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# A SYSTEMIC ORIENTED APPROACH FOR THE DEVELOPMENT OF BAMBOO PRODUCTS: CASE STUDY FOR THE REGION OF PUEBLA, MEXICO

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This paper describes the process of an industrial design project using bamboo from Mexico as a main material and the articulation of the industry value chain. It has a Systems Oriented Design (SOD) approach that analyzes different layers of information and knowledge discovered during its development, which started with the definition mapping and finished with the development of different products. The purpose of this study is to understand the complexity of its scenarios, in an local unarticulated industry with lack of technology and an unstandardized production. The industrial production of the project required a systemic approach due to its complexity that had few boundaries that extended to local communities, policy-making and environment factors that delimited its scenarios. It also describes different methods in project and product development that aim for sustainability as a system property, referring to the management processes for the project using System Thinking Methods (STM) with different loops of information and cross collaboration with stakeholders. This process permitted the evaluation and assessment of different variables of the current industry system that has enabled future scenarios.

*Keywords:* industrial design; product development; systems oriented design

# UN ENFOQUE SISTÉMICO PARA EL DESARROLLO DE PRODUCTOS DE BAMBÚ: ESTUDIO DE CASO EN LA REGIÓN DE PUEBLA, MÉXICO

Este artículo describe el proceso de un proyecto de diseño industrial utilizando bambú producido en México como materia prima y la articulación de la cadena de valor de la industria. Tiene un enfoque de Diseño Orientado en Sistemas (SOD) que analiza diferentes capas de información y conocimiento descubiertas durante su desarrollo, el cual comenzó con el mapeo de definición y finalizó con el desarrollo de diferentes productos. El propósito de este estudio es comprender la complejidad de sus escenarios, en una industria local desarticulada, con falta de tecnología y una producción no estandarizada. La producción industrial del proyecto requería un enfoque sistémico debido a su complejidad y los pocos límites que se extendían a las comunidades locales, la formulación de políticas y los factores ambientales que delimitaban sus escenarios. También describe diferentes métodos en el desarrollo de proyectos y productos que apuntan a la sustentabilidad como una propiedad del sistema, refiriéndose a los procesos de gestión del proyecto utilizando Métodos de Pensamiento del Sistema (STM) con diferentes circuitos de información y colaboración cruzada con las partes interesadas. Este proceso permitió la evaluación y valoración de diferentes variables del actual sistema industrial que ha posibilitado escenarios futuros.

*Palabras clave:* diseño industrial; desarrollo de producto; diseño sistémico

## 1. Introduction

Future resources have been a topic for the problems that we are facing today, like climate change, population growth, water supply among others. All of these topics are related to systems and most of them are interconnected to each other. There is an importance to develop sustainable systemic solutions for the future as we deal with the complexity of our current scenarios.

A system is defined, according to H. Meadows (2009) “as a series of interconnected elements that are coherently organised in such a way that they can fulfil an objective. A system must be made up of 3 things: elements, interconnections, and function or purpose”.

Systems have an inner characteristic of complexity in which the system scenarios are interconnected and require a systemic approach to enable a process that could result in a sustainable solution. This interconnection and complexity is defined as “wicked problems” (Rittel & Webber, 1973; Buchanan, 1992).

These socio-technical scenarios (Geels, 2004; Pereno et al., 2021) are determined by a technological dimension in which the elements, interconnections and function of the system is defined by a cluster of stakeholders (Freeman, 1984) that interact in a common context.

The initiatives proposed and carried out in this project involve different stakeholders that collaborated to develop a local bamboo industry by defining the elements of the current socio-technical scenarios. This process involved analysing the opportunities within the system to define a Product-Service System (PSS) that generates enough value through an innovative business model by integrating products and services in a defined system (Pádua et al. 2017).

The need to take a systemic approach and methodology is motivated by the nature of the interconnectedness and complexity, where: “all problems we define, as human constructs, can be described as problem sets, with each distinct problem merely a component of a set or problem system” (Jones, 2013).

