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Holistic development model for a regenerative city through bamboo: A case of Bengaluru 2030 (A C40 Women4Climate project)

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Abstract

The C40 Climate Action Planning Framework and C40's Deadline 2020 programme were created to support cities in developing climate action plans with the level of ambition and action needed to play their part in meeting the objectives of the Paris Agreement to stay within the 1.5°C target through rapid, systemic, and transformational changes. Bengaluru, India's IT hub has been a C40 city since 2017 and is considered as the pilot area under this project. Bengaluru is a signatory to C40's Deadline 2020 (achieve 50% carbon reduction by 2030 and carbon neutrality by 2050), which requires Bengaluru to prepare a Climate Action Plan (CAP). This project aims to deploy nature-based solutions to curb the environmental impacts on cities and meet the population's needs, making them regenerative. A regenerative city improves the cultural and social life of its citizens by protecting the environment and improving the local economy. A healthy natural ecosystem in the city is the fundamental requirement for equitable, resilient, and safe urban spaces. Bamboo is an eco-friendly, resource-efficient building material and an excellent carbon sink. This project seeks to understand the current state of environmental impacts of Air and water pollution in the city of Bangalore and intercede through nature-based interventions with Bamboo as a mainstream material in construction, phytoremediation, and air pollution mitigation by identifying points of action, consistent with national and international climate action and sustainability commitments among governments. The resulting development model will be a document laying out a Climate Action Plan for lowering GHG emissions and building community climate resilience with Bamboo. This Bamboo City model will provide a road map for Bengaluru to achieve carbon neutrality by 2030 and regenerative status thereafter. It is adaptable to any other city globally.

My City, My Pride, My Responsibility.

Keywords Bamboo; C40cities; Nature-based Solutions; Regenerative; The Bamboo City

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1. Introduction

Cities, as the engines of growth, consume a substantial amount of energy and emit significant amounts of greenhouse gases (GHGs). The building and infrastructure sector contribute over 40% of CO_2 emissions globally (Fig1 & 2) (IEA 2019). The tremendous production and release of CO_2 have led to severe consequences and repercussions, contributing to life-threatening issues in urban areas. The adverse effects of a non-sustainable built environment have not only put a strain on the environment but also affected humanity. In this scenario, bamboo stands as an ideal nature-based solution capable of achieving soil and moisture conservation, providing water security, preventing soil erosion, repairing degraded lands, improving air quality, and providing livelihood options and economic security because of its manifold uses and industrial applications rendered possible by recent advances in the technology. The project proposes to use bamboo, a sustainable resource for development, housing, and infrastructure in the city to cut greenhouse gas emissions and also provide income opportunities, ensuring the triple bottom line of integrated sustainable development encompassing environmental, economic, and social growth.

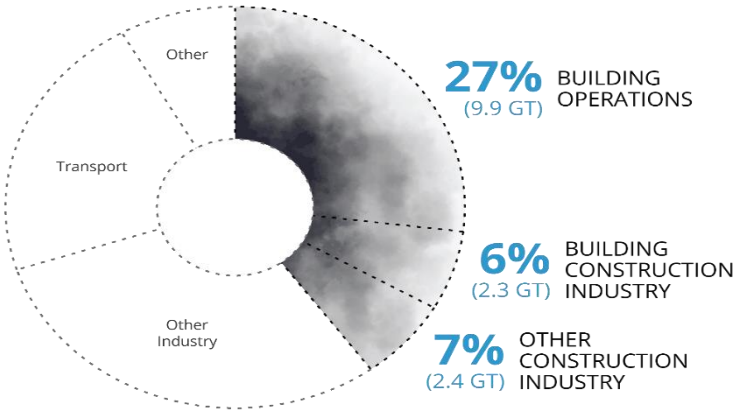


Figure 1. Annual Global CO_2 Emissions Source: IEA 2022

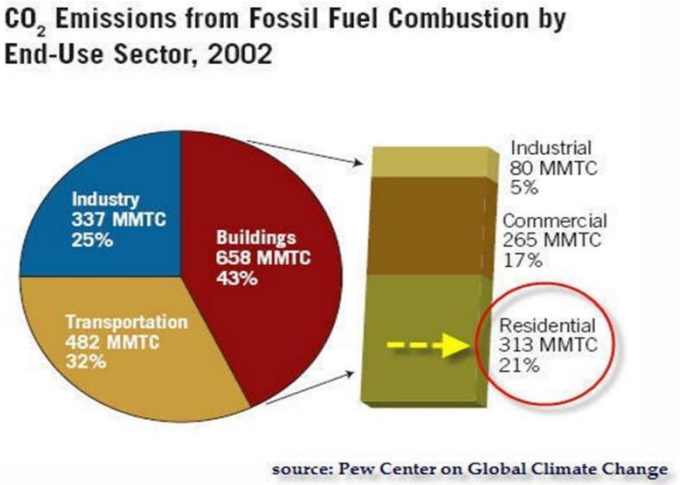


Figure 2. CO2 Emissions from fossil fuel combustion by end-use sector Source: Pew Center on Global Climate Change

1.1 Aim and Objectives

The primary aim of this Development Model is to lay out an Action Plan for making a city carbon-neutral by 2030. This involves working out a systemic plan involving all stakeholders for reforestation with bamboo in degraded lands, along water bodies, parks, densely populated areas of the city, and rural areas surrounding the city and integrating development with bamboo including buildings and infrastructure. This will result in many advantages as listed in Fig.3

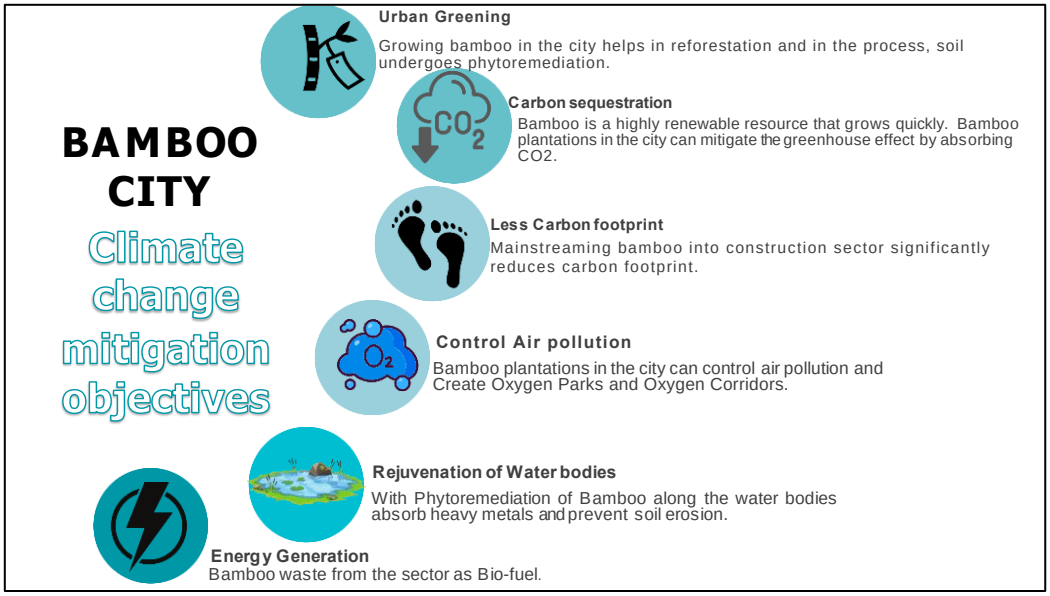


Figure 3 The Bamboo City Climate Change Mitigation Objectives (Source: Author)

1.2. Scope

The scope of the Bamboo City project has two main components: Urban reforestation with bamboo and its integration into the development, housing, and infrastructure of the city.

a) Urban reforestation: The project proposes one bamboo plant per citizen in the city. It will include site selection, suitable bamboo species selection, bamboo plantation, community engagement, advocacy, determining a budget, funding, securing resources for procurement of saplings, planting, maintenance, monitoring, and evaluation, and policy interventions.

b) Bamboo for development, housing, and infrastructure: The project proposes a 30 % inclusion of bamboo in the sector in the city. It includes the construction of houses, schools, community buildings, offices, public infrastructure, landscaping, streetscapes, etc. It includes capacity building for employment and income generation, research and development, waste management, and energy generation using bamboo.

1.3 Project at a Glance

Table 1Project at a glance (Source: Author)

Project Title	The Bamboo City – Holistic Development Model for a Regenerative City through Bamboo: A Case of Bengaluru 2030
Author	Ar. Prof Neelam Manjunath
Initiative	C40 cities; Women4Climate Cohort Programme
City (Area, Elevation)	Bengaluru (2196 sq. km, 920m)
Coordinates	Latitude: 12°58′18″ N Longitude: 77°35′37″ E
Population	13 million
GDP	US$110 billion
Project Timeline	2023-2030
Climate Risks addressed	 Urban Heat Urban Flooding Air Pollution Water Pollution Water Scarcity
Stakeholders involved	BBMP, BMRDA, BIAPPA, BDA, Citizens, Construction Professionals, Bamboo Industry, Academia, and others
Proposed to be involved	WBO, INBAR, Individual researchers, NGOs, Private Institutions, and others
Important sectors addressed	 Housing and Infrastructure  Urban Greening  Water Resource Management  Air Pollution  Energy and Waste Management

1.4 Limitations and Challenges

Developing a bamboo city in an existing city can be sustainable and possible with innovative concepts, but it comes with certain limitations.

1.4.1. Monoculture: Monoculture with bamboo plantations in the city can harm local ecosystems by reducing biodiversity. However, limiting bamboo plantations to one-third of the green area along with other plantations avoids monoculture and thus preserves biodiversity.

