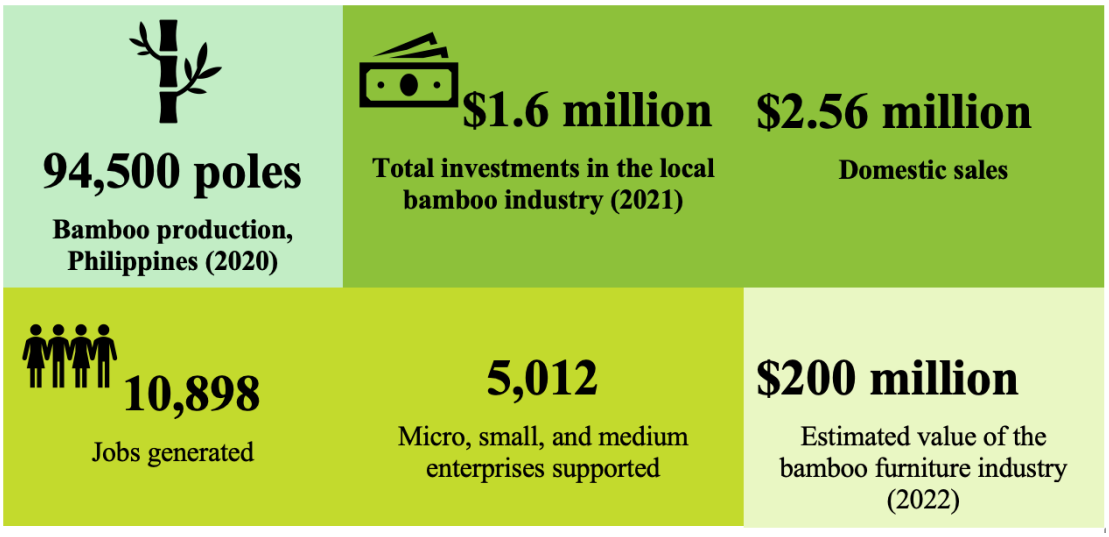
55. **Philippines.** Bamboo is native to large parts of the Philippines, with 62 species, including 21 species that are native to the country. Estimates of the total area of bamboo stands in the country range from 39,000–53,000 ha, mainly growing sporadically or in patches in backyards

[48] The Global Green Growth Institute. 2022. *National Roadmap for Bamboo Sector Driving Ecosystem Restoration and Resilient Economic Growth by Unlocking Nepal's Bamboo Sector*.
[49] E. Wagemann and MH Ramage. 2019. Briefing: Bamboo for construction in Pakistan – a scoping review. Proceedings of the Institution of Civil Engineers – Construction Materials. 172(1): 3–9. https://doi.org/10.1680/jcoma.17.00045
[50] S. Safdar, B.E. Tefera, O. C. Gatwaza. 2024. Value Chain Analysis of Bamboo in Pakistan. INBAR.
[51] F. Mera and C. Xu. 2014. Plantation Management and Bamboo Resource Economics in China. *Ciencia y Tecnología*. 7. 1–12. 10.18779/cyt.v7i1.93.
[52] INBAR. 2022. *Trade Overview*.

and riverbanks.[53] Bamboo has been used housing construction since before the Spanish colonization of the country in the 16th century. Most homes throughout the archipelago were nipa huts (*bahay kubo*), made from light, locally available materials such as bamboo, rattan, and cogon. Bamboo, as well as timber, was used for posts and beams.[54] In addition to home construction, bamboo has been used for centuries for many other purposes, and it continues to be a material for construction, furniture and handicraft manufacture, food, musical instruments, farm and fishing implements, pulp and paper, and fuel for cooking and heating (footnote 1).

56. In 2020, bamboo production in the Philippines reached 94,500 poles.[55] In 2021, total investments in the local bamboo industry were worth $1.6 million, with domestic sales of $2.56 million (Figure 13). The industry generated 10,898 jobs and supported 5,012 micro, small, and medium-sized enterprises. In 2022, the value of the bamboo furniture industry was estimated to be $200 million and is expected to grow at a compound annual growth rate of 6.1%.[56] The Philippines is the world's 6th largest exporter of the material. Key export destinations are France, Germany, Japan, the United Kingdom, and the United States. However, many of those involved in the bamboo industry are part of the informal sector, and bamboo has not reached its full potential as a driver of economic growth because of limited investment, outdated technologies, and gaps in various policies.

Figure 13: The Economic Impact of Bamboo in the Philippines



Source: Asian Development Bank. *From Roots to Revenue: Securing Finance and Climate Solutions Through Bamboo Agroforestry*.

[53] Philippine Council for Agriculture, Aquatic, and Natural Resources Research and Development. *Bamboo Industry Strategic Science and Technology Program Bamboo Industry Profile*. https://ispweb.pcaarrd.dost.gov.ph/bamboo/
[54] AMP Sales. 2013. Building in the Past: A Preliminary Analysis of the Construction Materials and Methods Used in Structure A in Barangay Pinagbayanan, San Juan, Batangas. *Hukay.* 18. pp. 1-30. https://journals.upd.edu.ph/index.php/asp/issue/view/408.
[55] Philippine Bamboo Industry Development Council. 2021 Report. Cited in M. Gil. 2021. PH to Cultivate 'Bamboo Villages' to Tap Growing World Demand. *Philippine News Agency*. 21 August.
[56] 6Wresearch. 2022. Philippines Bamboo Furniture Market (2024–2030) Outlook. https://www.6wresearch.com/industry-report/philippines-bamboo-furniture-market-outlook.

*57. **Thailand.** About 69 species of bamboo can be found in Thailand. Bamboo has long been used in the country for a range of products and is also exported as bamboo poles and processed bamboo products including plywood, furniture, tissue, wicker, charcoal, and as a foodstuff. Exports of bamboo products are increasing over time (Table 1,*

Figure 14).

Table 1: Export Value of Bamboo Products from Thailand, 2015–2019

Product	Export of bamboo products (million THB)					Expansion rate (2018-2019)
	2015	2016	2017	2018	2019	
food products	355.32	473.07	405.39	434.92	440.16	1.20
unprocessed bamboo	43.89	55.51	59.32	106.84	94.73	-11.33
processed bamboo products	3.13	4.3	16.61	17.28	36.34	110.30
furniture	0.00	0.00	8.79	4.09	7.32	78.89
wickers	21.85	33.87	7.98	7.28	6.74	-7.55
bamboo pulp	1.18	0.92	0.71	0.81	1.06	30.30
bamboo charcoal	0.12	0.17	0.15	0.72	0.81	12.50
total	**425.49**	**567.85**	**498.95**	**571.94**	**587.16**	**2.66**

Source: Customs Department cited in Bamboo Value-Chain Analysis in Thailand, Thailand Environment Institute, 2021. US$1 = B34.6.

58. Commercial bamboo growing operations are scattered throughout the country, totaling approximately 147 square kilometers (km^2).[57] The largest bamboo plantation is in the Eastern Region with an approximate area of 64 km^2. Despite many bamboo species growing well in Thailand, and the country's climate and geographical terrain supporting its growth, bamboo cultivation is still limited. It has not been promoted with farmers and support is limited for the management of bamboo plantations. This has adversely affected the quality of bamboo as a raw material for furniture or other products. The Royal Forestry Department developed a Draft Master Plan for National Bamboo and Rattan Resources Management (2018–2036) to help manage and utilize bamboo and rattan resources in support of social and economic development and environmental protection and conservation.

[57] Thailand Environment Institute. Bamboo Value Chain Analysis in Thailand. 2021

Figure 14: Thailand's Bamboo Value Chain

Source: Thailand Environment Institute. Bamboo Value Chain Analysis in Thailand. 2021

59. **Viet Nam.** There are 210 bamboo species grown in Viet Nam.[58] The country's bamboo and rattan industry provide approximately 3.4 million jobs and exported good valued at $348 million in 2018.[59] However, the industry remains focused on low value-added products, such as disposable chopsticks and paper production. Weak coordination among chain actors and resources and information asymmetries are significant barriers to upgrading to more value-added products. Another constraint is pressure on bamboo resources, due to overexploitation and mismanagement.[60] Farmers have limited understanding of sustainable bamboo cultivation and

[58] H.N. Nguyen and V.T. Tran. 2010. *Bamboo resources of Vietnam*. Forest Science Institute of Vietnam. 8 December. https://vafs.gov.vn/en/2010/12/bamboo-resources-of-vietnam/
[59] Tran Van Hiep, La Thi Tham, Le Minh Thong. 2024. Analyzing economic performance and value added distribution in the Luong bamboo value chain: A case study of Thanh Hoa province, Vietnam. *Trees, Forests and People*. 16.
[60] S. Benedikter, T.Q. Truong, G. Kapp, M.L. Vasquez Coda. 2022. Towards an Integrative Perspective on Commercialized Wild-Gathered Bamboo Use: Insights into the Extraction of Lung Bamboo in the Vietnamese Uplands. *Aust. For.* 85. pp. 116–132. https://doi.org/10.1080/00049158.2022.2137958.

harvesting. Small, rural bamboo enterprises also compete with more lucrative employment in the cities, and struggle to retain their workforce.

60. A case study of bamboo plantation production in Thanh Hoa Province found that two-thirds of harvested bamboo supplied two value chains: chopsticks and votive paper, with the remainder used for primary construction and agricultural purposes. High value-added bamboo products such as flooring, decking and furniture have not been a focus for development in Viet Nam.[61] Bamboo is typically cultivated in mountainous and harvesting sites are located far from roads. Most of the bamboo in Thanh Hoa Province is harvested and transported manually, resulting in high harvesting costs and low productivity.[62] The processing companies retained a far bigger proportion of the net profit than the farmers and traders, who retained less than 10% of the total value added. Thanh Hoa Province has promulgated a strategy to develop the bamboo industry but transformation from a low-value-added model to a high-value-added model faces headwinds from the lack of quality of bamboo materials, cooperation among chain actors, technology required for bamboo processing, financing for small-scale producers, and marketing activities (footnote 62).

Government Initiatives in Support of Bamboo Agroforestry

61. India, Indonesia, the PRC and the Philippines have all made national commitments to fostering the bamboo agroforestry and related industries.

62. **India.** India has one of the largest bamboo reserves in the world, particularly in the northeastern states. In 2018, the Government of India restructured and relaunched the National Bamboo Mission (NBM) to focus on the development of the bamboo sector value chain.[63]The NBM is now subsumed under the Mission for Integrated Development of Horticulture.[64] The NBM promotes "holistic growth of bamboo sector by adopting area-based, regionally differentiated strategies and to increase the area under bamboo cultivation and marketing of bamboo and bamboo-based handicrafts."

63. **Indonesia.** In Indonesia, bamboo has been designated as one of the six of commodity of non-timber forest products to be developed in the forestry sector based on the Minister of Forestry Regulation P.21/Menhut-II/2009.[65] In 2024, the Ministry of Industry announced that it was preparing a roadmap for development of the Indonesian bamboo industry. The goals of the road map are:

- to seek a solid legal basis to support the bamboo industry, to provide a basis for policies to support investment and growth of the bamboo industry;

[61] M. Sass. 2018. *Quality Criteria of Dendrocalamus barbatus Raw Material and Products Along the Bamboo Value Chain in Thanh Hoa and Hanoi province, Vietnam: Present State and Prospects*. https://katalogbeta.slub-dresden.de/id/0021142524/#detail.
[62] T. V. Hiep. 2021. *Key Factors Affecting Small Bamboo Enterprises Upgrading in North Vietnam: Case studies from Chuong My, Hanoi and Thanh Hoa Province*. TU Dresd.
[63] Press Information Bureau, Government of India, Ministry of Agriculture & Farmers Welfare. 2019. National Bamboo Mission. 16 July. https://pib.gov.in/Pressreleaseshare.aspx?PRID=1578975
[64] India Science, Technology and Innovation Portal. Mission for Integrated Development of Horticulture (MIDH). https://www.indiascienceandtechnology.gov.in/st-visions/national-mission/mission-integrated-development-horticulture-midh.
[65] D. Ekawati, T. Yanuariadi, A. Rabik. 2022. Capacity building model for developing bamboo industry in Indonesia: A shared learning platform for multi-stakeholder partnerships. XV World Forestry Congress. May. Seoul, Republic of Korea. https://openknowledge.fao.org/server/api/core/bitstreams/5f4da02d-fdbc-4cb7-87b0-66a8246dd811/content

- build a steady and efficient national bamboo industry institution with professional, accountable governance;
- enable the national bamboo industry to achieve independence in sourcing raw materials;
- improve the skills of bamboo industry players in dealing with the latest technological developments; and
- support the down-streaming of bamboo products and increase continuous innovation to compete with international markets.[66]

64. **PRC.** The PRC has been at the forefront of promotion of bamboo cultivation and bamboo-derived products. It has been active in supporting proof-of-concept projects for bamboo-derived construction materials, in particular LBL, which has become the most-used engineering bamboo material in the country.[67] Examples of structures to prove the feasibility of using bamboo materials include:

- two-story houses using LBL for vertical studs, beams, girders, and walls;
- a veranda-style library constructed in LBL in a children's park;
- a three-story office building in bamboo; and
- a pedestrian bridge (footnote 20).

In 2023, the Government of the PRC initiated a three-year action plan to promote the use of bamboo as an alternative to plastic products to curb pollution.[68]

65. **Philippines.** The Government of the Philippines has been an active promoter of bamboo industry development. In the mid- to late 20th century, as the Philippines urbanized, demand for timber increased. Wood from the narra tree was prized for construction, but high demand led to unsustainable harvesting practices. When narra was put on the list of threatened plants and protected from further over-use, a demand was created for alternatives.[69] As a result, in the 2010s, engineered wood products from locally sourced bamboo, rattan, and other fast-growing trees became more popular.[70]

66. In 2010, the government issued Executive Order No. 879 creating the Philippine Bamboo Industry Development Council, with a mandate to establish a bamboo industry development program. The executive order also included directions for bamboo to comprise at least 25% of the materials uses for desks and other furniture public elementary and secondary schools, and

[66] *Antara News Agency*. 2024. Developing bamboo road map for sustainable industry in future. 15 May. https://en.antaranews.com/news/313488/developing-bamboo-road-map-for-sustainable-industry-in-future

[67] G Chen, Y Yu, X Li, et al. 2020. Mechanical behavior of laminated bamboo lumber for structural application: An experimental investigation. *European Journal of Wood and Wood Products*. 78(1). pp.53–63. doi:10.1007/s00107-019-01486-9.