The objectives of this case study are:

1. Analyse the system local scenarios for the bamboo production in Mexico.
2. Mapping the variables of its parts and relations.
3. Document the development for the product-service systems of the local industry.

The involvement of the working team during the project, had an approach as Systems Designers or “Systems Architects” (Sevaldson, 2011), as the project management extended beyond the logistics of its processes towards an intuitive and holistic process.

This case study presents the systematisation of the local bamboo industry driven through a product-service system (Ceschin & Gaziulusoy, 2016), which was defined after analysing the information generated through a methodology based on socio-technical scenarios (Gaziulusoy, 2010). This process is focused on encouraging the local bamboo industry in

Mexico (Cortes, 2007), particularly in the region of Puebla, as a productive alternative for its communities that could generate a positive economic, social and environmental impact.

The process of the project involves “Action Research” (Lewin, 1946) to obtain information of the system scenarios through activities, to develop both soft and hard skills within the stakeholders. Most of the prospective planning of these activities are described as a System Design (SD) process. “The SD approach seeks to create not just industrial products, but complex industrial systems” (Barbero & Toso, 2010).

### 1.2 Analysis of the local system of bamboo in Mexico

To define the local system of bamboo production in Mexico, there is a need to make a cross analysis to identify its value chain and its scenarios (Pereno, et al. 2021). There is little information about this value chain of bamboo, this is because until a few years ago the use of bamboo in Mexico had remained virtually unknown. Bamboo was only used as a traditional element in some areas of the country but it has the potential for innovative industrial use (Borowski et al., 2022; Bowyer et al., 2014; Van der Lugt et al., 2009).

There are about 39 native species of bamboo from Mexico (Cortes, 2007), most of them are herbal types, others have a considerable size for its production. Due to the geographical and climatic characteristics of the country there is a potential production capacity, this being one of the sustainable materials with a high growth in demand in international markets.

**Figure 1: Distribution of native bamboo in Mexico**

Note: Areas with major representation of native species of bamboo in Mexico.

Currently the production of bamboo comes from “family systems” (Aguirre, 2018) in which the farmers use part of their land to cultivate bamboo along with other productive plants. Most of these plantations have an average extension from 1 to 5 ha, and the sum of these plantations can be estimated over 1,000 ha in the region of Puebla.

The most common types of bamboo that are found in this region are Bambusa Oldhamii, Guadua Angustifolia and Guadua Aculeata (Cerdeña, 2011). All of these types of bamboo are big forestal species of bamboo and have similar technical properties and characteristics.

The analysis of the local industry and its socio-technical scenarios gave some insight of the current situation of the value chain of bamboo in the region and made an effective and holistic reading of the territory (Battistoni, 2019). This analysis provided sufficient information to decide some of the next steps on the process as to define the tools that were applied.

## 2. Materials and Methods

There is no defined methodology for SD, but there are cross disciplinary processes that enable to have some applied methods to the process. As the complexity of a system is defined the elements of its methodology are established.

This requires flexibility within the process to generate different iterations or feedback loops as an agile methodology. While some of the system variables are clarified, others require a set of skills within the design team to be found as: “the ability to address many aspects simultaneously and to generate holistic, and at their best, synergistic responses is in fact a type of soft systems practice” (Sevaldson, B. 2011).

An area of opportunity for the development of a local bamboo industry lies in the possibility of working with the socio-technical scenarios of the system by designing a PSS that enables the articulation of the value chain with sustainable and circular characteristics.

The main process of the project was based on six phases:

1. Analysis and action research of the system local scenarios.
2. Using Framework tools to identify different transition opportunities.
3. Mapping the system and its interconnections to articulate the value chain.
4. Analysing the stakeholders within the system.
5. Identifying the system innovation opportunities.
6. Defining a PSS for the local industry, with market applications.

### 2.2 Action research

The process of Action Research (Lewin, 1946) helps to develop a qualitative approach to acquire the information that is needed to define the complexity of the project system. This particular information could be articulated as explicit information which gives an idea of the tangible needs for the socio-technical scenarios.