1.4.2. Compatibility: Integrating a bamboo city within an existing city's infrastructure is the biggest challenge. This may require modifications and revitalization of older urban areas is difficult.

1.4.3. Building Codes and Regulations: Existing codes of buildings may not specifically address bamboo construction. Creating new codes to ensure safety is complex.

1.4.4. Perception and Acceptance: Though many of the citizens are aware of the benefits of bamboo, adopting bamboo structures over traditional structures of concrete and steel requires lateral shift thinking. Many think bamboo buildings are prone to fire hazards but properly treated and coated bamboo meets safety standards in building codes and acceptance comes by seeing more bamboo buildings around, which takes time.

2. Relationship between the City and the Bamboo

2.1. Pilot City-Bengaluru

Bengaluru, formerly known as Bangalore, serves as the capital city of Karnataka, India. With a population of 13 million (Directorate of Economics & Statistics 2023), it stands as the third most populous city and fifth most populous urban agglomeration in India. Bengaluru is situated on the Deccan Plateau in Southern India, at 12.9716° N latitude and 77.5946° E longitude, and boasts an elevation of over 900m (3000 ft) above sea level, making it the highest of India's major cities. The city is divided into five taluks, namely Bengaluru North, South, East, Yelahanka, and Anekal, with 198 wards (Indian Institute of Science 2021).

Once with extensive greenery and several lakes, Bengaluru has suffered severe environmental degradation due to the exponential growth in population and multiple redrawing of the city's boundaries since the 1980s to accommodate workers, IT campuses, educational institutions, and residents (Sudharia et al., 2007).

Some of the major Climatic challenges Bengaluru faces are:

2.1.1. Air Pollution

Improper planning, coupled with increasing private vehicle usage and extensive deforestation, has resulted in declining air quality within the city (Fig.4). According to a study conducted by Green India, Bengaluru is ranked as the sixth most polluted city among the top ten in India (India 2022).

Figure 4. Bengaluru is to see a 74% rise in air pollution by 2030. Source: Urban Update, 2019

2.1.2. Urban Heat Island

Due to the large paved and concreted areas, the ambient temperatures in the city have gone up significantly (Fig.5).

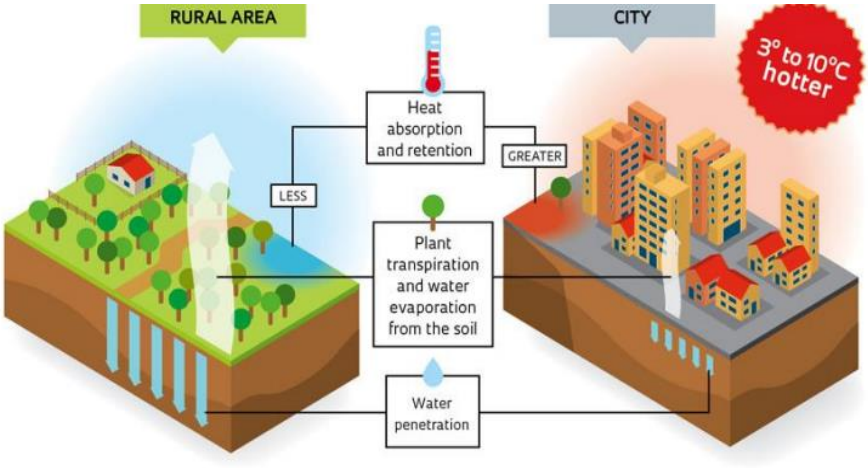


Figure 5. Depleting green cover and several high rises have transformed cities into Urban Heat Islands Source: www.teriin.org

2.1.3. Urban Flooding

The impermeable paving and roads, congested drains, and encroached catchment areas prevent rainwater from seeping into the ground or flowing into lakes through stormwater drains, causing sudden floods in the city (Figure 6).

Figure 6. The city is flooded following heavy rainfall. Source: Staff, S. 2022

2.1.4. Water Pollution

Most of the wastewater from the city is let into the lakes and water bodies by the residential colonies, authorities, and urban flooding (Fig.7)

Figure 7. Polluted lakes due to mismanagement of waste and sewage. Source: Citizen Matters, Bengaluru 2021

2.1.5. Water Scarcity

Recent studies indicate that Bangalore could face a severe drinking water shortage by the year 2030, making it the first Indian city to experience such a crisis. Shockingly, none of the city's lakes presently contain water suitable for either drinking or bathing (BBC News, 2018).

2.2. Bamboo- A Nature Based Solution

Bamboo is a versatile plant that thrives in tropical, subtropical, and sub-temperate regions globally (Figure 8). Its growth patterns are closely tied to population density, and it has been a go-to natural resource in these regions for centuries. Even today, bamboo continues to serve as a practical solution for various applications (Table 2).

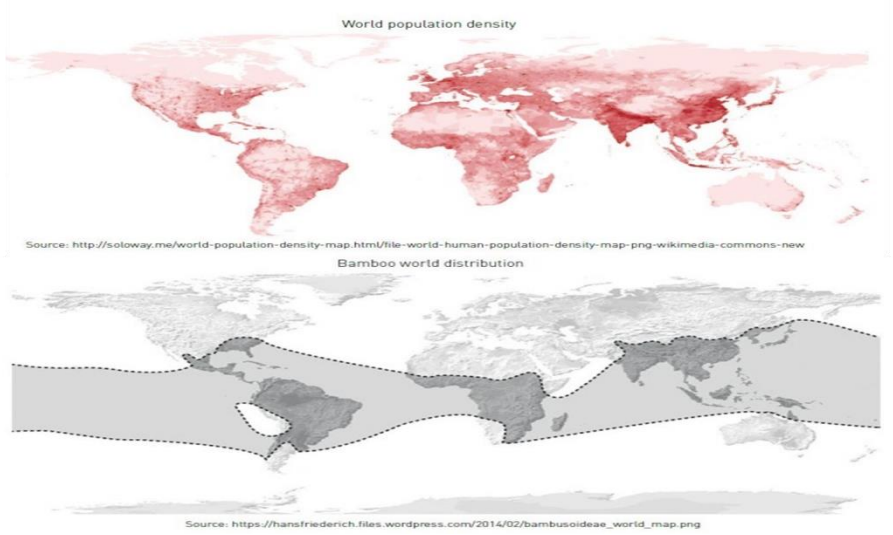


Figure 4. World Population Density and Bamboo World Distribution

Table 2. Bamboo Resources around the world

Continents	**Population (projected for 2050) (Million)**	**Bamboo Supply**	**Bamboo civilization**
Asia	5268	High	Well Developed
Africa	1766	Medium	Average Development
South America	809	Less	Under Development
Europe	628	Less	Recently introduced bamboo houses
Northern America	392	Less	Under Development
Australia and Antartica	46	NIL	Not Developed

2.2.2. Properties of Bamboo

a) Ecological properties

Bamboo is a plant that does not need replanting and new shoots keep growing every year. It is regenerative (Figure 9) and hence is an extremely resource-efficient material. Due to its rapid growth, it absorbs CO2 quickly and has many other ecological properties (Figure 10). It has a small harvesting cycle which is a major advantage over other trees (Figure 11).

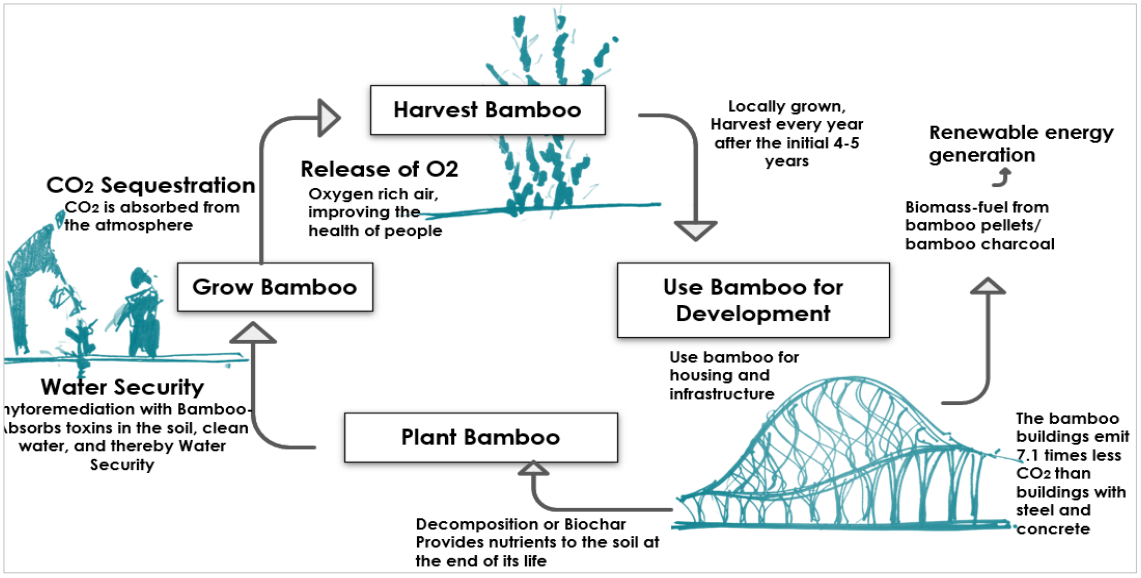


Figure 5. Bamboo Regenerative Cycle showing circularity (Source: Author)