[68] The State Council of the People's Republic of China. 2023. China promotes bamboo as eco-friendly substitute for plastics. https://english.www.gov.cn/news/202311/02/content_WS65438f33c6d0868f4e8e0e5a.html.

[69] Republic of the Philippines Department of Environment and Natural Resources. DENR Administrative Order 2007/01. Establishing the National List of Threatened Philippine Plants and Their Categories, and the List of Other Wildlife Species. https://www.philchm.ph/wp-content/uploads/2019/06/dao-2007-01.pdf

[70] Billion Bricks. The History of Sustainable Construction Materials in the Philippines. Undated. https://billionbricks.org/blog/the-history-of-sustainable-construction-materials-in-the-philippines/

prioritizing “the use of bamboo in furniture, fixtures and other construction requirements of government facilities.” [71]

67. Bamboo was one of the industry clusters that the Department of Trade and Industry (DTI) decided to develop as part of its support for the Philippine Development Plan. In 2016, the DTI finalized the *Philippine Bamboo Industry Roadmap*.[72] Stakeholder engagement in 2018 for an enhanced version on the plan considered input from both the supply side propagators of bamboo and plantation developers, and the demand side, including of producers of furniture and handicrafts, engineered bamboo, construction, biofuel, food products, and pulp and paper.[73]

68. However, the Philippines' National Building Code, which is aligned with national development frameworks and climate action plans to promote climate change-resilient infrastructure, is not applicable to the lowest income housing projects.[74] This represents a missed opportunity to incentivize sustainable practices throughout the construction industry.

IV. THE SOCIAL IMPACT OF BAMBOO HOUSING

69. In tropical and subtropical countries, including numerous ADB DMCs, bamboo is commonly used as a housing construction material, and has been for centuries. At the same time, the phenomenon of organized construction projects using bamboo and engineered bamboo-derived materials to create innovative, modern housing and other structures is rapidly evolving.

The Need for Housing

70. It could be argued that use of bamboo for housing construction in developing Asia falls into two categories, and that views of bamboo as a building material are polarized. The first category is traditional houses that rely on long-standing vernacular construction practices, whereby bamboo is viewed as a “poor man’s timber,” the housing as “shabby,” and therefore less socially valued than modern dwellings of brick, cement and concrete (reference 8). The second is modern, often ”proof-of-concept” bamboo structures, designed by professional architects, inspired by the ecological and aesthetic advantages of bamboo. Affordable housing in this category is often constructed with the assistance of NGOs, and using more engineered bamboo materials, as well as poles bound together with steel or 3D printed jointing solutions.

71. Affordable, disaster-resilient housing is one of the most pressing issues for developing countries. Closing the global housing gap could cost an estimated $650 billion per year, or approximately 1% of global gross domestic product.[75] To address the need for decent, affordable housing that is both sustainable and disaster resilient, it will be necessary to bridge the gap between these two camps.

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[71] The Senate of the Philippines. Executive Order No. 879, s. 2010. https://issuances-library.senate.gov.ph/executive-issuance/executive-order-no-879-s-2010

[72] Republic of the Philippines Department of Trade and Industry, the Philippine Bamboo Industry Development Council, and the Philippine Board of Investments. *The Philippine Bamboo Industry Development Roadmap*.

[73] Republic of the Philippines Philippine Board of Investment. 2018. Enhanced version of PH bamboo roadmap to be finalized soon–BOI. 17 January. https://boi.gov.ph/enhanced-version-of-ph-bamboo-roadmap-to-be-finalized-soon-boi/.

[74] Implementing Rules and Regulations of The National Building Code of the Philippines (PD 1096). http://www.iibh.org/kijun/pdf/Philippines_02_IRR_of_NBC_of_the_Philippines.pdf.

[75] McKinsey Global Institute. 2014. *A blueprint for addressing the global affordable housing challenge*.. https://www.mckinsey.com/%7E/media/McKinsey/Featured%20Insights/Urbanization/Tackling%20the%20worlds%20affordable%20housing%20challenge/MGI_Affordable_housing_Full%20Report_October%202014.pdf.

Reinventing Traditional Bamboo Housing

72. Most of the low-income housing needs in developing countries are not met by government-led housing programs; rather, families self-build working with locally hired masons, incrementally, as funds become available and as the family grows and its housing needs evolve.[76] This approach often leads to the selection of suboptimal housing materials choices, and a rejection of traditional materials like bamboo.[77] Moreover, efforts to encourage masons to adopt more sustainable construction practices and introduce innovative materials fail because of difficulties overcoming the negative image of traditional materials. Another reason is masons who are familiar with bamboo and use it in vernacular architecture are often resistant to learning new ways to use a traditional material. It is also difficult to disrupt the established social norms and networks that shape mason construction practices in incremental homebuilding.[78] On the other hand, traditional and vernacular architecture using locally available materials has the advantage of being well adapted to the social conditions and environment of its specific location (footnote 11).

73. Bamboo is a material used in traditional architecture, and preservation of its use helps enable culturally significant practices to continue and thrive. Bamboo can also blend historical techniques with modern design, creating sustainable and culturally relevant structures that both honor tradition and embrace innovation.[79] Vernacular architecture practices that utilize bamboo can be used (and where necessary revived) and revised to incorporate advances in materials, such as those that increase the durability of bamboo, and use engineered bamboo products. They can thus be transformed in the service of sustainable and climate-resilient development.

74. Taking a cue from incremental building practices, bamboo houses could be developed as basic or starter homes, with durable foundations that families could then add to later (footnote 8). Programs that promote bamboo plantation, harvesting and processing, as well as promoting bamboo as a construction, have potential big social impact.[80] Bamboo housing has economic benefits, resulting from lower costs of using locally available materials, and from income-generating possibilities. These include conventional agricultural jobs common in developing regions, as well as higher-skills jobs in house construction, manufacture of engineered bamboo construction materials and processing bamboo into other value-added products such as furniture. Developing housing based on locally available building materials and supporting skills development of local people increases their capacity for income generation. This can in turn prevent outmigration to look for work, thus improving the social fabric.[81] However, the potential of bamboo as a building material cannot be fully realized unless the building permit rules allow for

[76] R. Goethert. 2010. Incremental Housing, a proactive urban strategy. Monday Developments. https://web.mit.edu/incrementalhousing/articlesPhotographs/pdfs/PagesMondayMag.pdf.
[77] J. Parry. 2018. *Bahay, Buhay A survey of owner-driven housing construction practices, financing modalities and aspirations for a resilient home in disaster-prone areas in Cebu Province, Philippines*. Habitat for Humanity's Terwilliger Center for Innovation in Shelter. https://www.habitat.org/sites/default/files/documents/Terwilliger%20Center%20-%20Bahay%2C%20Buhay%20Report.pdf
[78] J. Parry. 2019. *Beyond Building: How Social Norms Shape Low-Income Home Construction Insights from social norms and housing decision-making research in India, Kenya and Peru*. Habitat for Humanity's Terwilliger Center for Innovation in Shelter. https://www.habitat.org/sites/default/files/documents/TCIS_Social%20Norms_Exec%20Summary%20Final.pdf
[79] World Bamboo Organization. Why Bamboo? https://www.worldbamboo.net/bamboo
[80] R. Manandhar, J.H. Kim, and JT Kim. 2019. Environmental, Social and Economic Sustainability of Bamboo and Bamboo-based Construction Materials in Buildings. *Journal of Asian Architecture and Building Engineering*. 18:2. pp. 49–59. DOI: 10.1080/13467581.2019.1595629.
[81] A.C. Ham, and J. Shroyer. 1993. Bamboo Housing in Costa Rica: An Analysis of a Pilot Housing Program. *Housing and Society* 20(2): pp. 25–33. doi:10.1080/08882746.1993.11430161.

bamboo construction on equal terms with timber construction. This will likely require changes to existing regulations and building codes. Tohis, together with the challenge of shifting social norms among masons and home builders, is one of the most important facets of the enabling environment that is needed for a breakthrough in the use of bamboo as a modern construction material.

Examples of Bamboo-Based Housing in Asia

75. There are numerous examples from DMCs of bamboo-based, innovative housing architecture. On example from Viet Nam, is the floating bamboo house for those with water-based livelihoods in the Mekong Delta, designed by H&P Architects.[82] The firm also designed a prototype for low-cost bamboo housing, similar to what is considered to be the vernacular architecture, using local materials such as bamboo, fiberboard, and coconut leaf, located in a flood-prone area, and designed to be more resilient to flood damage than conventional buildings (footnote 10).

76. The Pemulung House project in Bali, Indonesia, was developed by architecture firm Ibuku create a series of 18-square meter modular bamboo homes for garbage collectors who earn their livelihood by collecting and selling recyclable waste. All the floors and walls are made of bamboo, and the roofing and insulation are covered by recycled materials such as bottles and tetra packaging.[83]

77. In the eastern and northeastern states of India, bamboo has historically been used for construction purposes, using the wattle and daub construction technique, on a foundation of tamped earth or cement mortar. Modern iterations of this construction technique incorporate wooden, or bamboo frames filled with split prefabricated wall panels. Social enterprise Bamboo House India offers such homes in the market.[84] The Indian Plywood Industries Research and Training Institute, in collaboration with the UK Timber Research and Development Association developed bamboo housing technology. The design was tested for its seismic performance and demonstrated that bamboo can be utilized to create earthquake-resistant frames and wall panels.[85]

Cement Bamboo Frame Technology

78. One of the most developed examples of enhanced traditional bamboo construction practices is the cement bamboo frame technology (CBFT), which was developed by the Hilti Foundation in 2012. It is an innovative construction technology that uses treated, load-bearing bamboo as its sole structural element.[86] CBFT is inspired by ancient Latin American building techniques, *bahareque encementado*, a technique that has long existed in central Colombia, and has been adopted in an area highly vulnerable to earthquakes to build homes with excellent seismic resilience. CBFT blends this with Asian bamboo construction traditions and Europe's high standards in timber construction. It results in a prefabricated and sustainable frame system comprising treated load-bearing bamboo, metal connections and mortar-cement plaster. This

[82] Archello. Bamboo floating house.2022. https://archello.com/project/floating-bamboo-house-fb-house.
[83] Arch Daily. 2011. Pemulung House / IBUKU. https://www.archdaily.com/884519/pemulung-house-ibuku#:~:text=Located%20in%20Denpasar%2C%20the%20project,a%20mezzanine%20sleeping%20area%20above.
[84] Bamboo House India. Social Enterprise creating livelihood opportunities at the base of the economic pyramid. https://www.bamboohouseindia.org/.
[85] J. Vengala and S. Raghunath. 2015. Seismic performance of Bamboo housing-an overview. Proc. World Bamboo Congr.1. 389–407. https://www.researchgate.net/publication/356493961_Seismic_performance_of_Bamboo_housing-an_overview.
[86] Hilti Foundation. 2019. *Tackling the Global Housing Crisis with Bamboo*. https://www.hiltifoundation.org/stories/tackling-the-global-housing-crisis-with-bamboo.

enables the rapid construction of strong homes. The frame is covered with a mesh to hold cement mortar plaster, and the result is smooth outer walls that look like conventionally constructed homes. CBFT has been tested for resistance to earthquakes of magnitude 7-8 and typhoons with winds of up to 300 kilometers per hour, as well as for resistance to fire and insect infestation (Figure 15).

Figure 15: Features of a Cement Bamboo Frame Home

Source: Base Bahay Foundation.

79. CBFT has been primarily used in the Philippines and Nepal to build affordable homes. To date, more than 1,400 affordable homes for over 7,000 people in need have been built with CBFT (Hilti Foundation). The Base Bahay Foundation Inc., (initiated by the Hilti Foundation) promotes its use through training at its Bamboo Academy, contractor accreditation, and research and development.[87] This is done in partnership with local and overseas academic institutions, on topics such technology optimization, life cycle assessments, property characterization of bamboo, codes, and approvals, and other related alternative building technologies.[88] CBFT homes have an estimated lifetime of up to 60 years, which translates to a 60% lower environmental impact compared to a conventional concrete house, according to a life cycle analysis by ETH Zurich.[89] According to Base Bahay, the construction cost of a CBFT home is approximately 30% lower than a conventional concrete house (reference 29). Together with Base Bahay Foundation and other local partners, the Hilti Foundation is showcasing CBFT for larger structures, with projects including a weaving center in Batangas, a food processing center for banana chips in a rural area close to the source of produce, and a market hall in the Metro Manila area near a housing project.

80. The adoption of CBFT has also created a value chain, and a model that can be adopted wherever bamboo is grown and used. Base Bahay Foundation started to introduce bamboo treatment facilities offering third parties both training and technology transfer. There are now nine treatment facilities across the Philippines, producing poles that are used in resort and hotel construction, as well as affordable, sustainable social housing (footnote 29). Base Bahay is the major off-taker for one such treatment facility operated by Kawayan Collective, in Dumaguete, Negros Oriental, Visayas, which has capacity to process 2,400 bamboo poles a month, sourced from local smallholder farmers. The collective operates a franchise model, and its vision is for "every town of the Philippines with at least 3,000 clumps of bamboo within a 20 kilometer radius to have a bamboo treatment facility, just like the corn or rice mill," locally owned and maintained,

[87] Base Bahay Foundation. Bamboo Academy. https://base-builds.com/training-2/.
[88] Base Bahay Foundation. Research and Development. https://base-builds.com/research/.
[89] E. Zea Escamilla, G Habert, JF Correal Daza, et al. 2018. Industrial or Traditional Bamboo Construction? Comparative Life Cycle Assessment (LCA) of Bamboo-Based Buildings. ETH Zurich Research Collection. https://www.research-collection.ethz.ch/handle/20.500.11850/286148.

but benefiting from aggregated sales, operations and brand-awareness across the Kawayan Collective cooperative network.[90]

Disaster Recovery

81. Bamboo housing also has a unique role to play in post-disaster recovery, as both temporary and long-term shelter.[91] Because bamboo frequently grows in regions that are susceptible to hurricanes and typhoons, stands that have been flattened during storms can be repurposed immediately to construct temporary shelters. Bamboo housing performs well in such climates. In Indonesia, volunteers from engineering and design consultancy Ramboll and University College London, together with local NGO Grenzeloos Milieu, built safe and sustainable bamboo houses in the wake of multiple earthquakes that had devastated the region in 2018.[92]

Seismic Performance

82. Traditional bamboo structures have excellent seismic performance during earthquakes.[93] This is attributed to their light weight relative to strength, shock absorption qualities of traditional jointing systems, and internal bonding, which helps evenly distribute forces throughout the building's structure (footnote 8). A PRC study modeling the seismic performance of a multi-story structure using laminated bamboo in the frame found that its performance was good enough to "justify further popularization and use in earthquake-prone areas."[94]

Thermal Comfort and Energy Efficiency

83. An important aspect of sustainability in housing is its ability to offer thermal comfort and energy efficiency. Emerging research shows that bamboo structures score well compared to conventional structures in both regards.