There is a deeper level of information that is unarticulated and is related to Tacit Knowledge (Polany, M. 1966). This particular information has qualitative characteristics and is valuable in relation with the system definition. “A system must consider relations with the regional context, evaluating by-product valorisation solutions not only from a technical but also from a socio-environmental point of view” (Pereno, et al. 2021).

Action Research enables a process to obtain information through activities that involve the stakeholders and is conducted in order to define the problems and necessities of its

scenarios (Ulicka & Cruz, 2015). This is a co-generative process that reveals relevant knowledge using qualitative social research techniques. Some of these activities were established to promote communication and define articulation with the stakeholders.

**Figure 2: Bamboo farmers forum**

Note: Region of Puebla, Mexico (2016)

These activities had the purpose of defining boundaries in the local socio-technical scenarios, while clustering its stakeholders.

The obtained information by the making of the previous activities gave a structure for the system scenario. It also helped to understand the behaviour of the stakeholders in a local context while defining the interconnectedness of the system. This information helped to decide which frameworks would be used to visualise the variables of the system.

### 2.4 Frameworks for systematisation

The use of frameworks, which are a representation of mental models, enables a synthesis of the system complexity by using mental models for a cognitive representation of external reality (Jones et al., 2011). Frameworks as a representation of mental models, were used in the project as a tool to facilitate the analysis of information in the PSS.

One of the frameworks as a systematisation design is Ten Types of Innovation (2013), this is a tool that is useful to make a diagnosis to enrich the opportunities for innovation. This diagnosis helped to analyse the existing scenarios of the industry. This tool makes it possible to identify errors of omitted or forgotten dimensions that could be strengthened, as well as identify opportunities and build sophisticated innovations (Keely et al., 2013).

The types of innovation are distributed in a structure that is divided into 3 categories:

1. Configuration: internal aspects of project operations.
2. Offering: the tangible elements that are offered to the client.
3. Experience: the external characteristics of the system towards the market.

Each part of the tool represents a scenario of the system that focuses on its socio-technical scenarios. In order to function and transcend requirements in a clear structure, an understandable relationship between its stakeholders and a future projection is aligned with the original objectives and the analysis of its needs.

According to Battistoni (2019) “the process and use of data framework is vital to understand the scope of the projects which allows moreover to define the boundaries of the system, from the social, regional, urban or industrial system”.