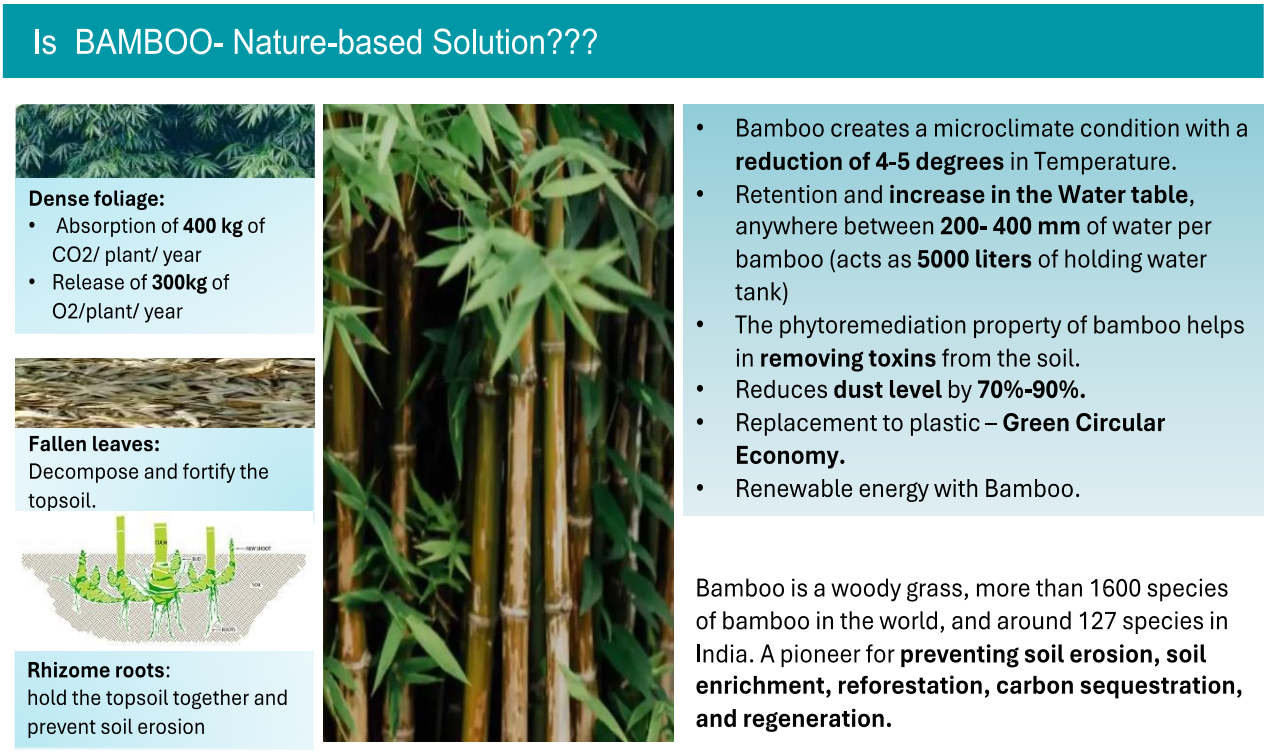
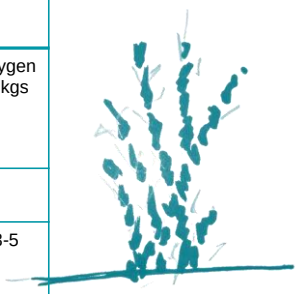


Figure 6. Ecological Properties of Bamboo (Source: Author)

Comparison between Traditional Tree and Bamboo

Tree

Traditional Tree (average values)	Parameter	Bamboo (average values)
The lungs of the planet A tree produces 200kgs of Oxygen per year(bigger the tree, more oxygen is produced)	Oxygen release	Produces **35%** more Oxygen A bamboo produce 300kgs of Oxygen per year
200kgs/year/plant	CO2 absorption	400kgs/year/plant
Mature for lumber in 30-40 years (approx.)	Harvest Cycle (years)	Mature for harvest in 3-5 years
Tree is killed when it gets cut down	After harvest	New Culms emerge from the Clump after every harvest
Very slow	Growth rate	Very fast
Thick trunks require chainsaws and heavy machinery	Equipment and labor to cut	As hard as Oak , lightweight, hollow and easily cut with hand saw



Bamboo clump

Figure 7. Comparison between traditional tree and Bamboo (Source: Author)

b) Mechanical properties

Bamboo is an extremely versatile material for several uses in our daily lives in addition to being ecological and an extremely resource-efficient material. Hence it can be used in several industries as a raw material for manufacturing materials for development, building, and infrastructure sectors.

Table 3: Energy use and Co2 emissions per kg of different building materials, Source: Laiyee, 2011

Material	Extraction MJ/kg	Processing MJ/kg	Transportation km	Energy use MJ/kg	Carbon emission CO_2/kg
Bamboo	0.044	1.71	300	2.58	0.13
Wood	0.047	7.01	800	7.22	0.41
Laminated bamboo board	0.52	9.32	200	9.98	0.53
Laminated wood board	0.20	12.76	200	13.22	0.74
Steel (10 per cent recycled content)	1.40	27.15	1000	28.65	2.21
Cement	0.03	4.62	500	5.27	1.05
Concrete (C40)	1.27	2 kWh/m3	10	1.12	0.20
Cement mortar (1:2.5)	2.70	2 kWh/m3	10	1.64	0.31
Expanded perlite concrete	4.66	2 kWh/m3	10	9.39	0.61
Brick	0.044	1.57	50	1.75	0.14
VIPs	38.25	5.4 kWh/m3	800	36.97	2.16
Aluminum	-	-	-	155.0	8.24
Polystyrene	-	-	-	86.6	2.50
Plaster board	-	-	-	6.75	0.38

The above table (Table 3) shows the embodied energy of various building materials. Embodied energy (EE) of building materials comprises the total energy expenditure involved in the material production including all upstream processes such as raw material extraction and transportation. The embodied energy of Bamboo is very low, making it an extremely sustainable material for building construction.

Table 4 Energy balance of various building materials in MJ/m3 or N/mm2 (Source: J.A. Janseen,1990)

Steel	1500
Concrete	240
Wood	80
Bamboo	30

Energy balance refers to the amount of energy needed to produce a unit of building material with a specific level of load-bearing capacity. Bamboo has an exceptionally low energy balance, making it an ideal and sustainable option for constructing buildings (Table 4). It can also replace steel for small buildings and structures.

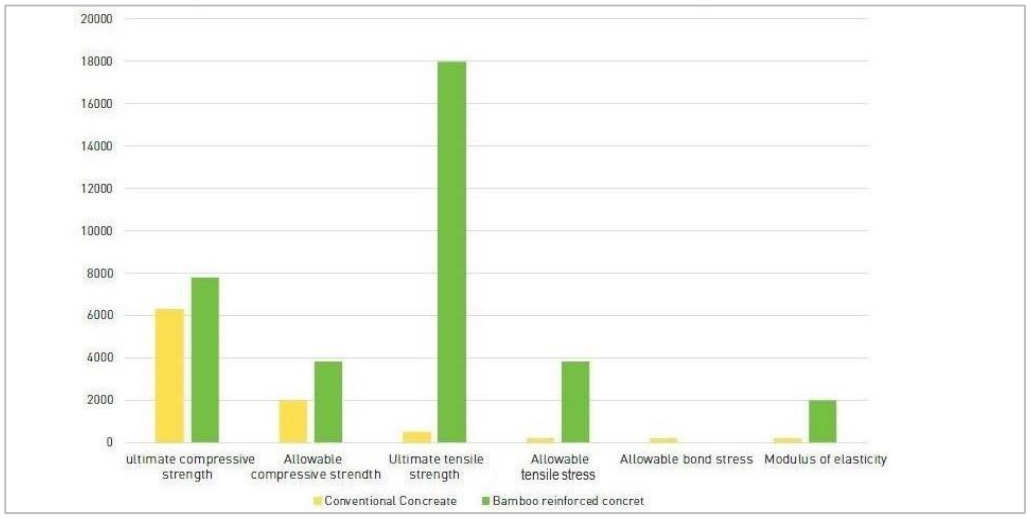


Figure 8. Comparison between conventional concrete and bamboo reinforced concrete (Source: Wei Wen: May 2015)

The figure presented above illustrates a comparison between conventional concrete and bamboo-reinforced concrete (Fig.12). It's notable that the latter possesses a substantial strength advantage and shows promise as a sustainable replacement for steel reinforcement.

Developing countries, which generally have the highest demand for steel-reinforced concrete, often lack the means to produce the required amount of steel. Rather than relying on the unpredictable global steel market, bamboo offers a more sustainable and cost-effective alternative. Employing bamboo-reinforced structures could prove to be a valuable solution for constructing affordable buildings.

In fact, during COP27, bamboo was recognized as one of the top five solutions to mitigate global warming. By substituting traditional materials such as carbon and steel with bamboo, we can significantly reduce carbon emissions associated with the housing industry, as reported by the Washington Post in 2022.

For all the above-cited reasons, bamboo has been identified as a nature-based solution to combat climate change in cities for this project.

2.3. Bamboo and Bengaluru

Figure 13. Pictures of Bamboo Bazaar, Bengaluru. Courtesy: Author

Bamboo has a long history in Bengaluru, with numerous bamboo markets scattered throughout the city. The tradition of bamboo craftsmanship dates back hundreds of years in these markets, featuring an array of bamboo products like ladders, baskets, bamboo screens, mats, fences, blinds, furniture, hand fans, hanging lamps, and more. Raw materials are typically procured from Sawantwadi in Maharashtra, Bhadravathi, Shivamogga, Chikmagalur, and Mysuru in

Karnataka, with recent procurement from the nearby town of Nelamangala. Many skilled artisans have been depending on these markets for their livelihood for several generations.