84. A PRC case study comparing the thermal performance of a traditional dwelling with bamboo-woven mud walls and a brick-concrete dwelling in the hot and humid area with abundant bamboo resources.[95] The study found that while the bamboo structure was more sensitive to temperature changes, it was more suitable for the hot and humid climate, especially during summer nights. The brick-concrete building was more favorable in terms of thermal comfort during summer days. The bamboo-woven mud walls dwelling could be retrofitted, together with introduction of adjustable natural ventilation techniques, using cost-effective local methods to maximize thermal comfort, and make it overall superior in this regard to modern brick-concrete structures.

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[90] Kawayan Collective Agriculture Cooperative Business Brief. 2025.
[91] UM Habitat. *Green Materials Bamboo*. https://unhabitat.org/sites/default/files/download-manager-files/BambooNotes.pdf
[92] Archello. Lombok Bamboo Housing. 2019. https://archello.com/project/lombok-bamboo-housing
[93] M. Kyakula., and I. Gombya. 2008. Suitability of Bamboo for Construction and Environmental Preservation. *Journal of Civil Engineering Research and Practice*. 5(1). doi:10.4314/jcerp.v5i1.29190.
[94] J.C. Zhao and H.X. Qiu. 2023. Seismic performance assessment of a multi-story bamboo frame structure. *Advances in Bamboo Science*. 2. https://www.sciencedirect.com/science/article/pii/S2773139122000118#:~:text=The%20inter%2Dstorey%20drift%20ratio,had%20a%20reasonable%20deformation%20pattern.&text=The%20seismic%20performance%20of%20laminated,use%20in%20earthquake%2Dprone%20areas.
[95] D. Ding, B. Shu. 2024. Thermal characteristics of dwellings with bamboo-woven mud walls in summer: A case study. *Journal of Building Engineering*. 82. https://www.sciencedirect.com/science/article/abs/pii/S2352710223023896#:~:text=This%20study%20demonstrates%20superior%20overall,to%20modern%20brick%2Dconcrete%20structures.

85. Similarly, a study in Malaysia found that bamboo vernacular houses using indigenous building materials were able to achieve sustainable energy consumption without compromising on indoor thermal comfort. The researchers compared an indigenous bamboo house and modern brick house at a village located in the Ulu Gombak Forest Reserve, Selangor. The study found that the use of bamboo, together with other vernacular house design features such as raising a house on stilts, and locating the house on a hilly site, can create a thermally comfortable indoor environment, particularly at night. [96]

86. A study of bamboo residential building energy efficiency in cold and severely cold region of the PRC quantifies bamboo's potential for energy efficiency and carbon emission reduction throughout the building life cycle (footnote 20). The researchers modeled a six-story residential building constructed using reinforced concrete and using laminated bamboo lumber in five different settings. Comparing the two building types of inventory analysis of the materialization, operation, and end-of-life stage, it found that use of bamboo instead of the conventional reinforced concrete structure would reduce energy consumption by 3%~5% and reduce CO_2 emissions by 7%~20%.

87. Bamboo housing can also be designed to be extremely energy efficient, both in construction and in cooling and heating. For example, the Energy Efficient Bamboo House, was designed by architects Studio Cardenas, and constructed in a rural area of Zhejiang Province. [97] It was developed a modular bamboo construction system, replicable on a large scale, and using locally sourced materials, as the area that has abundant bamboo. The design incorporated geothermal heat pump technology for both heating and cooling, which was 25% more energy efficient than conventional systems.[98]

88. Bamboo has been described as "a powerful ally in the fight against climate change, land degradation, and environmental sustainability."[99] This is due to its propensity for rapid growth, and its hardiness, making it able to flourish in a range of soils and climatic conditions.[100] It also has a remarkable carbon sequestration capacity, far beyond that of trees. Its contribution to climate action is two-fold: as a means of carbon sequestration, and as a replacement for other materials with a larger carbon footprint. Bamboo, and bamboo agroforestry in particular, can play an important role as one of a suite of options used to rapidly regenerate degraded lands and reduce soil erosion.[101]

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[96] N.D. Dahlan and A. Ghaffarianhoseini. 2016. Comparative Study on the Thermal Environmental Responses of Indigenous Bamboo and Modern Brick Houses in Hot-Humid Climate of Malaysia. *Jurnal Teknologi*. 78(11). DOI:10.11113/.v78.8041

[97] Studio Cardenas. Energy Efficient Bamboo House https://www.studiocardenas.it/index.php/en/thermal-control/148-energy-efficient-bamboo-house

[98] J. Miley. 2017. *This Energy Efficient Bamboo House is Designed to Have Minimal Footprint*. Interesting Engineering. 15 September. https://interestingengineering.com/culture/this-energy-efficient-bamboo-house-is-designed-to-have-minimal-footprint

[99] World Bamboo Organization. Why Bamboo? https://www.worldbamboo.net/bamboo

[100] M. Rani, M. Lathwal, Vikas et al. 2024. 12th World Bamboo Congress. Role of bamboo in environmental conservation and sustainable development. https://www.worldbamboo.net/_files/ugd/9191d7_274bf6e2aa9a4f7c850b1e60f7a8220f.pdf

[101] K. Buckingham. 2015. Bamboo: The Opportunities for Forest And Landscape Restoration. World Resources Institute World Bamboo Congress. 20 September. Damyang, Republic of Korea. https://www.worldbamboo.net/_files/ugd/9191d7_b62a3fb33c4346a99adc0e5cb9d03976.pdf

V. ENVIRONMENTAL IMPACT AND CONTRIBUTION TO CLIMATE ACTION

89. Bamboo has been described as "a powerful ally in the fight against climate change, land degradation, and environmental sustainability."[102] This is due to its propensity for rapid growth, and its hardiness, making it able to flourish in a range of soils and climatic conditions (footnote 100). It also has a remarkable carbon sequestration capacity, far beyond that of trees. Its contribution to climate action is two-fold: as a means of carbon sequestration, and as a replacement for other materials with a larger carbon footprint. Bamboo, and bamboo agroforestry in particular, can play an important role as one of a suite of options used to rapidly regenerate degraded lands and reduce soil erosion.[103]

Agroforestry or Monoculture?

90. Bamboo can be grown in a plantation or as an integrated part of an agroforestry is a farming system that combines trees, shrubs and perennial plants with crops and/or livestock.[104] There are advantages and disadvantages to both scenarios (Table 2). Bamboo agroforestry orchard systems help improve soil health and prevent soil erosion, as well as promoting greater resistance to pests and diseases, more so compared to bamboo monoculture (footnote 104). This makes planted areas most resilient to climate change. There are also agricultural benefits, including increased yield from different crops grown together with bamboo. This crop diversification in turn strengthens food security and improves nutrition. It can exceed the yield of bamboo monoculture by 10% to 60%, depending on the crops. As bamboo has a multi-year waiting period from planting to harvest, multi-crop agroforestry gives farmers an opportunity to generate income in the intervening years. Farming multiple crops also enables labor to be used throughout the year. Bamboo cultivation does not require a lot of fertilizer and pesticides, which makes it an economically favorable crop. However, bamboo agroforestry systems have some disadvantages compared to bamboo monoculture. They are more complex to manage and require a lot of site-specific expertise to determine the best blend of crops.

Table 2: Comparative Advantages and Disadvantages of Bamboo Agroforestry and Plantations

	Bamboo agroforests	**Bamboo plantations as monoculture or mixture of bamboo species**
Advantages	Multiple crops more options Better risk management Early returns because of Different crops higher total productivity More tolerance of pests and diseases Crop maintenance rather than weed control Environmental benefits (improved soil, erosion control, carbon sequestration)	Simpler to plan and manage Laborers require less skill Easier to mechanize Maximizes production of one crop
Disadvantages	No recipe for implementation Knowledge intensive depending on a number of different crops More complex management including attention to timing of management	Reliance on the market for a single crop More susceptible to pests and diseases Not using all ecological niches so lower total productivity Surges and lulls in labor demand

[102] World Bamboo Organization. Why Bamboo? https://www.worldbamboo.net/bamboo
[103] K Buckingham. Bamboo: The Opportunities for Forest And Landscape Restoration. World Resources Institute World Bamboo Congress. 20th September 2015 Damyang, South Korea. https://www.worldbamboo.net/_files/ugd/9191d7_b62a3fb33c4346a99adc0e5cb9d03976.pdf
[104] Pacific Agribusiness Research for Development Initiative Bamboo Agribusiness Compendium October 2021 https://www.pidf.int/wp-content/uploads/2022/08/PARDI-2-_Bamboo-Agribusiness-Compendium_-2021-1.pdf

	More difficult to mechanize certain operations	No early yields, all early cash flow is negative

Source: Pacific Agribusiness Research for Development Initiative Bamboo Agribusiness Compendium October 2021.

Soil and Water Protection

91. Bamboo is an asset to control soil erosion (footnote 100). It grows well on steep hillsides, road embankments, gullies, or on the banks of ponds and streams. There are many studies demonstrating the effectiveness of bamboo in controlling erosion and conserving soil. For example, in the PRC, Zhao et al. reported that bamboo plantations reduce the soil erosion by 85% in the Loess Plateau region.[105] Bamboo plants have deep root system. This has important implications for water conservation, limiting water loss from soil and reducing the risk of flooding.[106] The root system also enables bamboo to remove contaminants that have leached into the soil, such as lead.[107] For example, bamboo species were used to rehabilitate soil in Allahabad, India, on land that was degraded due to brickfield mining.[108]

Biodiversity Protection

92. A healthy forest supports health biodiversity. Bamboo forests have a positive impact on biodiversity and offer excellent habitats for a variety of flora and fauna. In South Asia, elephants, wild cattle, deer, leaf monkeys, pigs, rats, mice and squirrels have been found to make their home in bamboo forests.[109] In Nepal, red pandas and many of the country's endangered species inhabit bamboo forests.[110] Bamboo also serves as a nesting site for birds.

Invasion Risk

93. It is important to note, however, that bamboo uses one of two growth strategies. Clumping type bamboo develops new culms at the margin of an existing clump. Running type bamboo spreads via long, running shoots and can become an invasive species. Invasive bamboo species can displace trees and reduce tree density, to the detriment of plant and animal diversity.[111] Other ecological risks include serious disease or insect attacks due to reduced biodiversity. Forest degradation is a risk too, because without maintenance, a bamboo forest will degrade faster than other types of forest if it is abandoned, due to lack of nutrients available to new bamboo shoots (footnote 20).

[105] Q. Zhao, P. Shi, P. Li, et al. 2023. Effects of Vegetation Restoration on Soil Organic Carbon in the Loess Plateau: A Meta- Analysis. *Land Degradation & Development*. 34(7). pp. 2088–2097

[106] I.E. Jeffery, O.O. Akinyemi, A.A. Adedoyin, et al. 2023. Potentials of bamboo and its ecological benefits in Nigeria. *Advances in Bamboo Science*. 100032.

[107] M. Rani, M. Lathwal, AN Singh, et al. 2023. Effect of Lead Contamination on Morphological Attributes and Biomass Allocation of Bambusa balcooa (Roxb.). *International Journal of Environment and Climate Change*. 13(11). pp. 67–76.

[108] Anonymous. 1997. Healing degraded land [J]. *INBAR Magazine*. 5(3): pp. 40–45.

[109] K. Paudyal, L. Yanxia, T.T. Long, S. Adhikari, S. Lama, and K.P. Bhatta. 2022. *Ecosystem Services from Bamboo Forests: Key Findings, Lessons Learnt and Call for Actions from Global Synthesis*. International Center for Bamboo and Rattan.

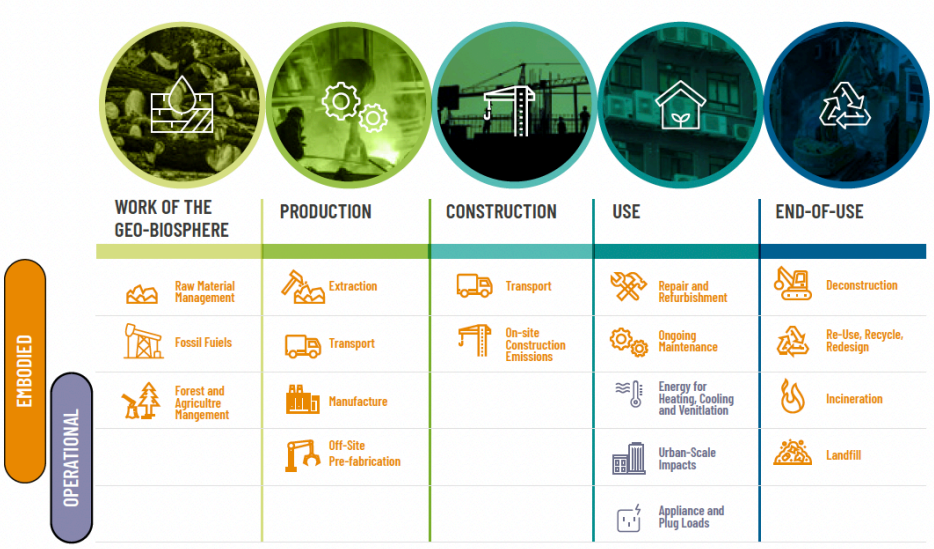
[110] S. Ayer, S. Timilsina, A. Aryal, et al. 2023. Bamboo forests in Nepal: Status, distribution, research trends and contribution to local livelihoods. *Advances in Bamboo Science*. 100027.

[111] Q.F. Xu, C.F. Liang, J. H. Chen, et al. 2020. Rapid bamboo invasion (expansion) and its effects on biodiversity and soil processes. *Global Ecology and Conservation*. 21:00787.