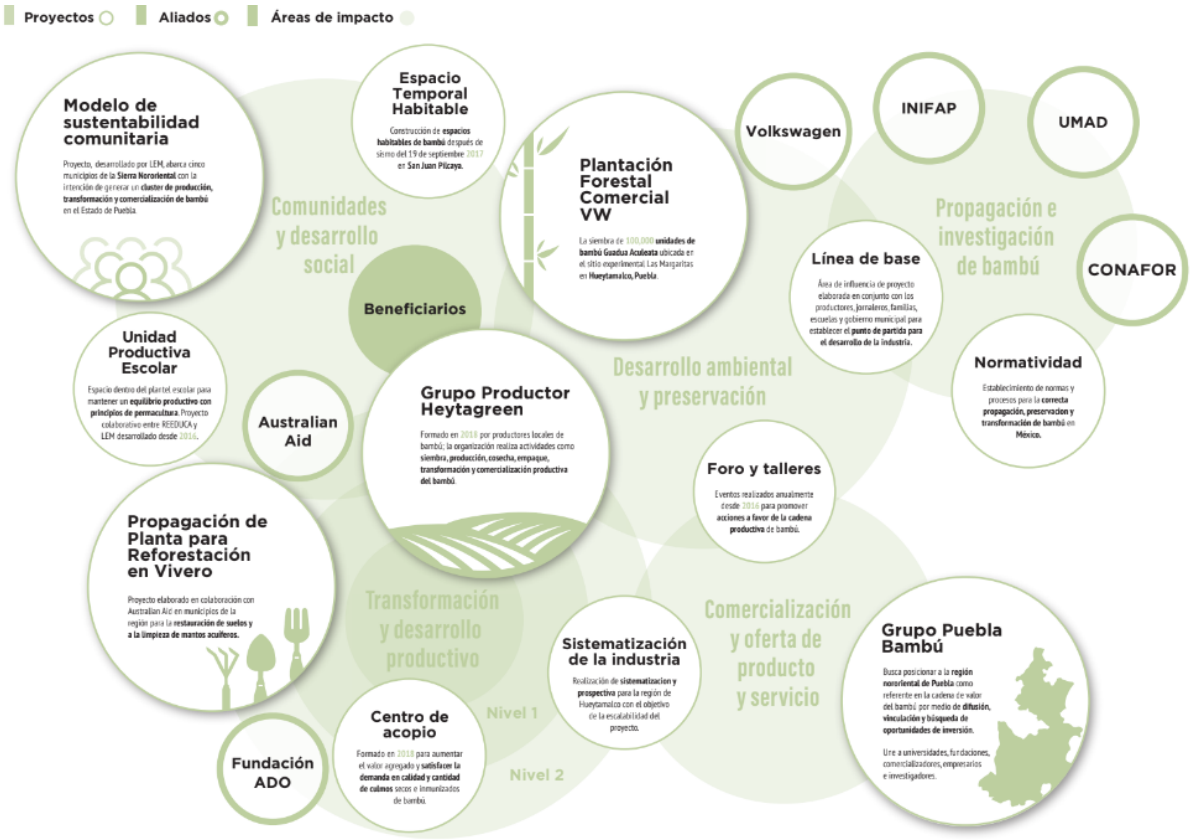
The follow-up of these activities helped to establish a map based on the structure of the local bamboo value chain. Each of these activities were carried out through collaborative work with the stakeholders. This approach helped to achieve ownership of the project. This process was developed as a necessity to advance through the complexity of the scenarios of the system (Jones, 2013).

### 2.5 Mapping the system variables

The common process of mapping the variables, parts and relations of a system is through a visualisation that helps to communicate within the complexity of a system with different stakeholders. Mapping the complexity of a system can be achieved by using different layers of information. This is called a Giga-mapping and one of its main functions is to: “define areas and points for intervention and innovation” (Sevaldson, 2011).

As the system of a project grows there is a tendency for dematerialization of its outcomes (Papanek, 1972), this could result in the definition of the PSS. Mapping these possibilities is helpful to visualise the complexity and decide how to divide them into subcategories with new layers of information. As shown in the local bamboo industry mapping (Fig. 3) the layers of information include different subprojects, alliances with stakeholders and impact areas.

**Figure 3: Local bamboo industry mapping in Mexico**



Note: Description of the projects, alliances and impact areas in the industry of local bamboo.

These layers of information are visualised as stages of intervention, however the final result of the PSS was uncertain. For this reason it was important to define a process that enables an “extreme learning situation” (Sevaldson, 2011). These stages of intervention seeked to improve the socio-technical scenarios and the articulation of the value chain through a collaborative process.

These innovations reflected the “values, characteristics and qualities” (Keeley et al. 2013) of the socio-technical scenarios. As a result of the process of mapping some of the variables of the industry needed to scale into the PSS. This scalability had to include most of the current value chain and it triggered the articulation of the local industry.