Figure 14. Hennur Bamboo Forest

Hennur Bamboo Forest (Marasandra Forest) is a man-made bamboo forest in Bangalore city for eco-conservation and environmental upliftment (Fig.14). Every year a trail is organized in this luxuriant Bamboo Forest in Bengaluru. The trail is a 10 km loop completely in the forest, with minimal elevation in each loop for people to experience the Oxygen park with its rich biodiversity. There are several parks in the city which have been planting bamboo for ecological benefits and biodiversity enhancement.

Figure 15. Two-bedroom house at IPIRTI, Indian Plywood Industrial Research and Training Institute, Bangalore, India. Designed by the author

Bangalore is home to several prestigious institutions that have been extensively researching the utilization of bamboo in the construction industry for a significant period. The Indian Plywood Industries Research & Training Institute (IPIRTI) and the Indian Wood Science Institute (IWST), both located in Bangalore, have been at the forefront of developing value-based bamboo products such as ply, boards, and roofing sheets.

Figure 16. Terminal 2, Kempe Gowda International Airport, Bengaluru. Photos Courtesy: Author

Terminal 2 at Kempe Gowda International Airport is termed as the most beautiful airport which is also due to the Bamboo used for its interiors. Majority of the interiors are crafted with bamboo and cane, a renewable material considered to emit zero carbon to symbolize the Garden City brand of Bengaluru (Fig.16). Ar. Neelam Manjunath was consulted as a Bamboo material expert for material properties, selection, and design viability for vetting by the project architects SOM, New York in 2017 for pitching it to their clients.

2.3.1. Bamboo and CGBMT, Manasaram Architects and Aditi Constructions

CGBMT (Center for Green Building Materials and Technology), in collaboration with Manasaram Architects and Aditi Constructions, Bangalore, has been conducting extensive practical field research for over 25 years under the leadership of Ar. Neelam Manjunath. Their efforts have been instrumental in the widespread adoption of bamboo as a sustainable building material in India and beyond, effectively bridging the gap between laboratory innovation and practical implementation. The projects (Fig.17-22), were done in Bengaluru by CGBMT, Manasaram Architects, and Aditi Constructions. Prove the suitability and acceptability of Bamboo as a building material in Bangalore beyond doubt.

Figure 17. State-level Energy Park, Bangalore **Figure 18.** Bamboo Symphony, Bangalore

Figure 19. House of 5 Elements, Bangalore

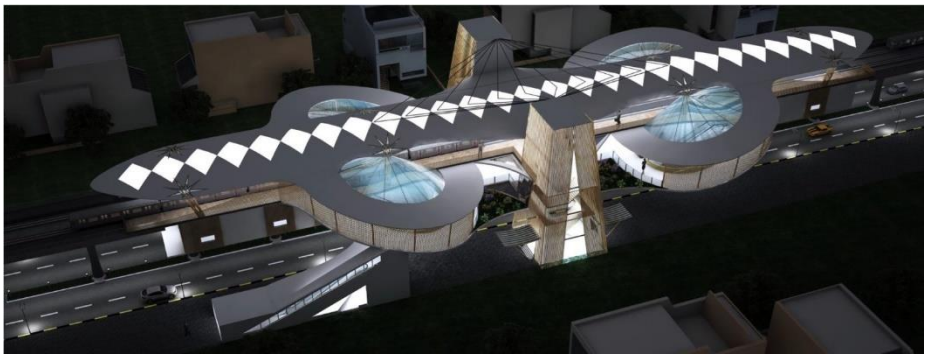


Figure 9. Proposed Metro Station

Figure 10. Proposed Police Bhavan for KSRP, Bangalore

Figure 22. Proposed Millet Center by Agriculture Ministry

Considering all the above factors, using bamboo for reforestation and development of Bengaluru city seems to be extremely logical and viable.

3. Draft Action Plan and Project Implementation

To guarantee the success of the project, we have developed a comprehensive plan that involves gathering, analysing, and interpreting data, as well as making timely and informed decisions. This project differs from others in that it is an action-based initiative that will necessitate implementation. Therefore, it's imperative to create a meticulously designed project plan to achieve our milestones within established deadlines.

3.1 Project Inception and Preparation

In May 2022, the Women4Climate Initiative was launched by C40 Cities in Bengaluru, which presented an excellent opportunity for Ar. Neelam Manjunath, to pitch her project aimed at combating climate change in Bengaluru under the Women4Climate Cohort Program. With 37 years of experience in sustainability and a desire to mainstream bamboo in the construction industry due to its natural properties and ability to mitigate climate change, C40 Cities provided a suitable platform to scale the project to the city level for grassroots action. A team comprising local, national, and international advisors and researchers has been formed under CGBMT, the Centre for Green Building Materials and Technology in Bangalore, to work on this project.

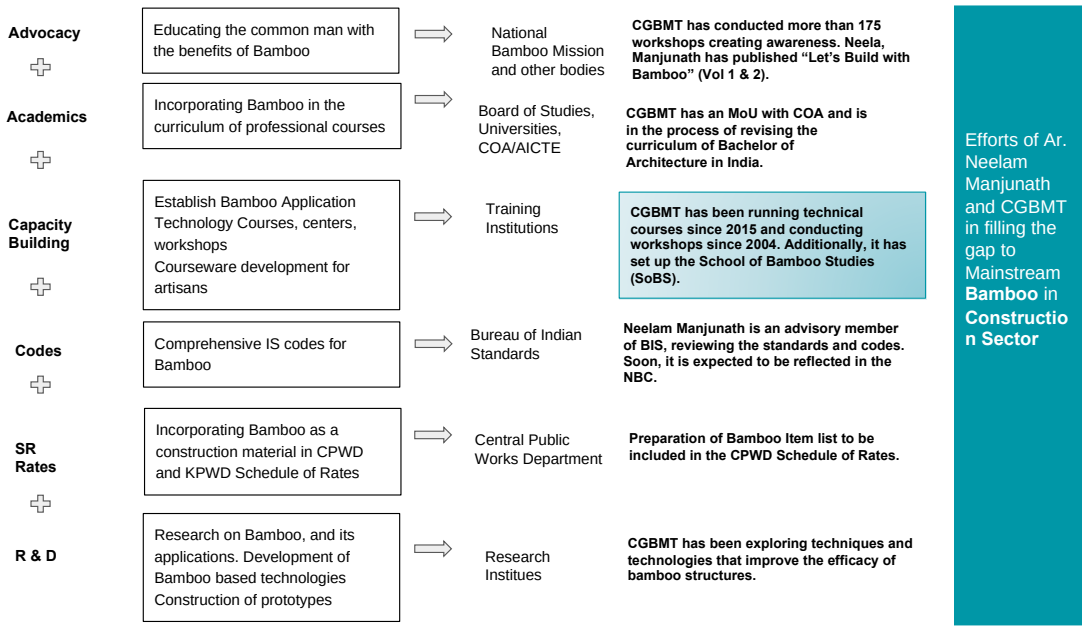


Figure 11. Efforts of Ar. Neelam Manjunath and CGBMT to Mainstream Bamboo in Construction Sector

3.1.2 The Systemic Process plan

We have divided the entire implementation process in five stages with clear milestone to be achieved at the end of each stage to make evaluation and monitoring of the progress visible.