Environmental Sustainability of Bamboo Materials

94. Bamboo-derived materials can significantly contribute to environmental sustainability by displacing other materials for construction, and as an energy source. Taking a whole of life cycle approach, i.e., considering all the carbon costs of material choices, it is possible to conceptualize, and, given the necessary data, measure the embodied emissions in building materials, as well as the operational emissions from a building's energy use and energy-source emissions (Figure 16).[112]

Figure 16: Carbon Impacts of Materials Across the Whole Building Life Cycle



Source: United Nations Environment Programme, & Yale Center for Ecosystems + Architecture. 2023. Building Materials and the Climate: Constructing a New Future. https://wedocs.unep.org/20.500.11822/43293.

Bamboo for Construction

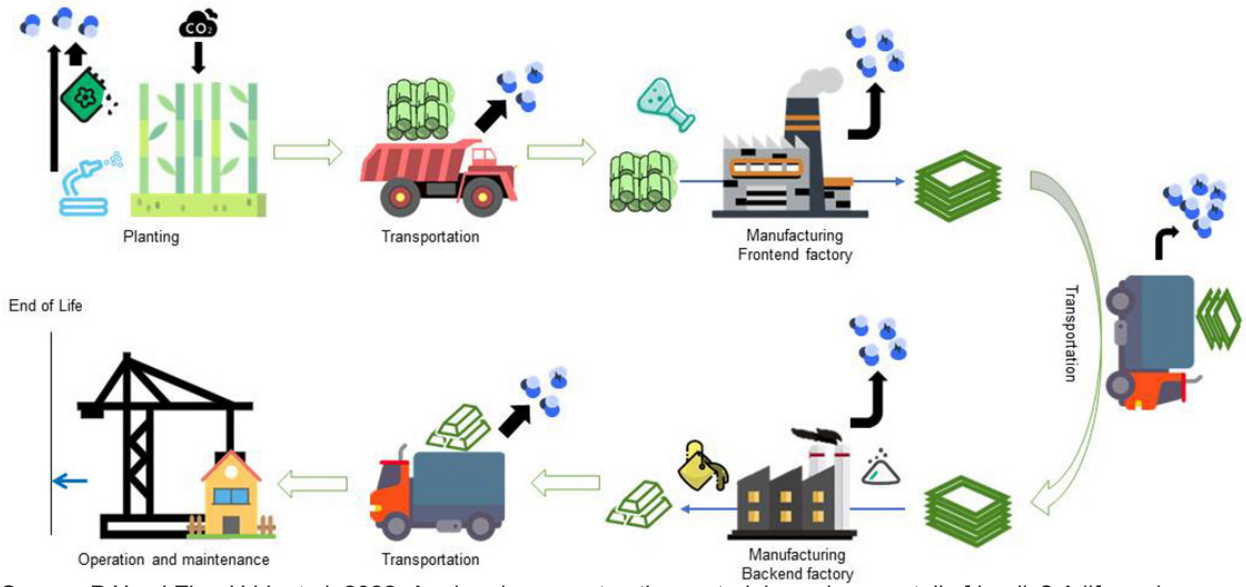
95. The construction industry is one of the most significant sources of carbon emissions, especially in the production of certain foundational materials including cement, concrete, and steel.[113] It is also a significant user of timber. The use of these materials is also set to increase, especially in low-income countries, due to rapid urbanization and the quality limitations of existing housing stock.[114] Bamboo can play a significant role in filling this gap, and in a more environmentally sustainable way than construction practices using conventional materials (footnote 106).

Life Cycle Assessment

[112] C Magwood, J Ahmed, E Bowden, et al. 2021. *Achieving Real Net-Zero Emission Homes: Embodied Carbon Scenario Analysis of the Upper Tiers of Performance in the 2020 Canadian National Building Code*. Builders for Climate Action. https://www.buildersforclimateaction.org/uploads/1/5/9/3/15931000/bfca-enercan-report-web_08_21.pdf.
[113] J Oomen. 2022. *Net-Zero Homes: How Circular Economy Solutions to the Housing Crisis in Low-Income Countries are Key to Achieving Global Climate Targets*. Habitat for Humanity Terwilliger center for Innovation in Shelter.
[114] J Oomen. 2022. *Building for the Future: What Does Net Zero Building Look Like in the Global South?* Engineering for Change.

96. Life cycle assessment (LCA) is a useful way to compare the performance of bamboo vs. other construction materials in terms of their environmental impact. This can be used as a methodological framework to calculate carbon emissions from production through the manufacturing and use life cycle (Figure 17) (footnote 10).

Figure 17: Bamboo Building Materials Life Cycle



Source: P Xu, J Zhu, H Li, et al. 2022. Are bamboo construction materials environmentally friendly? A life cycle environmental impact analysis. *Environmental Impact Assessment Review*. 96. https://www.sciencedirect.com/science/article/abs/pii/S0195925522001196#:~:text=The%20life%20cycle%20of%20bamboo,the%20end%20of%20life%20

97. There are few systematic life cycle studies of bamboo but the science is rapidly emerging. One life cycle environmental impact analysis compared bamboo and conventional construction materials.[115] It identified 12 environmental impact categories from global, regional and local perspectives, and used mathematical modeling to estimate the environmental impact values (EIV). Results show that the total EIV of bamboo construction materials was significantly lower than that of other building materials. Results also show that the environmental impact of bamboo construction materials can be easily controlled.

98. The degree of carbon emissions associated with bamboo products depends heavily on how they are manufactured. For example, a study of bamboo products from the PRC found that emissions were comparable with wood products manufactured in North America or Europe when both manufacture with the emissions from the coal-powered source of electricity used in production in the PRC was included and offset by the carbon storage of bamboo during the growth stage.[116]

[115] P Xu, J Zhu, H Li, et al. 2022. Are bamboo construction materials environmentally friendly? A life cycle environmental impact analysis. *Environmental Impact Assessment Review*. 96. https://www.sciencedirect.com/science/article/abs/pii/S0195925522001196#:~:text=The%20life%20cycle%20of%20bamboo,the%20end%20of%20life%20

[116] X Liu. 2021. *Carbon Footprint Analyses of Structural Bamboo Products*. The University of British Columbia. https://open.library.ubc.ca/soa/cIRcle/collections/ubctheses/24/items/1.0445323

99. Transportation also plays a role. Thus, using bamboo for housing construction near where it is grown, rather than transporting conventional materials in from afar, could contribute to the sustainability of bamboo materials in housing construction. A comparative LCA calculated the carbon emissions of four different construction materials—bamboo, brick, concrete hollow block, and engineered bamboo—used in building construction in Colombia.[117] The study showed that transportation was a significant contributor to environmental impact, as well as reinforcement materials. The engineered bamboo construction system has the lowest environmental impact. It concluded that adoption of bamboo-based construction systems has significant potential to support regenerative development.

100. Using the LCA methodology to understand the environmental sustainability of buildings is complex and usually relies on access to extensive data, which may not be available for low-cost housing projects such as social housing in developing country settings. Researchers at the Swiss Federal Institute of Technology and the Base Bahay Innovation Center in the Philippines developed a simplified LCA for social housing projects, with a set of basic and advanced parameters.[118] The intention was to enable users without civil or engineering background to carry out simplified LCA calculations. Using this methodology, the researchers found that CBFT could potentially reduce emissions by up to 60% compared to conventional construction systems.

Energy

101. Bamboo is currently underutilized as a fuel source. It is considered as a renewable source because new culms grow from existing clumps after harvesting, and it does not require replanting. Bamboo can play a significant role in energy conversion because it is rich in lignocelluloses.[119] These are a potential source of second-generation biofuel and are considered a promising alternative to petroleum-based fuel[120] It can be transformed into four different energy forms through various conversion technologies: bioethanol, bio-oil, biogas, and biochar.[121] Bamboo has potential to generate thermal energy, as well as electricity, through gasification. For example, in 2021, Clean Power Indonesia (CPI) piloted a 700 kWp bamboo-based biomass power plants on Mentawai islands, one plant in each of three villages. The plants provided reliable electricity to 1,200 households. According to CPI, "the sustainability of the mini grids is high: each village is realizing about 3,000 tons of carbon dioxide equivalent per year from emission avoidance and carbon sequestration due to new bamboo planting."[122] Biofuel-from-bamboo projects have also been initiated in other countries, including Ghana, Ethiopia and Colombia.[123]

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[117] E Zea Escamilla, G Habert, DJF Correal, et al. 2018. Industrial or Traditional Bamboo Construction? Comparative Life Cycle Assessment (LCA) of Bamboo-Based Buildings. *Sustainability*. 10(9):3096. https://doi.org/10.3390/su10093096.

[118] E. Eleftheriou, L.F. Lopez Muñoz, G. Habert, et al. 2022. Parametric Approach to Simplified Life Cycle Assessment of Social Housing Projects. *Sustainability*. 14: 7409. https://doi.org/10.3390/su14127409.

[119] H.K. Bajwa, O. Santosh, and C. Nirmala. 2024. Bamboo: A potential source of lignocellulosic biomass for production of advanced biofuels. 12th World Bamboo Congress. Taipei,China. 18–22 April. https://www.worldbamboo.net/_files/ugd/9191d7_5e0adaf943a84252995f38a60db5f360.pdf

[120] A. Yousuf, D. Pirozzi, and F. Sannino. 2020. Chapter 1 - Fundamentals of lignocellulosic biomass. Abu Yousuf, Domenico Pirozzi, Filomena Sannino. (eds). *Lignocellulosic Biomass to Liquid Biofuels*. Academic Press. pp. 1–15. https://doi.org/10.1016/B978-0-12-815936-1.00001-0.

[121] Z. Liang, A. Neményi, G. P. Kovács, and C. Gyuricza. 2023. Potential use of bamboo resources in energy value-added conversion technology and energy systems. *GCB Bioenergy*. 15. pp. 936–953. https://doi.org/10.1111/gcbb.13072

[122] Clean Power Indonesia. 2021. Facts About the Mentawai Bamboo-Based Biomass Power Plants. 9 April. https://cleanpowerindonesia.com/green-habitat-works/mentawai-biomass-powerplant-bamboo-facts/

[123] Bamboo: 2021. A Substitute for Wood for Biofuel. 6 JULY. World Bio Market Insights. https://worldbiomarketinsights.com/bamboo-a-substitute-for-wood-for-biofuel/.

Bamboo Charcoal

102. Bamboo can serve as a viable alternative to wood for biomass energy, used for cooking by over a third of the world's population.[124] As a cooking fuel, bamboo charcoal is more environmentally friendly alternative to wood. Unused charcoal and ashes can be added to soil, and the relatively high levels of silica in biochar increases nutrient uptake by plants. Charcoal production can also be a source of rural household income generation. Bamboo makes a good precursor to produce activated carbon, a key component in widely used filter materials.[125] Bamboo charcoal has a four-fold higher absorption rate than conventional charcoal and 10 times more surface area.

Bamboo Biochar

103. Biochar is a carbon-rich substance, created by pyrolyzing organic waste, and used for soil remediation. It is typically used as a soil component, or an additive to composts and fertilizers. It improves soil quality by improving carbon sequestration and also improves the soil's capacity to retain water and increase crop yields. Biochar soil has potential as a large-scale solution to offset global greenhouse gas emissions.[126] Bamboo biochar has several advantages over wood-derived biochar. It can be harvested each year for 3–5 years, whereas wood can only be harvested every 20 to 50 years. Bamboo can also be regenerated without replanting. Bamboo produces approximately a third more oxygen than trees and replenishes fresh air by capturing up to 12 tons of carbon dioxide per hectare. Moreover, it can increase the amount of carbon stored in soil for thousands of years.[127] Bamboo biochar is easy to produce on a small scale with basic equipment.[128]

Bamboo as a Substitute for Plastic

104. Plastics contribute to climate change through the greenhouse gases that are emitted throughout their life cycle. Plastic use continues to increase, and the resulting emissions are expected to double by 2060 if plastics production and use stays on its current trajectory.[129] In 2022, the International Bamboo and Rattan Organization and the Government of the PRC co-launched the Bamboo as a Substitute for Plastic Initiative.[130] The aim was to promote the potential of bamboo in reducing plastic pollution, replacing plastic products and providing a nature-based solution for energy-intensive and difficult-to-degrade plastic products.[131] A year later published a

[124] INBAR. SDG 7: Affordable & Clean Energy.https://www.inbar.int/programmes/sdg7-green-energy-2/
[125] H. Wei, S. Deng, B. Hu, Z. Chen, B. Wang, J. Huang, G. Yu G. 2012. Granular bamboo-derived activated carbon for high CO_2 adsorption: the dominant role of narrow micropores. *Chemsuschem*. 2012;5:2354–2360. doi: 10.1002/cssc.201200570.
[126] P. Lucchini, R.S. Quilliam, 2014. T.H. Deluca, et al. Does biochar application alter heavy metal dynamics in agricultural soil? *Agr Ecosyst Environ*. 184. pp.149–157. doi: 10.1016/j.agee.2013.11.018.
[127] K. Chaturvedi, A. Singhwane, M. Dhangar, et al. 2023. Bamboo for producing charcoal and biochar for versatile applications. *Biomass Convers Biorefin*. 13. pp. 1–27. doi: 10.1007/s13399-022-03715-3.
[128] International Biochar Initiative. Biochar Production Technologies. https://biochar-international.org/about-biochar/how-to-make-biochar/biochar-production-technologies/.
[129] International Bamboo and Rattan Association. 2024. Bamboo and plastic pollution. New global initiative seeks to leverage bamboo to fight the scourge of plastic pollution. May.
[130] International Bamboo and Rattan Association. 2023. Global Action Plan for Bamboo as a Substitute for Plastic (2023-2030).
[131] International Bamboo and Rattan Association. BASP initiative https://www.inbar.int/basp/.

related global action plan to mobilize stakeholders and galvanize progress toward implementation of the initiative

Bamboo's Contribution to Climate Action

105. The process of photosynthesis, through which plants capture and transform carbon dioxide into solid biomass is one of the best options for reducing atmospheric CO_2 and mitigating the effects of climate change (M Rani et al.). Bamboo forests are impressive carbon sinks due to their unique features of fast growth and high annual regrowth after harvesting, with most of the carbon in bamboo (approximately 70%) stored in the underground rhizomes. They have a higher rate of carbon sequestration than other types of forest, such as fir.[132] Per hectare, bamboo sequesters 1.46 times the carbon of fir forests and 1.33 times tropical rainforests.[133] As such, they are favored for afforestation to reduce carbon dioxide concentrations and mitigate climate change (footnote 20). When bamboo is used for engineered construction materials, the chemical treatments it undergoes can extend its lifespan from 2–3 years in its natural form to 30–40 years. As such, the carbon stored in natural bamboo remains there throughout the building's lifespan. When used as a substitute for other building materials, bamboo reduces the amount of embodied energy required (Table 3).[134]

Table 3: Energy Requirement for Production of Construction Materials

Building material	Density (kg/m^3)	Energy for production (MJ/kg)
Concrete	2,400	0.8
Steel	7,800	30
Wood	600	1
Bamboo	600	0.5

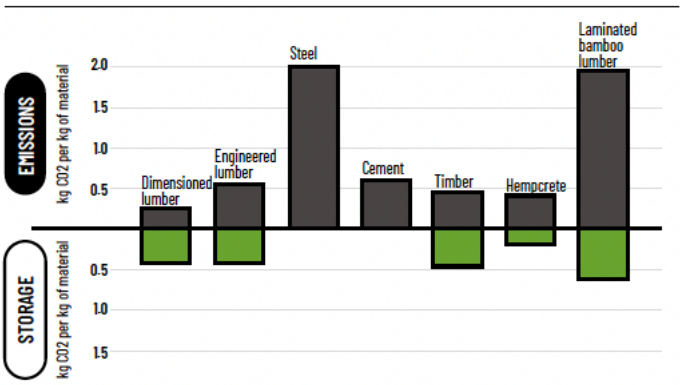
kg=kilogram, m=meter, MJ= megajoule
Source: R. Manandhar, J.H. Kim and J.T. Kim. 2019. Environmental, social and economic sustainability of bamboo and bamboo-based construction materials in buildings. *Journal of Asian Architecture and Building Engineering.* 18(2). pp. 49–59, DOI: 10.1080/13467581.2019.1595629.