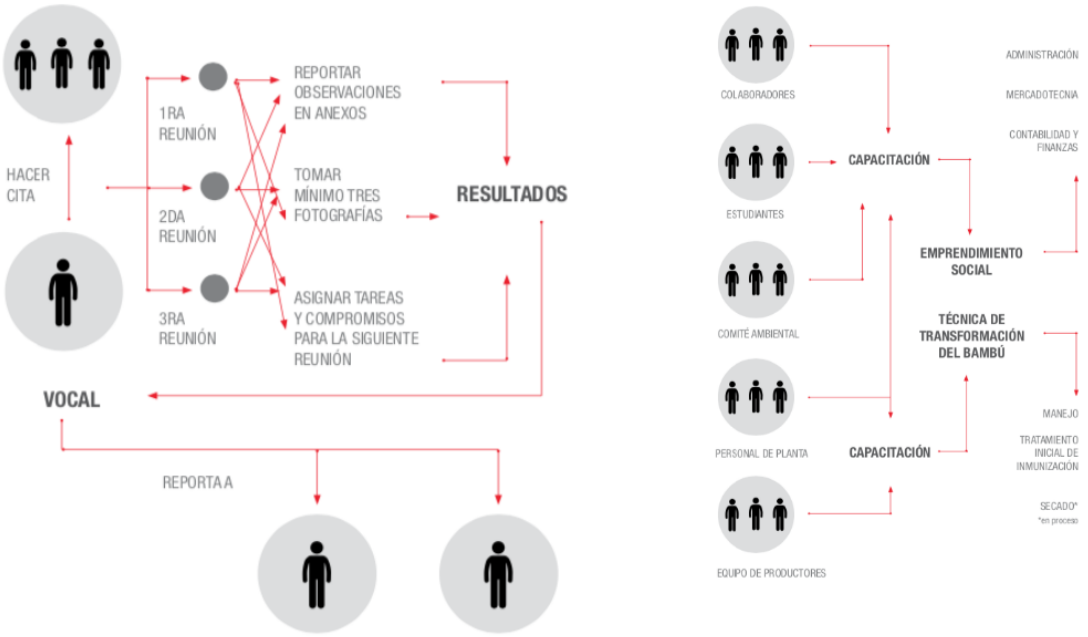
This visualisation process could be described as visual thinking (Sevaldson, 2011) while some of the questions related to the uncertain information had aroused and the scenarios for opportunities were shown. It is important to emphasise the testing of the process and to apply an iterative practice that serves as a guideline, not only as the final result of the mapping is shown, but during the information definition process.

The role of the System Designer or System Architect is: “to be a mediator between complex data and all actors of a project, translating the given information into efficient and simple visual language” (Battistoni, 2019). The result of this process was a decision making of future transitions that could mark the next steps of the project and started to evolve into an analysis of the stakeholders of the industry system.

## 3. Results and discussion

The results of applying a system approach for the development of the project were firstly analysed by the perspective or the stakeholders. A stakeholder is a central part of every system because most of the dependencies rely on the relationships with key elements within the socio-technical system. The concept of stakeholder was first developed for management purposes (Freeman 1984) and there is a responsibility for the project to: “keep the support of all of these groups, balancing their interests, while making the organisation a place where stakeholder interests can be maximised over time” (Freeman & Phillips 2002).

**Figure 4: System stakeholder analysis for the local bamboo industry**




Note: Description of the relations between stakeholders and their knowledge creation process.

It is important for the alliances between stakeholders to generate a boost and promote a common interest. The interconnectedness of the system is a reflection of the internal organisation of its stakeholders that allows communication within and between them. This organisation has an information base with a holistic perspective with its horizontal interactions and functions that helps to promote an holistic perspective (Battistoni, 2019).

There was an emphasis that the stakeholders' common interest was aligned with their functions, this allowed them to have a positive impact on their surrounding scenarios. It was important to stay focused on a human centred perspective to achieve a multi-systemic, multi-stakeholder complexity (Jones, 2013).

As the project approached to create a plausible PSS the necessity to define and identify opportunities that generated the articulation of the value chain through a model that could impact the industry system and its circularity.

### 3.1 Identifying system innovation opportunities

Structural innovations of a system can focus on an organisational level to activate different elements of value creation and to define a PSS with a common interest with its stakeholders. The main identification for the system innovation opportunities consisted of the following distribution:

- **Production:** approach to the people who were dedicated to planting, caring and producing bamboo. It is proposed that the bamboo material, once mature for use, could be gathered into a next level transformation as the figure 6 shows.