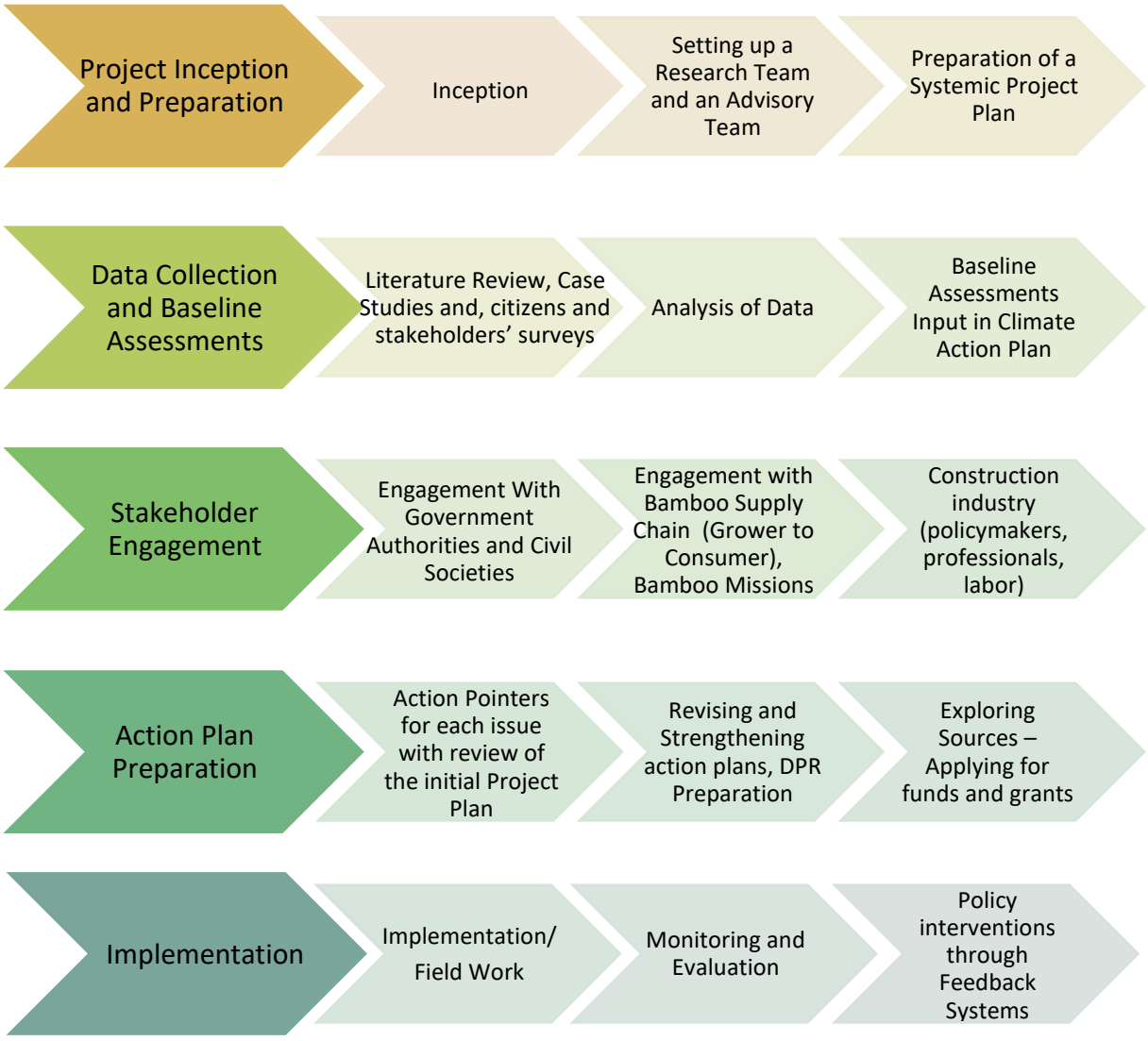


Figure 12. Holistic development model approach, a systemic plan process, Source: Author

3.2 Data Collection and Baseline Assessments

To develop a comprehensive understanding of Bengaluru city's social, political, and economic landscape (pilot city), a comprehensive research approach integrating both quantitative and qualitative methodologies was employed. The Data collection methods included:

1. Field observations,
2. Questionnaire surveys among the citizens and other key stakeholders,
3. In-depth interviews with the local authorities,
4. Literature Review

3.2.1. Key findings from the Data Collection of Bengaluru city:

a) Population

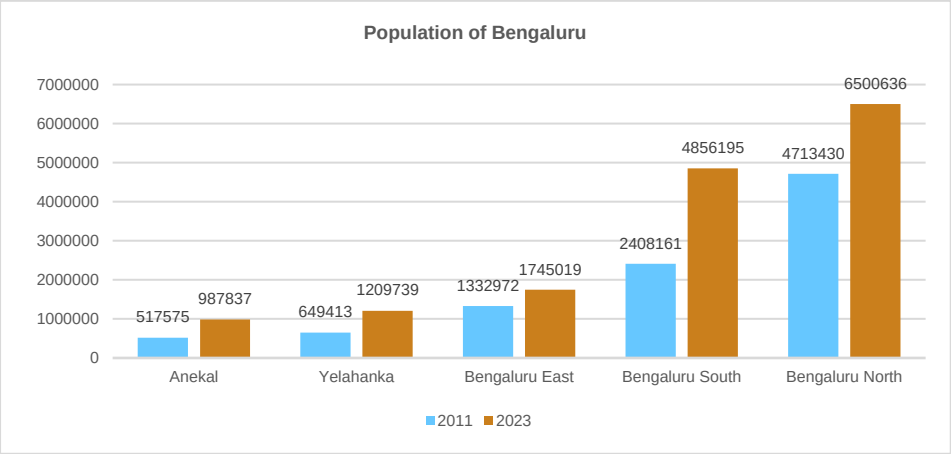


Figure 13. Population of Bengaluru city from 2011 to 2023, Source: Directorate of Economics and Statistics, Bangalore, 2023.

There is a **59% increase in population from 2011 to 2023**, three of the taluks have experienced two times increase in their population.

b) Land Use

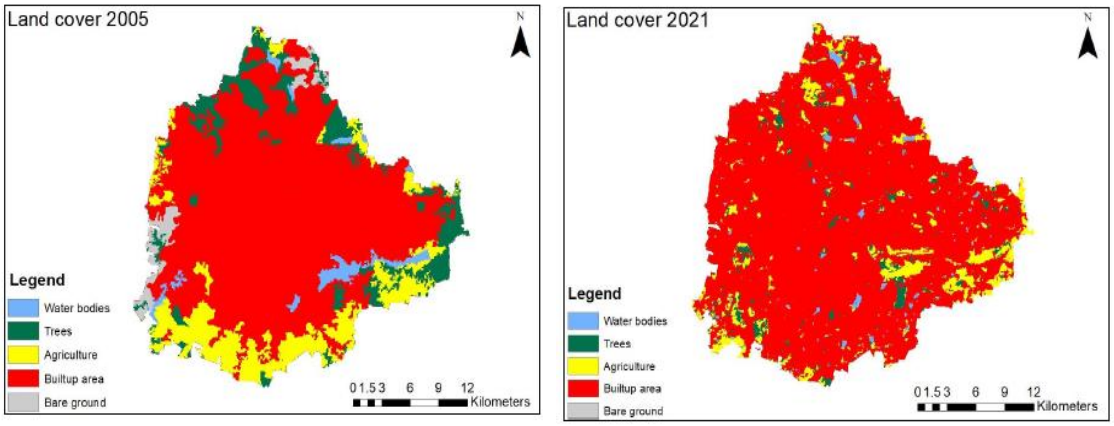


Figure 14. Land cover of Bengaluru city in 2005 and 2021, Source: DAAC

Change in land-use pattern in Bengaluru:

1. The city's built-up area increased from 493.49 km² representing 69.37% of the total city area in 2005, to 619.67 km² representing 87.07% of the entire city area in 2021.
2. The percentage of coverage of other land covers has decreased. Tree cover reduced from 11.14% in 2005 to 3.06% in 2021.
3. Waterbody coverage dropped from 2.69% in 2005 to 1.32% in 2021.
4. Green cover decreased from 14.09% to 8.37%. (Mohan Vedukala 2022)

c) Tree Survey

Bengaluru tree count status: In 2017-18, there was one tree for 7-8 people in Bengaluru. This could have now increased to one tree for 15-20 people, say IISc experts. (Deccan Chronicle 2016; The New Indian Express 2023)

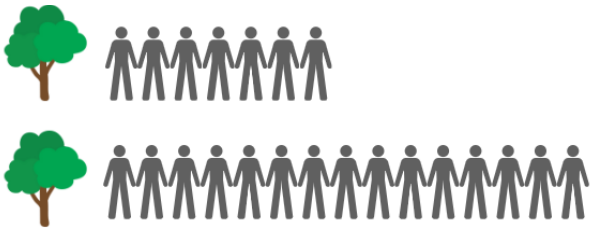


Figure 15. Tree/person in Bengaluru

d) Rainfall

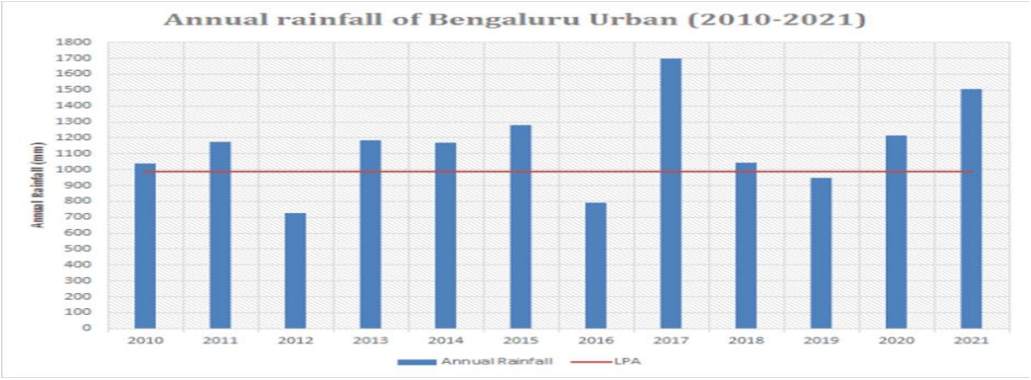


Figure 16. Annual rainfall of Bengaluru city from 2010 to 2021, Source: Vaidya, 2021

Bengaluru city observes an average annual rainfall of 990mm, with exceptions in 2012 and 2016 where the rainfall exceeded the average. This indicates a trend of increased rainfall/year in the city. However, despite this trend, Bengaluru still faces a shortage of water. The swift urbanization has resulted in the reduction of green cover, which has been replaced by concrete areas. This shift has led to an increase in runoff and a decrease in groundwater recharge.

e) Status of lakes

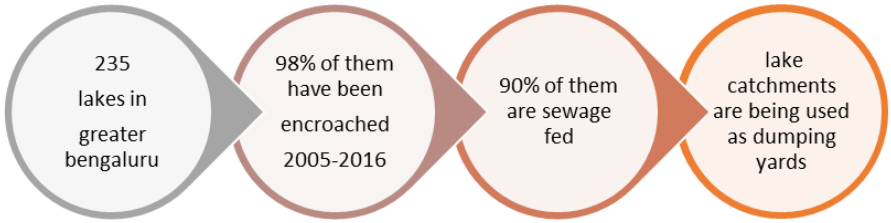


Figure 17. Condition of lakes in Bengaluru city, Source: Ramachandra et al. 2015

3.2.2. Key findings about Bamboo from the Literature Review:

a) Bamboo Carbon Sequestration Potential: Bamboo, a sustainable resource helps to curb air pollution as it absorbs greater amounts of CO2 due to its rapid growth and emits a significant amount of O2/acre compared to traditional trees. (Lin et al. 2017; Yiping et al. 2010).

b) Rejuvenation of water bodies: The phytoremediation property of bamboo helps in removing toxins from the soil and its wider root system holds soil firmly, thereby reducing soil erosion. Planting bamboo also helps in groundwater absorption, helping to increase groundwater capacity and rejuvenate lakes. (Bian et al. 2017; Nkeshita et al. 2020)

c) The bamboo buildings need 7.1 times less energy than a conventional building. (Manjunath Neelam et al. 2005). Thus, CO_2 emissions from bamboo buildings are proportionately less as compared to conventional buildings.