Treatment Issues

106. However, while bamboo-derived building materials have great potential as green building materials, some of this benefit is lost due to the carbon emissions from the range of toxic treatment chemicals used to improve its resistance to mold and corrosion. Studies have shown that using synthetic treatment chemicals, glues and high-temperature air for drying can treble the carbon emission of bamboo relative to timber-based products, and that laminated bamboo products can generate carbon emissions similar to those for steel (Figure 18: Carbon Emissions and Storage for Laminated Bamboo Vs. Other Materials). This is counterbalanced by bamboo's carbon storage potential, unlike steel and cement, but more environmentally friendly chemicals for bamboo treatment are needed to capture its full value as a way to reduce carbon emissions.

[132] T.M. Yen, and J.S. Lee. 2011. Comparing aboveground carbon sequestration between moso bamboo (Phyllostachys heterocycla) and China fir (Cunninghamia lanceolata) forests based on the allometric model. *Forest Ecology and Management*. 261(6). pp. 995–1002. doi:10.1016/j.foreco.2010.12.015.
[133] United Nations Environment Programme, & Yale Center for Ecosystems + Architecture (2023). Building Materials and the Climate: Constructing a New Future. https://wedocs.unep.org/20.500.11822/43293.
[134] R. Manandhar, J.H. Kim and J.T. Kim. 2019. Environmental, social and economic sustainability of bamboo and bamboo-based construction materials in buildings. *Journal of Asian Architecture and Building Engineering*. 18(2). pp. 49–59, DOI: 10.1080/13467581.2019.1595629.

Figure 18: Carbon Emissions and Storage for Laminated Bamboo Vs. Other Materials



Source: Xu et al. cited in United Nations Environment Programme, & Yale Center for Ecosystems + Architecture (2023). Building Materials and the Climate: Constructing a New Future. https://wedocs.unep.org/20.500.11822/43293.

Promoting Bamboo as a Sheltertech Climate Investment

107. Bamboo as a building material for affordable housing faces an uphill battle to be recognized as an important climate change investment, but it is one worth pursuing, simply because of the huge need for housing. A study commissioned by Habitat for Humanity's Terwilliger Center for Innovation in Shelter found that although climate tech has attracted increasing interest in the impact investing space, technology related to affordable housing (sheltertech) does not attract the interest it deserves.[135] One of the reasons is distorted investment priorities: only 5% of startup investments for climate change solutions went to the built environment between October 2022 and September 2023, and this was a decline in the share of climate tech investments compared to previous years, the study found.[136] At the same time, the mobility industry attracted 50% of climate tech investments, even though it is only responsible for 15% of emissions.[137]

108. However, demand for housing in developing countries presents a major opportunity for climate change mitigation and adaptation investments. With 1 billion people living in slums or informal settlements, 80% of which are in Asia and sub-Saharan Africa, the demand for housing stock has never been greater.[138] Meeting this colossal housing demand in the coming decades using environmentally conscious construction and renewable energy is a major opportunity for climate change adaptation and mitigation.

[135] P. Woodman, L. Kuster-Jaeggi, and J. Parry. 2023. *Emerging Opportunity: The Hidden Role of Sheltertech in Climate Tech Investing*. Habitat for Humanity International.
[136] O. Wyman. 2018. *Mobility 2040: The Case for Smart Mobility*. https://www.oliverwyman.com/content/dam/oliver-wyman/v2de/publications/2018/Aug/Mobility2040_Oliver-Wyman.pdf..
[137] E. Cox, D. Dowling, J.S. King, et al. 2023. *Net Zero Economy Index 2023. Bending the curve: can climate ambition and reality still converge?* PwC. www.pwc.co.uk/services/sustainability-climate-change/insights/net-zero-economy-index.html. September.
[138] R. King, M. Orloff, T. Virsilas, et al. 2017. Confronting the Urban Housing Crisis in the Global South: Adequate, Secure, and Affordable Housing. *Working Paper*.
DC: World Resources Institute. https://smartnet.niua.org/sites/default/files/resources/towards-more-equal-city-confronting-urban-housing-crisis-global-south.pdf.

Challenges of Using Bamboo for Carbon Offsets

109. Bamboo cultivation could potentially be used to generate carbon credits in three key ways. First, planting bamboo in degraded or deforested areas can create new carbon sinks. These projects can be certified to generate carbon credits based on the amount of carbon sequestered by the bamboo. Second, integrating bamboo into agricultural systems can enhance carbon sequestration while providing additional benefits such as soil stabilization and improved biodiversity. These integrated systems can also qualify for carbon credits. Third, projects that promote sustainable bamboo harvesting and processing techniques can generate carbon credits by reducing emissions compared to conventional practices. [139]

110. Bamboo agroforestry could be used toward a country's national determined contributions for reducing in carbon emissions. However, this will not be a short-term outcome, because 10 years of historical data is required to claim carbon credits. Generating this data in a way that is sufficiently rigorous to be recognized for carbon credit purposes is challenging, given the environments in which much of the world's bamboo is grown. In November 2024, ADB convened a carefully selected cohort of expert advisors to an ideation workshop, From Roots to Revenue: Securing Finance and Climate Solutions Through Agroforestry - The Case of Bamboo, to explore the potential of bamboo agroforestry from diverse perspectives, including development, finance, impact investing, fintech, climatetech, agroforestry, and digital technology. Participants noted that carbon credits are also traded at a minimum volume of 100,000 tons. This creates a need to find a way to consolidate or pool the farmers or the bamboo from various farmers together to create enough to support trading. In terms of how a farmer should be compensated, there is also the issue of whether it would be for the carbon sequestered through growing the plant or through its use, for example, in housing construction.

111. The risk of greenwashing also came up. In countries lacking robust regulatory systems, it is easy to manipulate data underlying carbon credits unlawfully. In terms of ensuring a fair value of the financial instruments and impact of bamboo, there needs to be a scientifically supported understanding of bamboo's carbon impact to make the case.

112. Data will play a key role in addressing these challenges. Potential bamboo monitoring mechanisms include:

- geotagging the root of the bamboo;
- use of artificial intelligence or smart technologies for smart monitoring;
- using the Internet of Things, building a sensing network, using chips to track and measure, for example, temperature;
- remote sensing, which could also be used to track, for instance, that the bamboo grows to a certain height before it is used.

113. Noting that the available methodology for project level forest management carbon sequestration is not applicable for bamboo because of its unique characteristics, Lou et al. developed a methodology for project level carbon sink of bamboo plantation and management. The methodology includes applicability, baseline and carbon accounting methods, with the aim of improving bamboo management for increased carbon credit, assessment and monitoring. This

[139] ADB. From Roots to Revenue: Securing Finance and Climate Solutions Through Bamboo Agroforestry. https://events.development.asia/sites/default/files/course/2024/3%20From%20Roots%20to%20Revenue%20briefing%2024102024_JPFOR%20DISTRIBUTION.pdf

can help ensure that the certified carbon emission reduction is measurable, reportable and verifiable, and support the use of bamboo plantation management for carbon credits.[140]

VI. ALIGNMENT WITH GLOBAL STANDARDS AND FRAMEWORKS

114. Bamboo as a natural, renewable resource is one of its greatest strengths. However, it is also the source of one of the greatest challenges to promoting its use. Bamboo can be grown in monocultural plantations, which are more amenable to measurement and data collection. However, it also (often mostly) grows on small patches of public and private land, and as part of agroforestry ecosystems. Quantifying bamboo, measuring its dimensions, estimating its value, and quantifying its carbon capture capacity is more challenging in such settings.

115. The qualities of raw bamboo present a challenge to standardization, and therefore to measurement by global standards. Raw bamboo poles do not have a uniform and standard shape, and mechanical characteristics vary widely across different species. How bamboo is treated and dried also has a profound effect on its durability, tensile strength, and resilience to pests and other threats to its structural integrity.

116. Engineered bamboo products, especially those used in construction, are a relatively young industry. There are standards by which to measure both the production processes and the products, exist, but they may not be widely known or used.

117. For bamboo to fulfill its potential as "green gold," especially as a tool for climate change mitigation, its qualities, and its carbon sequestration capabilities, must be measurable according to internationally recognized standards and frameworks.

International Standards Organization Standards and Bamboo

118. The International Standards Organization (ISO) has a technical committee devoted to bamboo and rattan (ISO/TC 296) standards relevant to bamboo.[141] Established in 2015, the aim of ISO/TC 296 is to "facilitate the international trade of bamboo and rattan products, as well as the sustainable use of bamboo and rattan resources through the development of international standards." There are six ISO standards directly related to bamboo with more in the pipeline. Full descriptions of the standards can be found in Annex 1.

ISO 21625:2020 Vocabulary related to bamboo and bamboo products.
This document defines terms related to bamboo, intermediate bamboo and bamboo products, and described for the purposes of by bamboo experts, industries, consumers and other stakeholders.

ISO 21629-1:2021 Bamboo floorings Part 1: Indoor use
This document specifies the technical requirements and test methods for indoor bamboo flooring for internal use and is applicable to unfinished and finished indoor bamboo flooring.

ISO 19624:2018 Bamboo structures—Grading of bamboo culms—Basic principles and procedures

[140] Y. Lou, G. Zhou, Y. Shi et al. 2015. Introduction to the Methodology for Carbon Accounting of Bamboo Plantation Projects. Proceedings of the 10th World Bamboo Congress. Republic of Korea. https://www.worldbamboo.net/_files/ugd/9191d7_827205312b4b4bcb8a5daa36bde1b2d1.pdf.
[141] ISO. ISO/TC 296 Bamboo and rattan https://committee.iso.org/home/tc296.

This document specifies grading procedures for visually and mechanically sorting bamboo poles for structural applications. The grading procedures in this document can be used in a quality acceptance regime, although this document does not define or address acceptance criteria.

ISO 22157:2019 Bamboo structures—Determination of physical and mechanical properties of bamboo culms—Test methods
This document specifies test procedures for specimens obtained from round bamboo culms. The data obtained from the test methods can be used to establish characteristic physical or mechanical properties to be used in structural engineering design or for other scientific purposes and intended for commercial testing applications.

ISO 22156:2021 Bamboo structures—Bamboo culms—Structural design
This document applies to the design of bamboo structures whose primary load-bearing structure is made of round bamboo or shear panel systems in which the framing members are made from round bamboo.

ISO 23478:2022 Bamboo structures—Engineered bamboo products—Test methods for determination of physical and mechanical properties
This document specifies test methods suitable for determining the following mechanical properties of engineered bamboo products, such as bending, tension and compression strength, as well as the determination of dimensions, moisture content and density.

See also section 6, ISO Circular Economy Standards.

Forest Stewardship Council Standards and Certification for Bamboo Supply Chains

119. The Forest Stewardship Council (FSC) is an international voluntary accreditation and independent third-party certification organization. Its stakeholders include individuals, businesses, governments and NGOs. FSC certification enables holders to market their products and services as "the result of environmentally appropriate, socially beneficial and economically viable forest management."[142] FSC also sets standards for the accreditation of certification bodies that certify compliance with FSC's standards.

FSC Standards
120. FSC standards for responsible forest stewardship rest on 10 principles that require any managers of certified forests to:

- comply with all applicable laws;
- maintain or improve the social and economic well-being of workers;
- uphold the rights of Indigenous Peoples;
- maintain or improve the social and economic well-being of local communities;
- manage their products and services in a way that maintains or improves their long-term economic viability, social benefits, and environmental benefits;
- maintain, conserve, and/or restore the ecosystem services and environmental values of managed forests; and also avoid, repair, or mitigate negative environmental impacts;
- establish a management plan that outlines their economic, environmental, and social policies and objectives;
- demonstrate progress toward meeting these objectives;
- maintain or improve high conservation values;

[142] Forest Stewardship Council. 1994. FSC-STD-01-001 FSC Principles and Criteria for Forest Stewardship Standard (STD) V(5-3) https://connect.fsc.org/document-centre/documents/resource/392.

- ensure that all management activities comply with FSC principles and criteria (Forest Stewardship Council. FSC-STD-01-001).

The FSC issues forest management certification for forest managers, and chain of custody certification for material suppliers and finished goods manufacturers.

Chain of Custody Certification

121. Chain of custody certification verifies that forest-based materials are produced according to FSC standards along the whole value chain. For an organization to qualify for chain of custody certification it must implement a management system that ensures that forest-based materials used, including reclaimed materials, are FSC-certified; that material is identified and tracked throughout the manufacturing and distribution processes; there is documentation relating to FSC-certified product production, purchase, and sales. Suppliers and manufacturers must also meet FSC's core labor requirements, including no use of child or forced labor; no discrimination in employment and occupation; and freedom of association and the right to collective bargaining. Certification is not done by FSC, but by an FSC-accredited certification third party and is subject to annual audits.