- **Increments of technology:** prefabrication of new materials would consist of different specialised processes that could result in panels, structures, covers, etc. Designing these materials could generate characteristics for new markets, or they could consist of personalised products that respond to a specific service.
- **Specialised consulting:** another component for this system was related to areas of design consulting, such as housing and furniture applications. These approaches came from the interest from new stakeholders that were looking for training, product development and experimentation proposals.
- **Sustainability and circularity:** the consumer awareness towards the use of sustainable products concerning environmental protection and circularity is becoming a common characteristic. This requires that the industry system works with standardised processes according to international regulations and sustainable certifications such as (FSC).

The identification of these innovation opportunities gave a better comprehension of the potential PSS and its main components, this also created a structure for the value chain that needed to be articulated as a “holistic panorama” (Battistoni, 2019).

This articulation involved activities and operations to produce the PSS, this also included every aspect of the socio-technical system and its stakeholders to obtain effective results that were aligned with the identified opportunities.

### 3.2 Local bamboo Product-Service System

The Product-Service System (PSS) that was developed during the project was a consequence of the need to increase technology levels to achieve prefabricated outcomes with a higher market demand. This improvement in the offer would benefit the collaborative work relationships between stakeholders by establishing a local industry cluster.

The PSS refers to: “innovative business models that are oriented to provide value to customers through utility or solutions of integrated bundles of services and products without the necessity of transferring the property of the physical product to the customer” (Pádua et al. 2017).

These products and services were developed as options to meet market demand and articulate the value chain of the local industry as the productivity increased. Within this offer there were some individual products that were connected with services that created a combination of a competitive advantage.

This transformation would require a production-consumption system through a business model innovation (Ceschin & Gaziulusoy, 2016). As the PSS advanced from a raw material towards a technology transformation material that aimed to offer a sustainable alternative with circular characteristics, the improvement of the material would benefit from the introduction of new products within the socio-technical system.

In order to tackle the opportunity for sustainable and circular materials, the industry system needed to be structured as an efficient supply chain that could offer products, goods and services to an increasing market demand. This required carrying out a consolidation process

of industrial development, with alliances that carried out internal processes of standardisation and certification.

**Figure 5: Bamboo coffee table**

Note: Coffee table developed with local bamboo GBB.

### 3.3 Industrial development

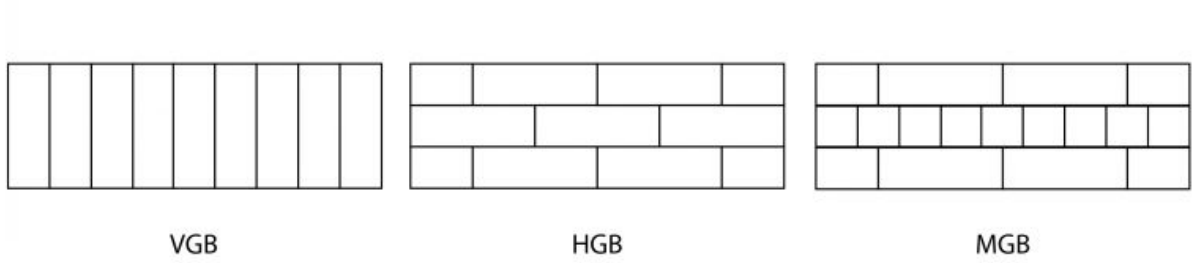
The main PSS that was developed to obtain the characteristics defined during the identification of the system innovation process was de Glue Bamboo Board (GBB). This material can offer multiple solutions for manufacturing different kinds of products and has many applications in the housing and furniture industries.

GBB has a great flexibility and hardness thanks to the arrangement of the internal layers of bamboo. These can contract and expand less than most solid woods, which provides greater stability. The GBB has a superior density from similar products made from wood and they are ideal for high strength applications.