Less Carbon footprint

Mainstreaming bamboo into construction sector significantly reduces carbon footprint.

Materials	Energy For production [joule]	Bamboo House		Conventional House	
		Qty. of Material	Total energy requirement	Qty. of Materials	Total [joule]
Concrete	1920	30	70080	175	864000
Steel	234000	.6	140400	3	702000
Wood	600	2	1200	2	1200
Bamboo	300	30	9000	0	000
		Total	220680		1567200

The bamboo building needs 7.1 times less energy than a conventional building. (Manjunath Neelam et al. 2005). Thus, CO2 emissions from bamboo buildings are proportionately less as compared to conventional buildings.

Figure 18. Energy used for construction of a bamboo house (Source: Author 2005)

3.2.3. Baseline assessments input in climate action plan

The Bamboo City Project's scope included developing a Plug-in action plan based on key findings. Utilizing data collection tools such as surveys allowed for the collation of information from a vast respondent pool, comprising citizens of the city. The data collected provided insight into public opinion, attitudes toward sustainable practices, and preferences for bamboo construction in the city. This data aided in the formulation of a strategy, as well as policy interventions and support required from the government to adopt in developing and making the bamboo city project exceptionable and maintainable in the long run. While baseline assessments have been conducted using available data, revisions will be made

whenever significant data is obtained. It's important to note that this action plan is dynamic, and being agile is crucial. The main assessments are as under:

a) Making Bangalore city carbon neutral required calculating the number of plants required for offsetting the CO2 emissions depending on CO2 absorbed by the plant (Fig.31)

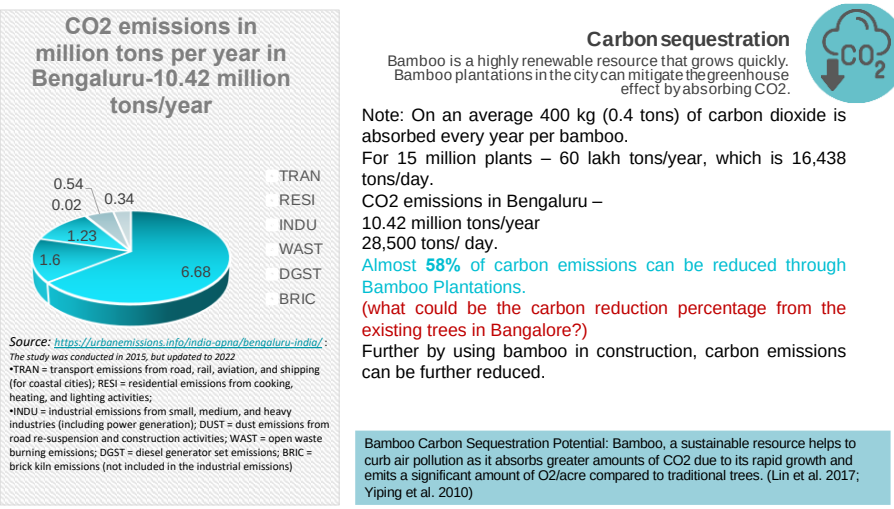


Figure 19. CO2 sequestration with bamboo plantation in Bengaluru city (Source: Author)

b) Since major planting had to happen in degraded lands, we collected the data to ensure its availability (Fig.32)

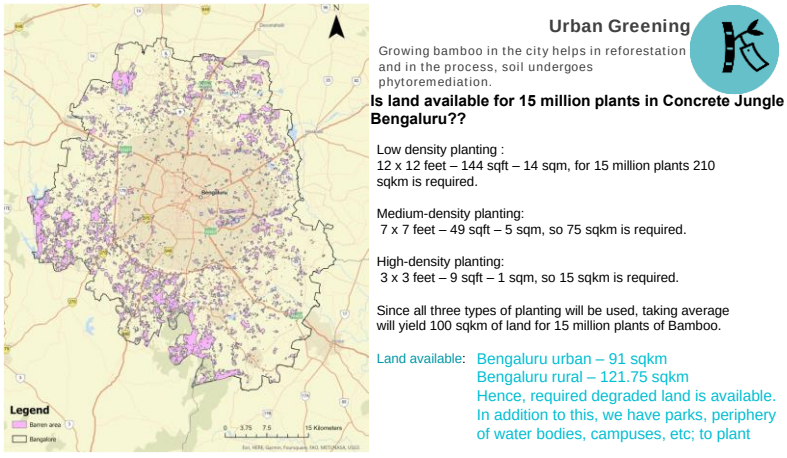


Figure 20 Land availability in Bengaluru city (Source: Author)

c. To ensure an even distribution of Oxygen throughout the city, we have proposed Oxygen corridors with bamboo plantations along roadsides, parks, open areas

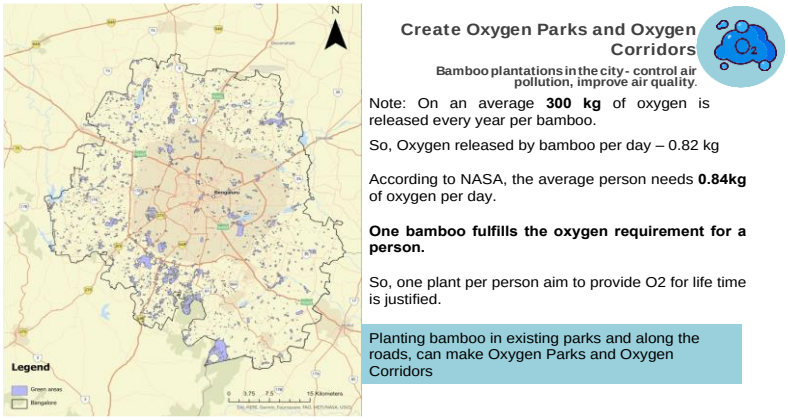


Figure 21 Creating Oxygen parks in Bengaluru city (Source: Author)

d. We calculated approximate CO2 mitigation for new construction (Fig 34) based on the actual field data by Ar. Neelam Manjunath in 2005 (Fig.30).

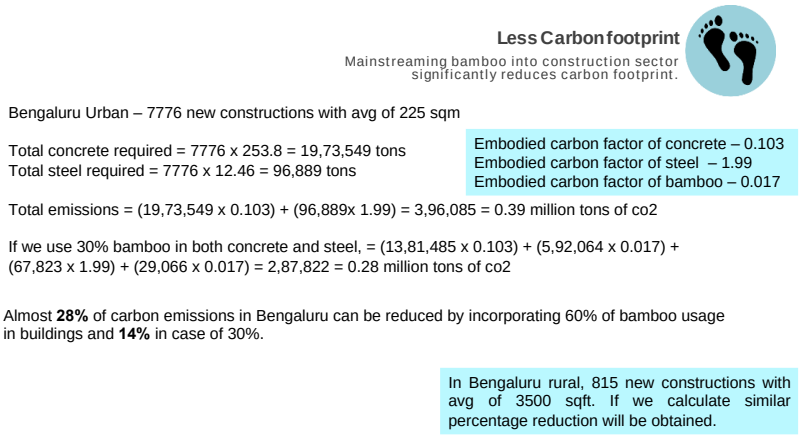


Figure 22 CO2 emission reduction by using 30% bamboo in Bengaluru city (Source: Author)

e. Using the property of bamboo of absorbing heavy metals from water and retaining water in its extensive roots, we have planned to plant bamboo around the lakes, on check dams, and in their catchment areas.

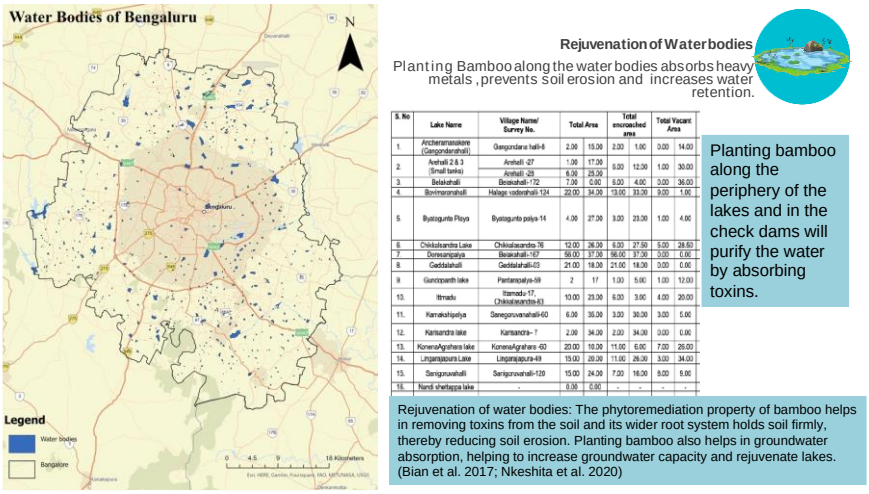


Figure 23
Rejuvenation of lakes in Bengaluru city (Source: Author)

f. Bamboo industries produce a lot of bio waste which can be used for various types of bio-fuels. We are proposing to have mini energy, gas, charcoal plants, etc to meet the energy requirements of remote localities.