FSC monitoring of supply chain integrity and action against violations

122. FSC also investigates false claims in FSC-certified supply chains through so-called transaction verification loops.[143] It takes punitive action against violators, including suspending certification.[144]

123. In June 2022 FSC launched a new transaction verification loop on FSC-certified bamboo, after several European stakeholders alerted FSC's investigation provider Assurance Services International (ASI) about potential false claims being made by certificate holders trading in bamboo.[145] This was the third time FSC had proactively revisited the bamboo supply chain. It collected data and samples for analysis of FSC-certified bamboo 425 certificate holders in 23 countries, many from the PRC. The products under investigation were natural bamboo, veneer, plywood and flooring products made from moso bamboo (Genus *Phyllostachys*).

124. In July 2023, FSC released the preliminary results of the investigation, which showed "potential volume mismatches that could be indicative of false claims in the bamboo supply chains," which had also been detected in the previous two transaction verification loops. The majority of FSC-certified forest management units harvesting bamboo are located in the Fujian Province and Zhejiang Province, PRC, and that FSC-certified bamboo products are mainly processed and manufactured in the PRC and in a couple of European countries, then sold to via supply chains in European and North American markets. Potential volume mismatches detected through data analysis indicated that non-certified bamboo may have entered certified supply chains, and ASI then identified potentially high-risk supply chain clusters for further investigation in the second phase of the TV loop,[146] and in September 2024, FSC announced certification suspensions for four bamboo plywood and other materials manufacturers.[147]

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[143] FSC. Supply Chain Integrity. https://connect.fsc.org/system-integrity/supply-chain-integrity.
[144] FSC. 2024. FSC blocks Chinese toilet paper company for making false claims. 30 October. https://fsc.org/en/newscentre/integrity-and-disputes/fsc-blocks-chinese-toilet-paper-company-for-making-false-claims
[145] FSC. FSC revisits integrity of bamboo supply chains. 2022. https://fsc.org/en/newscentre/integrity-and-disputes/fsc-revisits-integrity-of-bamboo-supply-chains.
[146] FSC. 2023. Potential risks identified in bamboo supply chains. 4 July. https://fsc.org/en/newscentre/general-news/potential-risks-identified-in-bamboo-supply-chains.
[147] FSC Integrity Risks Identified in Bamboo Supply Chains. 6 September 2024. https://fsc.org/en/newscentre/integrity-and-disputes/integrity-risks-identified-in-bamboo-supply-chains

Measuring the Contribution of Bamboo to Sustainable Infrastructure

125. Sustainable Asset Valuation (SAVi) is an assessment methodology was developed by the International Institute for Sustainable Development thinktank.[148] Its aim is to governments and investors steer capital toward sustainable infrastructure by answering questions such as:

- How does environmental, social and economic performance increase value for money for taxpayers?
- Is sustainable infrastructure systematically more expensive to build?
- Can these costs be recuperated during the use phase?
- Do sustainable assets trigger more positive externalities such as higher gross domestic product (GDP), Green GDP, employment, innovation, and productivity?
- Will this asset help trigger sustainable development?[149]

126. The SAVi methodology was used to assess a forest restoration project to address land degradation and water availability in the Brantas River Basin, Indonesia. The Maintaining and Enhancing Water Yield through Land and Forest Rehabilitation (MEWLAFOR) is a Global Environment Facility-funded project designed to restore degraded land in the Brantas River catchment by establishing 387 hectares of upstream agroforestry systems and 150 hectares of riparian bamboo plantations.[150] Upstream activities comprise agriculture and forestry. Downstream industrial activities include a PT Multibintang brewery.

127. SAVi assessment for the MEWLAFOR project showed that the nature-based infrastructure solution of land restoration is more cost-effective than building a reservoir for water storage and provides significant societal benefits. “Specifically, over 20 years, these interventions generate net benefits of between $104.34 million and $131.59 million in avoided flood and erosion damages along with improved water quality, carbon storage, job creation, agroforestry, and bamboo production,” the SAVi report states.[151]

Incorporating United Nations Guiding Principles on Business and Human Rights

128. The UN Guiding Principles on Business and Human Rights recognize:

- States’ existing obligations to respect, protect and fulfill human rights and fundamental freedoms;
- The role of business enterprises as specialized organs of society performing specialized functions, required to comply with all applicable laws and to respect human rights; and
- The need for rights and obligations to be matched to appropriate and effective remedies when breached.[152]

[148] International Institute for Sustainable Development https://www.iisd.org/mission-and-goals
[149] L Casier & E Cutler. 2023. *Sustainable Asset Valuation (SAVi) and the case for investing in Nature-based Infrastructure*.https://www.oecd.org/content/dam/oecd/en/events/2023/3/Session%206%20Mainstreaming%20resilience%20in%20projects%20IISD.pdf/_jcr_content/renditions/original./Session%206%20Mainstreaming%20resilience%20in%20projects%20IISD.pdf.
[150] Global Environment Facility Maintaining and Enhancing Water Yield through Land and Forest Rehabilitation (MEWLAFOR). https://www.thegef.org/projects-operations/projects/10757.
[151] A.M. Bassi, R Bechauf, E Cutler, et al. 2021. Sustainable Asset Valuation (SAVi) of Forest Restoration in the Brantas River Basin, Indonesia. International Institute for Sustainable Development. https://nbi.iisd.org/report/savi-forest-restoration-brantas-river-basin-indonesia/
[152] UN Guiding Principles on Business and Human Rights https://www.ohchr.org/sites/default/files/documents/publications/guidingprinciplesbusinesshr_en.pdf

129. Although not legally binding, governments and the world's largest companies have widely accepted the UN Guiding Principles, but they apply to all states and to all business enterprises, irrespective of their size, sector, location, ownership and structure. The foundational principles for states include protection against human rights abuses and set expectations that corporations will respect human rights throughout their operations. Businesses are required to avoid causing or contributing to adverse human rights impacts and seek to prevent or mitigate adverse human rights impacts that are directly linked to their operations, or as a result of their business relationships. These guiding principles can be used to adopt a human rights-based approach to bamboo agroforestry and can draw on experiences of other rights-based forest management initiatives.[153]

130. This is necessary, because as well as bamboo agroforestry's potential for economic and social transformation, it is possible for it to have a negative impact on human rights. For example, the United States government Bureau of International Affairs has reported cases of forced and child labor issues in the Myanmar bamboo industry. These include:

> "reports that children as young as age 10 are forced to work in the production of bamboo there. According to the International Labour Organization and nongovernmental organizations, forced child labor is pervasive, particularly in Karen, Shan, and Arakan States near military camps, with children constituting up to 40% of forced laborers being used for a variety of activities, including the production of bamboo. Some of these children are sent by their families to fulfill a mandate imposed by the military that requires each household in a village to undertake specified forced labor activities. Villagers, including children, were forced by local officials and the military to work cutting bamboo for the military camps. The forced child laborers are not paid for their work and face physical violence or other punishment if they refuse to work."[154]

Environmental, Social and Governance Frameworks and Standards

Global Reporting Initiative Standards

131. The Global Reporting Initiative (GRI) Standards are widely used by organizations to report their impacts environmental, social, and governance (ESG) impacts.[155] Apart from the three GRI Universal Standards, which apply to all GRI RSG reporting, there are 40 sector standards with direct relevance to bamboo currently at various stages of development. Several are directly relevant to bamboo. In the basic materials and needs groups, considered to be highest priority.

132. The GRI Sector Standard 13: Agriculture, Aquaculture, and Fishing 2022 came into effect for reporting from 1 January 2024, and is one of the sectors considered to have the largest sustainability impacts;

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[153] SwedBio. 2023. *Adopting a Human Rights-based Approach to Biodiversity & Climate Action*. https://swed.bio/wp-content/uploads/2023/10/Adopting-a-Human-Rights-based-Approach-to-Biodiversity-and-Climate-Action_layouted_161023_FINAL.pdf.

[154] United States Government. Bureau of International Affairs. 2021. List of Goods Produced by Child Labor or Forced Labor. ADB has temporarily put on hold sovereign project disbursements and new contracts in Myanmar effective 1 February 2021. https://www.dol.gov/sites/dolgov/files/ilab/child_labor_reports/tda2023/2024-tvpra-list-of-goods.pdf

[155] GRI. A Short Introduction to the GRI Standards. N.d. https://www.globalreporting.org/media/wtaf14tw/a-short-introduction-to-the-gri-standards.pdf

- the Textiles and Apparel Standard is currently under development by a multi-stakeholder working group.
- the Renewable Energy Standard includes biofuels producers; and
- the Forestry Standard covers forestry and logging, production of pulp and paper.

133. In the industrial standards group, bamboo falls under both the Construction Standard and the Construction Materials Standard. In the other services and light manufacturing group, bamboo falls under the Household Durables Standard.[156]
There are 34 topic-specific GRI Standards organized into three series (Table 4). Many sub-topics (Figure 19) are of direct relevance to bamboo agroforestry and associated industries. [157]

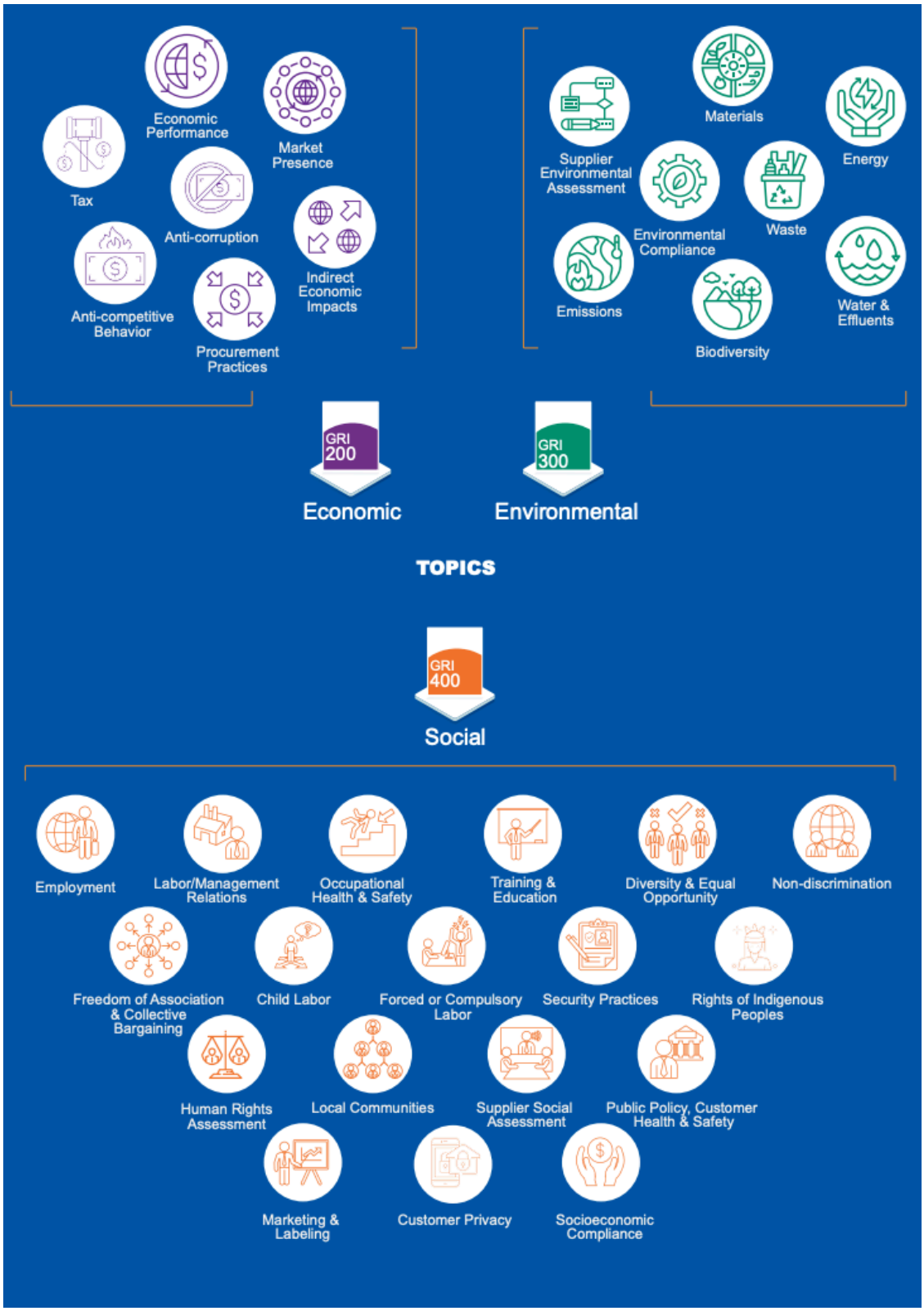
Table 4: Global Reporting Initiative Standards Series

Series	Description
200 series Economic (7 sub-topics)	Concerns an organization's impacts on the economic conditions of its stakeholders, and on economic systems at local, national, and global levels. It does not focus on the financial condition of an organization
300 series Environmental (8 sub-topics)	Concerns an organization's impacts on living and non-living natural systems, including land, air, water and ecosystems
400 series Social (18 sub-topics)	Concerns an organization's impacts on the social systems within which it operates

Source: GRI. The GRI Standards A Guide For Policy Makers.

[156] Global Sustainability Standards Board GRI Sector Program – List of prioritized sectors Revision 3 https://www.globalreporting.org/media/mqznr5mz/gri-sector-program-list-of-prioritized-sectors.pdf.
[157] GRI. The GRI Standards A Guide For Policy Makers. N.d.