The GBB is obtained by glueing layers of bamboo lamellas into a board with different configurations to obtain specific characteristics of strength and flexibility in different configurations. They are classified into three kinds:

- Vertical Glue Board (VGB)
- Horizontal Glue Board (HGB)
- Multiple Glue Board (MGB)

**Figure 6: Configurations of GBB**



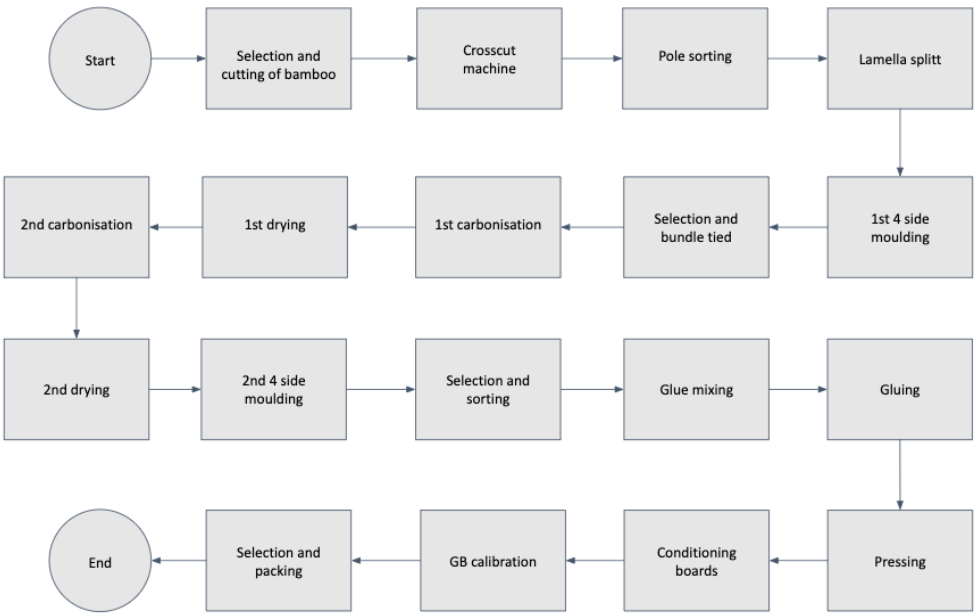

Note: First configuration for vertical glue board, second for horizontal glue board and third for mixed glue board.

These products have a variety of dimensions which come from the standardisation of the manufacturing processes and requirements for transformation. The development of the PSS had the advice of different experts from similar scenarios. These experts had the experience of developing GBBs in other countries with more developed industry systems.

The amount of production at the industry system is estimated as 1,177 cubic metres of GBB which is obtained from green poles of bamboo with an average density of 900 kg/cm. Each green pole is divided into a number of lamellas produced with a splitter.

The production process is divided in two different stages, the first part of the production is located near the plantations of bamboo and it is intended to facilitate the transport of raw material. This process starts with the selection and cutting of bamboo in the plantation, the green bamboo is selected by its diameter and its growth. Each pole is marked when the bamboo shoot is starting to grow to determine the maturity of the pole and the tight time for its cutting.

**Figure 7: Production process for GBB**



Note: Steps required for the production of GBB with a standardised process.

The processes that were created throughout the industrial development required collaborative practices between the stakeholders in a socio-technical scenario by establishing relations in a circular system. This allows the development of a sustainable industry and its value chain that considers the business model of the PSS (Pereno, et al. 2021).