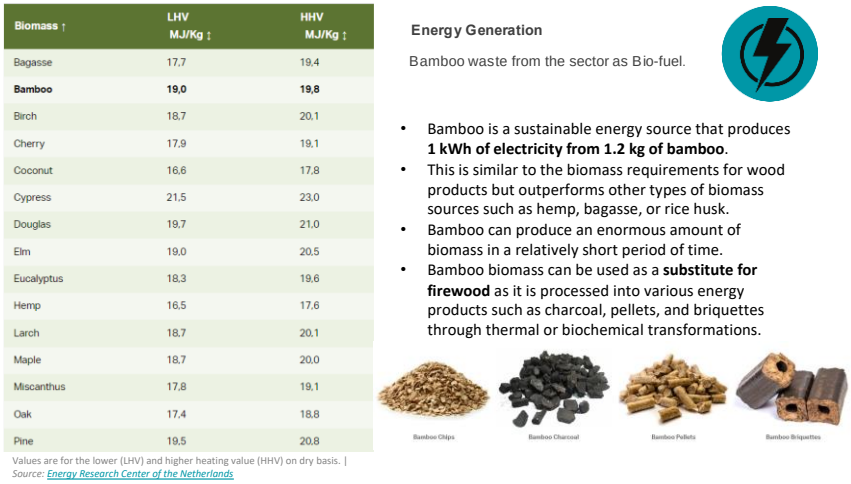


Figure 24 Energy production from bamboo (Source: Author)

With all the above-proposed actions, we calculated the total amount of CO2 that we would be able to reduce or mitigate and prepared a balance sheet for calculating the deficit for making Bangalore carbon neutral by 2030 (Fig. 31)

Carbon Neutral Status through Bamboo Plantations and mainstreaming bamboo into construction sector	
Carbon Sequestration	**Percentage Reduction**
Bamboo Plantations	58%
Use of bamboo in development, buildings and infrastructure	28%

Total of 86% carbon will be sequestered through planned bamboo plantations, remaining 14% of the carbon will be sequestered through remaining trees in Bengaluru. So, by these calculations Bengaluru will become carbon neutral by 2030.

Hence, Bamboo city project is justified to be included in Climate Action Plan of Bangalore city for it to become carbon neutral and regenerative thereafter.

Figure 25 Carbon Neutral Bengaluru City by 2030 (Source: Author)

3.3. Stakeholder Engagement

The development of a nature-based model for a regenerative city is an inclusive and collaborative undertaking, drawing upon insights from a diverse stakeholder network. This network encompasses groups with a vested interest, influence, or expertise in climate action, including but not limited to citizens of the city, government authorities, NGOs, and representatives from the bamboo industry such as growers, suppliers, entrepreneurs, investors, financiers, urban planners, and construction industry professionals (architects, designers, and engineers), academic institutions, research organizations, and bamboo organizations at both national and international levels.

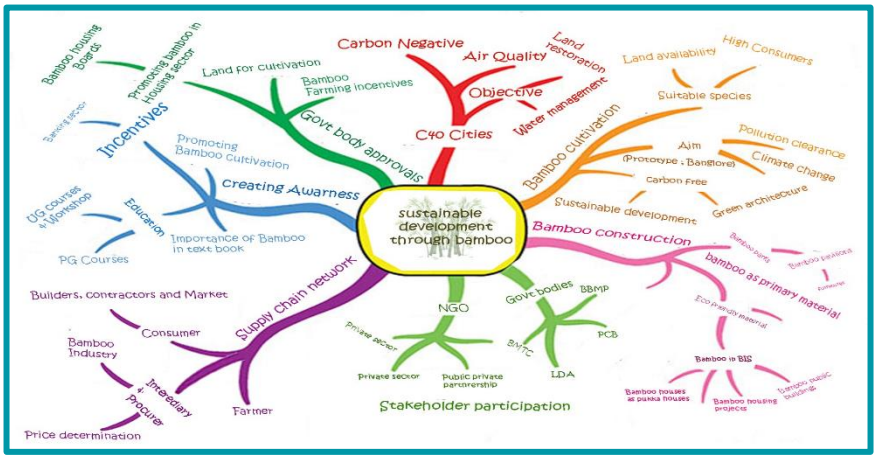


Figure 26 Mapping stakeholders for The Bamboo City project (Source: Author)

We proposed questionnaires for various stakeholder surveys to make the project as inclusive as possible (Fig 39). The surveys will be kept ongoing during the entire duration of the project to keep receiving data and make necessary changes in our CAP.

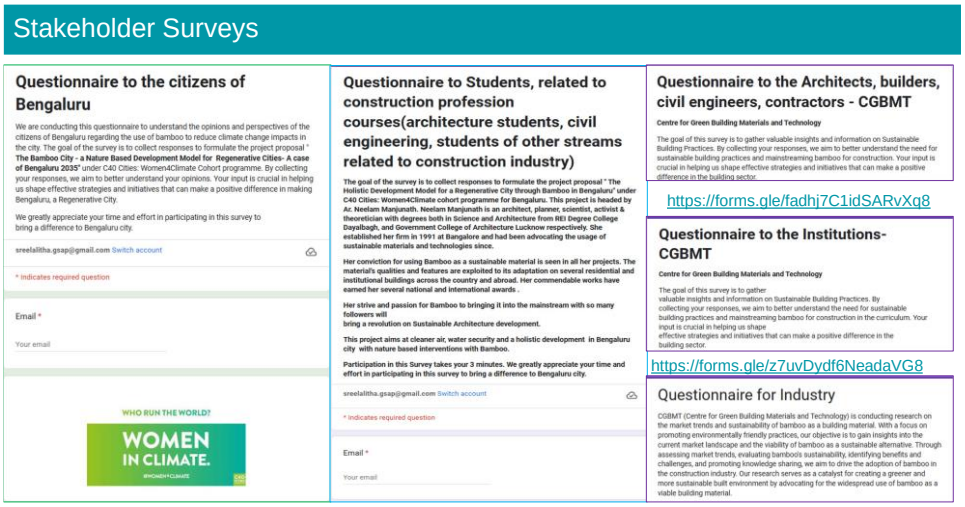


Figure 27 Stakeholder surveys for various groups (Source: Author)

3.4. Action Plan Preparation

Based on the results, an action plan leading to the on-ground implementation, monitoring, and evaluation is prepared with sector-wise tasks. We prepared a Legend to understand what our final implementation matrix would look like in terms of time, finances, benefits, etc. (Fig.40) The broad areas of action were listed (Fig. 41-45) to arrive at a feasible timeframe with detailed tasks.

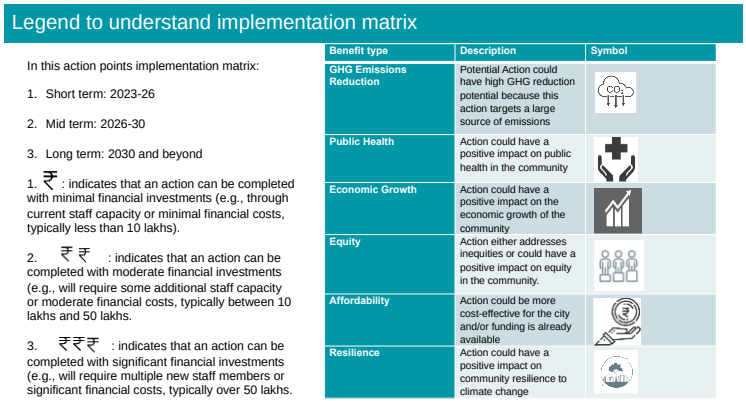


Figure 28 Implementation Matrix for Bamboo city project (Source: Author)

Figure 29. Plantation preparation (Source: Author)

Figure 30 Education and Skilling (Source: Author)

Figure 31 Construction of building prototypes (Source: Author)

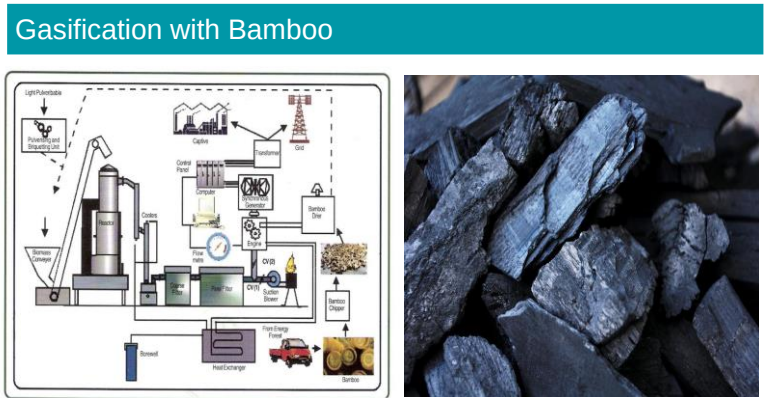


Figure 32 Gasification with bamboo (Source: IISc)

Figure 33 Start-up city- Bengaluru city (Source: Author)

3.5. Implementation

On the ground, the project implementation started in a small way with plantation on 18th September 2023 on World Bamboo Day at the CGBMT Headquarters site in Bengaluru, India. We are in the process of collaborating with various NGOs, citizen groups, investors, institutions, etc., for the preparation of a detailed DPR with the costs involved. Once a detailed DPR is prepared, Funds or grants will be raised from the Government, international organizations, CSR, philanthropists, and other sources working in the climate action sector. With the available funds and with collaborations in place implementation work will be carried out in phases.