Figure 19: Global Reporting Initiative Standards



Source: GRI. The GRI Standards A Guide For Policy Makers

VII. CIRCULAR ECONOMY PRINCIPLES AND BAMBOO

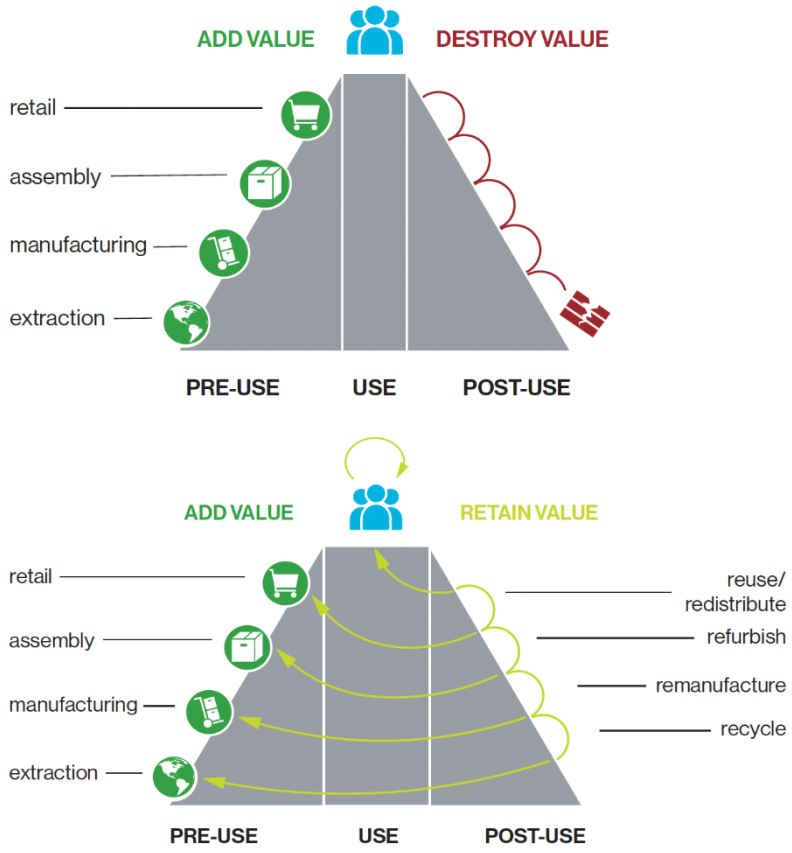
Circular Economy Principles

134. The circular economy is key to tackling climate change, because it is based on the principle that materials never become waste and nature is regenerated.[158] The Ellen McArthur Foundation defines circular economy principles as:

- design out waste and pollution,
- keep products and materials in use, and
- regenerate natural systems.

135. Circularity is concerned with resource cycles that add and retain value, rather than add and then destroy it (Figure 20) (footnote 113)..[159]

Figure 20: Value in the Linear Economy and the Circular Economy



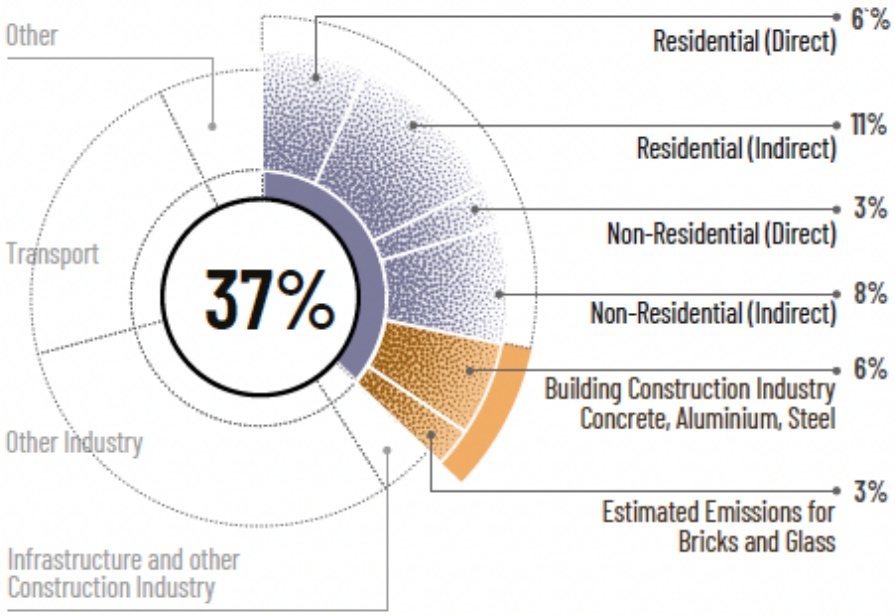
Source: J Oomen. Net-Zero Homes: How circular economy solutions to the housing crisis in low-income countries are key to achieving global climate targets. Habitat for Humanity Terwilliger center for Innovation in Shelter. 2022.

[158] Ellen MacArthur FoundationWhat is a circular economy? https://www.ellenmacarthurfoundation.org/topics/circular-economy-introduction/overview

[159] See annex 3 for a more complex illustration of the circular economy.

136. Circularity is highly relevant to the construction industry, because the built environment sector is one of the largest contributors to climate change, accounting for 37% of global energy-related carbon emissions (Figure 21).[160]

Figure 21: Global Share of Buildings and Construction Operational and Process Carbon Emissions, 2021



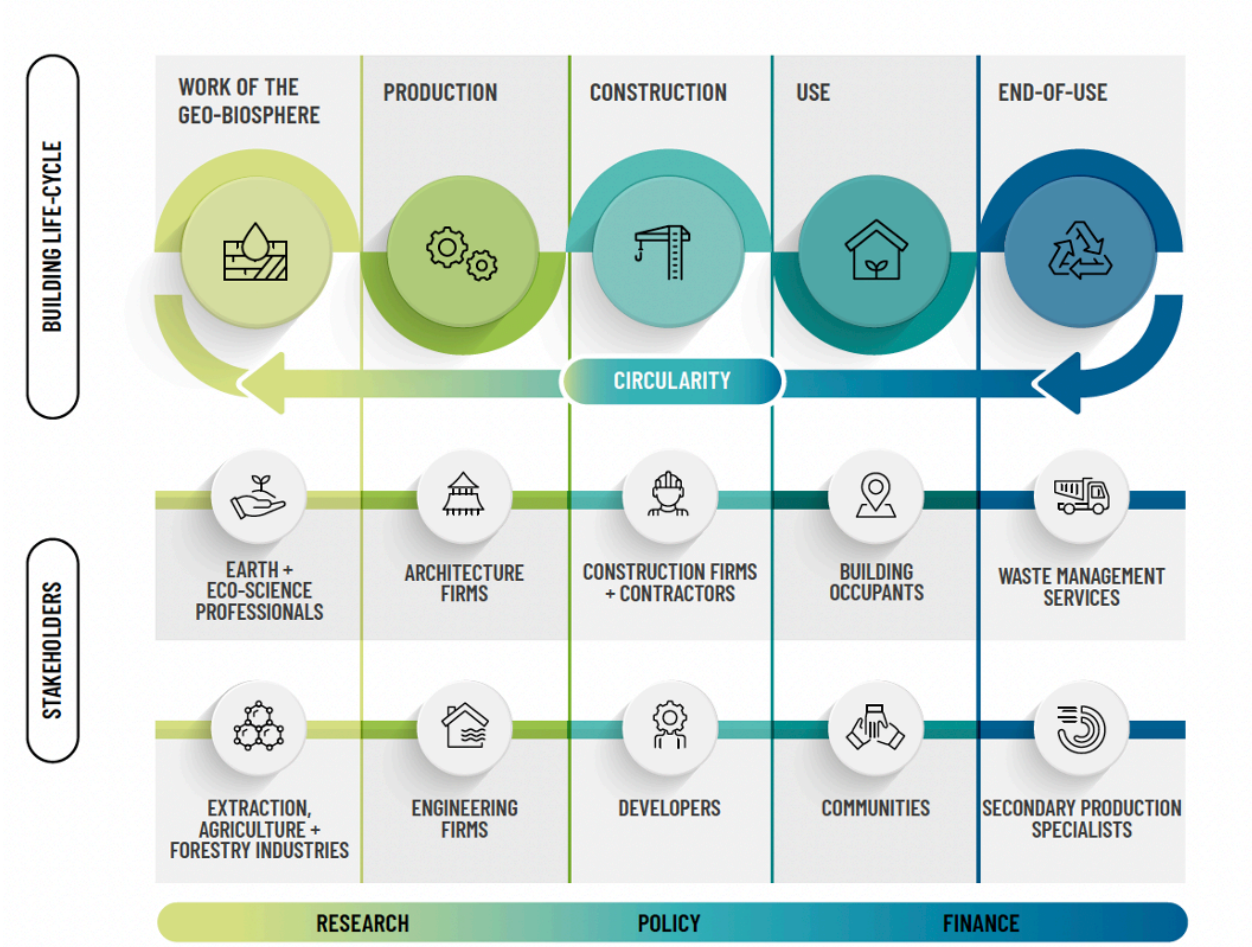
Source: United Nations Environment Programme, & Yale Center for Ecosystems + Architecture. 2023. Building Materials and the Climate: Constructing a New Future. https://wedocs.unep.org/20.500.11822/43293.

137. The heavy use of carbon-intensive building materials is a relatively recent phenomenon. Until the 1950s, most construction was done with biomass materials, notably wood, timber and earth-based materials. Only in recent decades did the majority of construction materials come from extractive, toxic, non-renewable processes, and by the turn of the century, metals and minerals constituted the most-used building materials for the first time in human history (United Nations Environment Programme, & Yale Center for Ecosystems + Architecture). In that sense, promoting the use of bamboo is a return to sustainable building practices, as much as it is an innovation.

138. If bamboo is to fulfill its potential as a sustainable building material, and in fact as a material for other products too, its manufacture and use will have to adhere to circular economy principles. This requires effort and participation from different stakeholders, including policymakers, financial investors and developers, manufacturers, builders, waste managers, architects and engineers, as well as building occupants (Figure 22). Each of these stakeholders has a role to play throughout the whole life cycle of materials, from natural resources extraction through design, production, and construction, and ultimately to use, end of use, and reuse (see also annex 2).

[160] UNEP. 2022 *Global Status Report for Buildings and Construction: Towards a Zero-emission, Efficient and Resilient Buildings and Construction Sector*. Global Alliance for Buildings and Construction.https://globalabc.org/our-work/tracking-progress-global-status-report.

Figure 22: Key Stakeholders in the Decarbonization of Buildings



Source: United Nations Environment Programme, & Yale Center for Ecosystems + Architecture. 2023. Building Materials and the Climate: Constructing a New Future. https://wedocs.unep.org/20.500.11822/43293.

Measuring Circularity

Circular Transition Indicators

139. The World Business Council on Sustainable Development developed the Circular Transition Indicators (CTI) with the aim of giving businesses a way to consistently and reliably measure their circular performance and its impact on sustainability.[161] The CTI include a framework and user guide, and there is an associated CTI tool that structures data and calculates outcomes and also supports users to confidentially request data from internal stakeholders and value chain partners.[162] Although a CTI assessment does not facilitate comparison between industries, companies or products, it points to scope for learning from other industries regarding product stewardship, such as the aluminum industry's Aluminium Stewardship Initiative.[163] Similar

[161] World Business Council on Sustainable Development. Circular Transition Indicators v4.0. 2023. https://www.wbcsd.org/resources/circular-transition-indicators-v4/#
[162] World Business Council on Sustainable Development**. CTI tool. https://ctitool.com/**
[163] Aluminium Stewardship Initiative. 2025. https://aluminium-stewardship.org/.

initiatives have been undertaken by the forestry sector (FSC) and the mining sector.[164] Extended producer responsibility policies and programs and product stewardship are gaining momentum in high-income countries, including in the construction industry.[165]

Life Cycle Assessment

140. LCAs are the best-practice method for products and services, and they LCA is a key tool in evaluating the extent to which circularity principles are being used. An LCA is systematic way to assess the environmental impact of a product, material, or process over the course of its entire life cycle.[166] An LCA entails conducting a life cycle inventory to determine the raw material and energy needs, atmospheric emissions, waterborne emissions, solid wastes, and other emissions for the whole life cycle of an output and for each process.[167] This leads to a life cycle impact assessment, in which the environmental impacts of the products are assessed and evaluated (see section 4 for details of several bamboo-related LCAs). To apply circular economy principles in bamboo product manufacturing, and to use LCAs to evaluate, it will be necessary to be able to trace the provenance of raw materials, as well as their journey through the processing, transportation and product manufacturing processes. FSC forest management and chain of custody certification (see section 5) are examples of how best practices in forest products use, including bamboo, are currently vouched for in international markets. LCAs are mentioned throughout the new ISO circular economy standards. See annex 3 for key terms and definitions used in life cycle assessment

ISO Circular Economy Standards

141. In May 2024, the ISO released three new standards pertaining to the implementation and measurement of the circular economy (Figure 23):

- ISO 59004: Terminology, Principles, and Guidance for Implementation
- ISO 59010: Guidelines for the Transition of Business Models and Value Networks
- ISO 59020: Measurement and Evaluation of Circularity

The ISO circular economy guidance provides uniformity and supports replicability of measurement.

[164] International Council on Mining and Metals. 2006. Maximizing Value Guidance on implementing materials stewardship in the minerals and metals value chain. September. https://www.icmm.com/website/publications/pdfs/mining-metals/2006/guidance_maximising-value-2006.pdf.
[165] Global Product Stewardship Council. About the GlobalPSC. https://www.productstewardshipcouncil.net/about-the-globalpsc/ and Carbon Pricing Leadership Coalition. P Crabbe. Stewardship in the Construction Industry. 7 October 2021. https://www.carbonpricingleadership.org/blogs/2021/10/14/stewardship-in-the-construction-industry
[166] Rochester Institute of Technology What is life cycle assessment (LCA)? 2020. https://www.rit.edu/sustainabilityinstitute/blog/what-life-cycle-assessment-lca
[167] T Uygunoğlu, P Sertyeşilişik, İB Topçu. 2021. 20 - Methodology for the evaluation of the life cycle in research on cement-based materials. J de Brito, C Thomas, C Medina, et al (eds). in *Woodhead Publishing Series in Civil and Structural Engineering, Waste and Byproducts in Cement-Based Materials*. Woodhead Publishing.

Figure 23: Summary of International Organization for Standardization Circularity Standards

Source: Circular Futures

ISO 59004:2024 Circular economy—Vocabulary, principles and guidance for implementation lays out six circular economy principles (systems thinking, value creation, value sharing, resource management, resource tracking and ecosystem resilience). It aims to "support organizations in contributing to the United Nations Agenda 2030 for Sustainable Development by facilitating a transition to a circular use of resources." [168]

ISO 59010:2024 Circular economy—Guidance on the transition of business models and value networks provides "guidance for organizations wishing to transition their value creation models and networks from a linear to a circular framework. This standard focuses on business-oriented strategies to implement circular economy practices at both organizational and interorganizational levels." [169]

ISO 59020:2024 Circular economy—Measuring and assessing circularity performance provides requirements and guidance for organizations to measure and assess their circularity performance, and "aims to standardize the process by which organizations collect and calculate data using mandatory and optional circularity indicators, ensuring consistent and verifiable results."[170]

Several connected standards and technical papers are also in development.