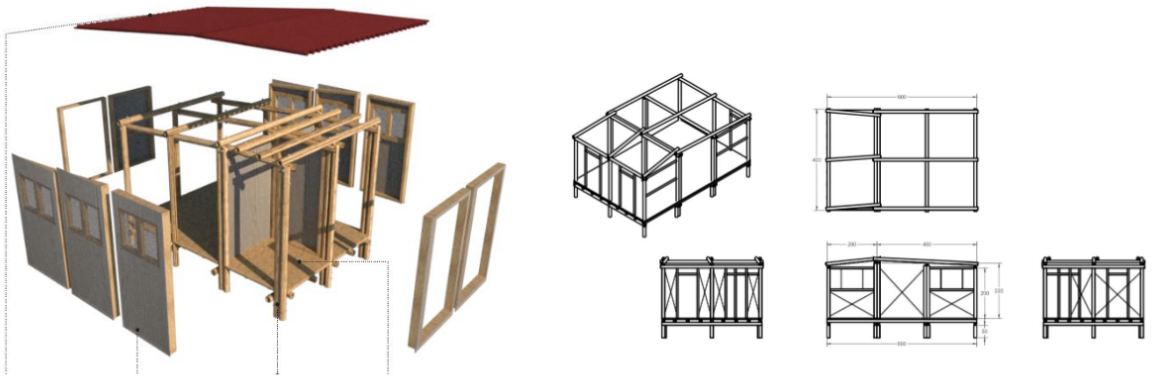
The configuration system involved all the activities and operations that go into generating GBB. Additional knowledge and training was needed to guarantee a proper standardisation and future certifications of the PSS. During this configuration some of the main characteristics were enhanced to match the requirements of the GBB applications in housing and furniture.

### 3.4 Housing and furniture applications

A relevant application of the GBB as a defined PSS is the WASH module for TECHO, which is an emergent housing element for areas of territorial irregularity, restoration due to natural disasters or rural areas. This module is made with a prefabrication construction system to reduce costs and installation times. Its materials allow high durability and climate resistance to benefit between 600 to 900 families annually.

This module provides a progressive community emerging infrastructure, through easy assembly and high sanitary technology. In Mexico, 3 out of 10 people do not have access to basic water, sanitation and hygiene equipment in their homes.

**Figure 8: Housing application for BBG**



Note: WASH module by TECHO Mexico.

This module guarantees access and proper management of water, sanitation, and basic hygiene for families in popular urban and rural settlements. BBG was used to make all building components, both structural and non-structural.

The versatility of the BBG as a building material has many applications in the construction field. It is strong and lightweight and can often be used without processing or finishing. By

building these modules with BBG some characteristics were gained, such as wind resistance and seismic forces.

To define the final market to which the brand will target, it is essential to take into account the future of sustainable consumption. Currently there are a variety of organisations focused on environmental awareness and the promotion of circular materials.

Currently, the market is concentrated in companies that seek to modify and adapt to environmental problems, emerging companies with a sustainable approach, experimental laboratories with materials, organisations and educational institutions.

## 4. Conclusions

The SD process that was taken during this project had some characteristics that enabled the development of a PSS that had some impact within the stakeholders of the current socio-technical scenarios. This gave the opportunity to evaluate some of the variables for the industry system and gave qualitative information that defined opportunities for the future transition.

As the local industry system interconnects in a value chain that moves towards a transition for sustainable and circular practices, a system methodology approach is needed to generate valuable knowledge that helps to understand the complexity of its variables. These relations within the local socio-technical scenarios were defined by the connectivity of the system with the use of bamboo as a sustainable material.

The project emphasises on the development of a PSS that could offer an opening to new market channels as an evolution of the system through its transformation on levels of technology.

The uncertainty of the project complexity leaves many questions unresolved that need to fill some gaps of information in the future. As the elements that involve the stakeholders and the technological barriers are resolved, the development of new PSS will enable the creation of future scenarios that will give new information for the industry system.

### 4.1 Future limitations

It's a part of the SD process to generate transitions for a paradigm shift as the current scenarios are changing. These changes are part of a collaborative process with the stakeholders of the system scenarios to enable the appropriation of any proposed outcome. In accordance with the dematerialization of the design practice in a system, by developing a PSS it will be recommended to apply an experience variable to this outcome as a Product Service Experience System (PSES).

This could increase the relations between the variables of the industry system, by increasing its complexity. This underlines the importance of developing an articulated value chain that could evolve into a sustainable and circular industry system for the local bamboo in Mexico.

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## 6. Sustainable Development Goals