3.5.1. Implementation:

Implementation is being carried out in the following sequence:

Plantation & Sustainable Harvesting – Demand Supply Value Chain Development - Bamboo-based Industries including the construction sector (Fig.45).

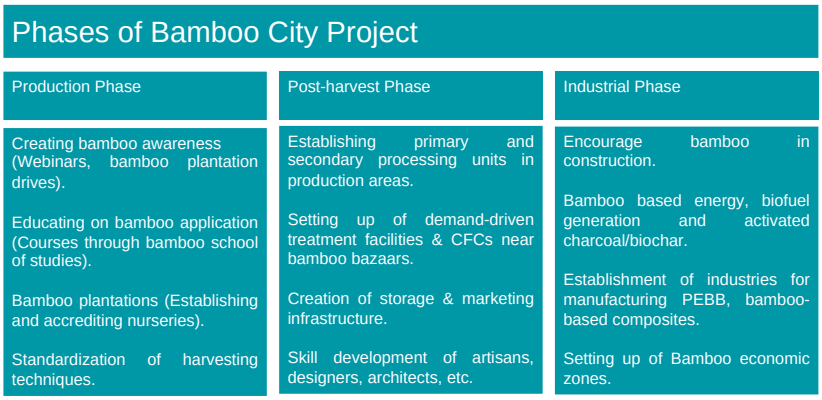


Figure 34 Phases of Bamboo city project for Bengaluru city (Source: Author)

Collaboration with expert organizations:

a. Advocacy:
b. Bamboo in Standardisation:
c. Community involvement:
d. Resource Allocation:
e. Preparation of comprehensive master plan:
f. Site preparation and plantation:
g. Maintenance and Harvesting:
h. Demand -Supply Value chain development:
i. Bamboo for development: Setting up of SMEs, Bamboo construction in housing and city infrastructure, etc.;

An action plan with a timeline of 7 years has been prepared and proposed till 2030 to make Bengaluru a carbon-neutral city by 2030 (Fig 47).

Timeframe: Some actions may be predecessors for other actions to be successful. The detailed time frame is shown in the GANTT Chart/Bar Chart.

In the above-mentioned action plan:

1. Short-term actions are actions that will be implemented in the next two years (2023-2024).

2. Medium-term actions are actions that will be implemented in the mid-term, or in the next five years (2023-2026).

3. Long-term actions are actions that will be implemented in the long term, or beyond the next seven years (2030 and beyond).

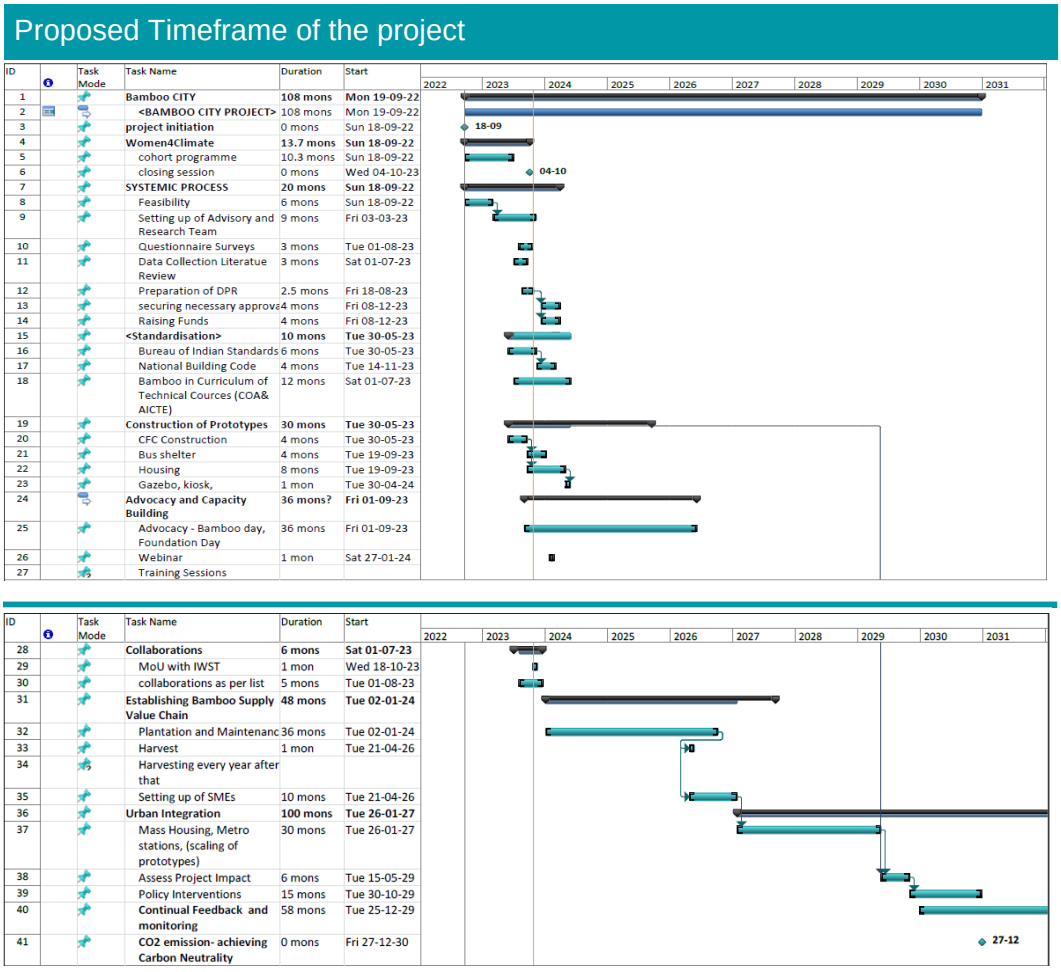


Figure 35 Timeframe of the project for Bengaluru city (Source: Author)

3.5.2 Proposed and approved component projects:

A) CGBMT is in the process of collaborating with Arief Rabik of Bamboo Village Trust, Indonesia to put up a Bamboo Village Initiative in Bangalore Rural district as part of this project.

B) The author submitted a joint project proposal to the Honourable High Courts of Karnataka along with the ESG organization for phytoremediation and water purification of a lake as part of Climate justice to the citizens who have a right over the Commons of the city. The High Court passed an order in favour of the proposal and directed the Govt to have it implemented (Fig 48).

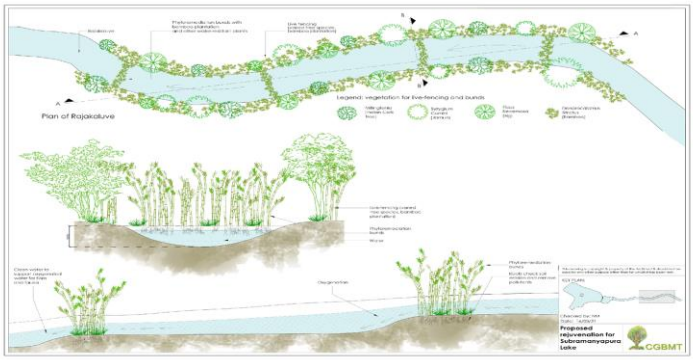


Figure 36 Rejuvenation of Subramanyapura lake in Bengaluru city (Source: CGBMT)

Lake Rejuvenation Project: An Intervention with Bamboo

Location: Subramanyapura lake

Planting bamboo can help to prevent soil erosion, and flooding and also serve as a natural fence while supporting the nesting and roosting of a variety of birds.

3.5.3 Evaluation Criteria:

"What gets measured, gets managed". Documentation, Monitoring & Evaluation a major component that we have. Inclusion as it is, is very important for dynamic adjustment to get the desired results. These data will also help in proposing policy interventions.

a. Documentation: Keeping records of the number and type of species planted as well as their growth process will be helpful in further planning;
b. Monitoring: Assessing the impact of the plantation on the air quality and water quality regularly and recording the same for future initiatives;
c. Calculation of CO_2 emissions from bamboo-based buildings and assess the circularity index;
d. Structural, durability, safety, and economic evaluation of bamboo as a building material to establish results

3.5.4 Policy Interventions:

To make interventions at city level policies, regulation support is crucial. These policies will become guidelines for the future of Bamboo City.

1. Urban Planning policies: Bamboo plantations and bamboo construction can become an integral part of the city's urban planning and development policies.
2. Government Incentives: Incentives for green buildings and tax redemptions on bamboo buildings, plantations, etc.
3. Building Codes and Regulations: Revising existing codes of buildings specifically to address bamboo construction. Developing new building codes and regulations to promote the use of bamboo as a primary building material

Conclusion

Nature has an innate ability to regenerate, forming the foundation of the intricate web of life and essential ecosystem services that sustain human livelihoods. As cities rely on nature, a model for regenerative cities must prioritize nature as a fundamental stakeholder when developing an action plan to address urban environmental, economic, and social issues.

Urban greening with bamboo presents an opportunity to absorb and store carbon, mitigate greenhouse gas emissions, provide a renewable resource for housing and infrastructure and development, remediate degraded lands, rejuvenate lakes, and reverse air pollution. These efforts will foster inclusive, equitable, resilient, and safe urban spaces while providing clean water, clean air, and local livelihood opportunities, especially for marginalized populations. Therefore, bamboo cities can serve as one of the most effective nature-based solution to curb global warming and achieve net-zero carbon goals, ultimately leading to regenerative cities.

Author Declaration

It is hereby confirmed that the manuscript has been read and approved by all the named authors and there is no conflict of interest. All regulations of our institution/institute/company including intellectual property rights have been followed and there are no impediments to publication.

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Conflict of Interest

The authors declare there is no conflict of interest

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