VIII. CONCLUSION AND RECOMMENDATIONS

142. Bamboo is such a commonplace plant across Asia and the Pacific that it is easy to overlook its transformational potential. Whether grown in large-scale, dedicated plantations, or found in backyards, on hillsides and on smallholder farms, it has value that in many places is yet to be fully appreciated. The barriers to reaching its full potential as a lucrative crop, sustainable material, and driver of economic growth are in many ways the same as those restricting

[168] ISO 59004:2024 Circular economy — Vocabulary, principles and guidance for implementation. https://www.iso.org/standard/80648.html
[169] ISO 59010:2024Circular economy — Guidance on the transition of business models and value networks. https://www.iso.org/standard/80649.html
[170] ISO 59020:2024Circular economy — Measuring and assessing circularity performance. https://www.iso.org/standard/80650.html

development in general: information asymmetries, in this case along the value chain; lack of government attention to the required regulations, standards and incentives; underinvestment from both the public and private sectors; and lack of education and knowledge from the grassroots up. From a social impact perspective, there are numerous steps that can be taken to promote the bamboo agroforestry sector, and the sustainable use of high-quality bamboo materials, for both climate action and financial inclusion, as laid out in the following recommendations.

143. **Convene national stakeholders within and beyond the government.** The development of a bamboo ecosystem cuts across several sectors, from agriculture, to the environment, housing, industry, transportation, energy and social and economic development. In addition, there are stakeholder in communities, NGOs and the private sector. Working with DMC governments to convene these disparate stakeholders can help them formulate a coherent bamboo policy and strategy.

144. **Work on both supply and demand.** Bamboo is easy to grow but often hard to sell. As well as promoting bamboo agroforestry, it is crucial to promote the markets for treated poles, manufactured goods, and construction materials both domestically and internationally.

145. **Identify and tackle the pain points along the bamboo value chain.** Supporting the use of bamboo, especially as a construction material, may require going further upstream, to the point where raw bamboo is treated. Confidence in the initial treatment process to ensure bamboo is insect-proof and of maximum tensile strength is key to promoting its use further downstream. In the other direction along the value chain, lack of nearby processing or manufacturing capacity makes it difficult for subsistence farming communities that grow bamboo to harness its potential for financial inclusion.

146. **Support the development of domestic manufacturing.** While there is a growing export market for treated bamboo poles for manufacture into construction materials such as flooring, promoting domestic used of treated bamboo poles and minimally engineered construction materials, and the manufacture of bamboo goods will support local solutions to affordable housing, improve livelihoods enable more of the value to accrue domestically.

147. **Address the polarizing status of bamboo as a construction material.** This requires engaging low-income homebuilders, masons and materials suppliers to shift the perception of bamboo as a poor person's building material. Bridging the gap between them and the high-end market by capitalizing on the existing momentum among architects, construction engineers and bamboo construction advocates can showcase the potential of bamboo architecture.

148. **Incentivize the use of bamboo in affordable housing.** This calls for action at multiple levels. In addition to socializing it as an attractive building material, national, regional and municipal levels of governments need to be on board to promote its use. Measures requiring government intervention include building codes that support the use of bamboo, and for the adoption of ISO standards for bamboo into national standards. There are also financial levers, such as tax incentives, to use bamboo.

149. **Work with other alternative materials sectors.** Bamboo occupies a unique space as both a traditional material, and when treated, as a modern one too. Where other innovative eco-friendly construction materials have found purchase, this may offer a soft point of entry for the promotion of bamboo.

150. **Foster international knowledge sharing.** Bamboo is found across Asia and the Pacific. Countries such as Indonesia, Viet Nam and the PRC, where proof-of-concept bamboo construction exists, can be used as exemplars for other countries too. Beyond the region, Latin America, specifically Colombia, has a rich heritage of bamboo use in housing construction and has already institutionalized it in building a codes. There is much that Asian countries can learn from their experience. The use of innovative technology, such as CBFT, can be more widely shared. Collaboration with existing bamboo research centers in DMCs, either within academic institutions or dedicated bamboo innovation laboratories such as the Base Innovation Center in Manila, Philippines, and fostering a regional network for bamboo innovation can support development of both the supply and demand sides of the bamboo market, especially the market for affordable, climate-resilient housing solutions.

151. **Work with communities that already want to go green.** Sharing data on the contribution that bamboo can make to climate change mitigation and adaptation is a way to incentivize them to include bamboo in their vision and plans, and to see bamboo as a development best buy, offering both social and climate action benefits.

ANNEXES

Annex 1. International Organization for Standardization Standards Relevant to Bamboo

1. ISO 21625:2020 Vocabulary related to bamboo and bamboo products[1]

This document defines terms related to bamboo, intermediate bamboo and bamboo products. This document is applicable to bamboo, intermediate bamboo and bamboo products in production and trade the standard is developed to obtain universal understanding about bamboo and bamboo products due to growing use of those products worldwide. Therefore, each term is described in such a way to be generally understood by not only bamboo experts, but also industries, consumers, and other stakeholders. The standard has been published in July 2020.

2. ISO 21629-1:2021Bamboo floorings Part 1: Indoor use[2]

This document specifies the technical requirements and test methods for internal use of indoor bamboo flooring. This document also specifies handling, storage, packaging, and marking requirements. It applies to unfinished and finished indoor bamboo flooring. This includes laminated bamboo flooring, bamboo scrimber flooring, bamboo-wood composite flooring, and flattened bamboo flooring.

3. ISO 19624:2018 Bamboo structures — Grading of bamboo culms — Basic principles and procedures[3]

This document specifies grading procedures for visually and mechanically sorting round, or pole, bamboo for structural applications using such fundamental elements. Visual sorting is based on the observable characteristics of the piece(s). Mechanical sorting is based on non-destructive measurement of properties known to correlate to characteristic values defining a grade. The grading procedures in this document can be used in a quality acceptance regime, although this document does not define or address acceptance criteria. This document applies only to bamboo graded in the seasoned state.

4. ISO 22157:2019 Bamboo structures — Determination of physical and mechanical properties of bamboo culms — Test methods[4]

This document specifies test procedures for specimens obtained from round bamboo culms. The data obtained from the test methods can be used to establish characteristic physical or mechanical properties for structural engineering design or other scientific purposes. This document provides methods for evaluating the following physical and strength properties: moisture content, density, and mass per unit length; strength properties parallel to the fiber direction, compression, tension, and bending, and strength properties perpendicular to the fiber direction, tension, and bending. It also provides methods to estimate moduli of elasticity in bending, compression, and tension parallel to fibers, and bending perpendicular to fibers. The test methods reported in this document are intended for commercial testing applications. The test methods reported in this document are intended for commercial testing applications and can also be adopted as benchmark methods for scientific research.

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[1] International Standards Organization 21625:2020(en) Vocabulary related to bamboo and bamboo products https://www.iso.org/obp/ui/en/#iso:std:iso:21625:ed-1:v1:en

[2] ISO 21629-1:2021Bamboo floorings Part 1: Indoor use https://www.iso.org/standard/79459.html

[3] ISO 19624:2018 Bamboo structures — Grading of bamboo culms — Basic principles and procedures https://www.iso.org/standard/65528.html

[4] ISO 22157:2019 Bamboo structures — Determination of physical and mechanical properties of bamboo culms — Test methods. https://www.iso.org/standard/65950.html#:~:text=This%20document%20provides%20methods%20for,fibre%20direction%2C%20tension%20and%20bending.

This document is organized to provide requirements for standard tests to be carried out to determine the material properties of full-culm bamboo as a structural material.

5. **ISO 22156:2021 Bamboo structures — Bamboo culms — Structural design**[5]
This document applies to the design of bamboo structures whose primary load-bearing structure is made of round bamboo or shear panel systems in which the framing members are made from round bamboo. Except as indicated in Clause 12, this document applies to one- and two-story residential, small commercial or institutional, and light industrial buildings not exceeding 7 m in height. This document is concerned only with requirements for mechanical resistance, serviceability, and durability of bamboo structures.

6. This document permits an allowable load-bearing capacity design and/or allowable stress design approach for the design of bamboo structures. Allowable load-bearing capacity and allowable stress approaches may be used in combination in the same structure.

7. This document additionally recognizes design approaches based on partial safety factor design and/or load and resistance factor design methods (5.11.1), previous established experience (5.11.2), or documented 'design by testing' approaches (5.11.3).

8. Other requirements, such as those concerning thermal or sound insulation, are not considered. Bamboo structures may require consideration of additional requirements beyond the scope of this document. Execution is covered to the extent that it impacts the quality of construction materials and products required to comply with the design requirements contained herein.

9. This document provides several modification factors, designated C_i. These are empirically derived factors, based on the best available engineering judgment, that are believed to be universally applicable to bamboo materials that are appropriate for building construction. Parameters affecting bamboo material performance are many and are addressed explicitly using experimentally determined characteristic values of strength and stiffness.

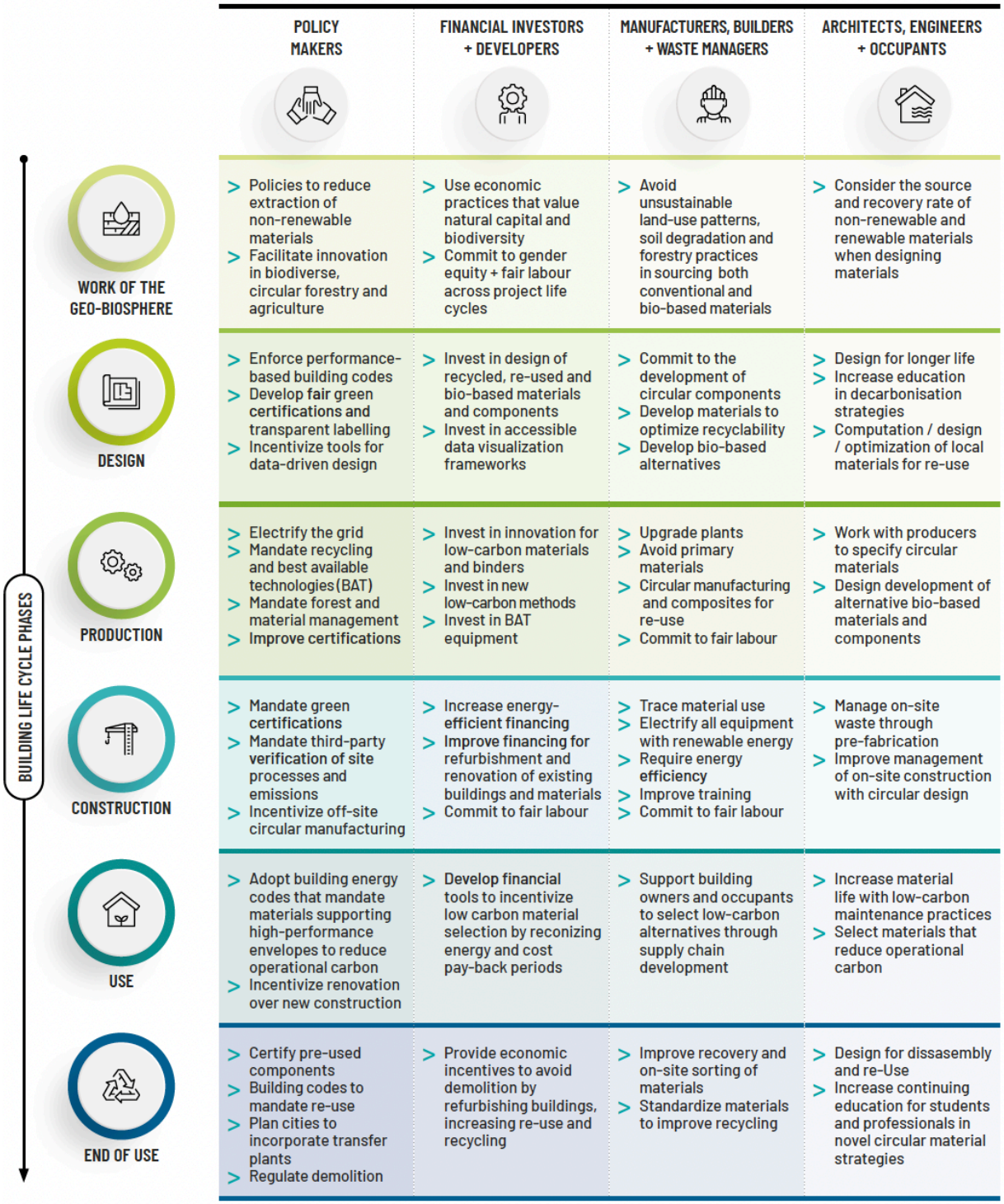
10. This document does not apply to:
- structures made of engineered bamboo products such as glue-laminated bamboo, cross-laminated bamboo, oriented strand, or densified bamboo materials;
- bamboo-reinforced materials where bamboo is not the primary load-bearing constituent; This includes bamboo-reinforced concrete, masonry, and soil; or
- scaffold structures constructed with bamboo.

11. **ISO 23478:2022 Bamboo structures — Engineered bamboo products — Test methods for determination of physical and mechanical properties**[6]
This document specifies test methods suitable for determining the following mechanical properties of engineered bamboo products:
a) modulus of elasticity in bending;
b) shear modulus;
c) bending strength;
d) modulus of elasticity in tension parallel to the fiber;

[5] ISO 22156:2021 Bamboo structures — Bamboo culms — Structural design.https://www.iso.org/standard/73831.html.
[6] ISO 23478:2022 Bamboo structures — Engineered bamboo products — Test methods for determination of physical and mechanical properties. https://www.iso.org/standard/75683.html.

e) tension strength parallel to the fiber;
f) modulus of elasticity in compression parallel to the fiber;
g) compression strength parallel to the fiber;
h) modulus of elasticity in tension perpendicular to the fiber;
I) tension strength perpendicular to the fiber;
j) modulus of elasticity in compression perpendicular to the fiber;
k) compression strength perpendicular to the fiber and shear strength;
i) shear strength parallel to the fiber.
In addition, the determination of dimensions, moisture content, and density are specified.
This document applies to prismatic shapes of glued laminated bamboo and bamboo scrimber intended to resist flexure, shear, axial loads, or combinations thereof.

Annex 2.
Figure A2: Who Does What to Decarbonize Materials?



Source: United Nations Environment Programme, & Yale Center for Ecosystems + Architecture. 2023. Building Materials and the Climate: Constructing a New Future. https://wedocs.unep.org/20.500.11822/43293.

Annex 3.

Figure A3: The Butterfly Diagram: Visualizing the Circular Economy