Lisbon School of Economics & Management
Universidade de Lisboa

MASTER

ECONOMIA E GESTÃO DE CIÊNCIA, TECNOLOGIA E INOVAÇÃO

MASTER'S FINAL WORK

DISSERTATION

EXPLORING BAMBOO AND CLT AS SUSTAINABLE CONSTRUCTION MATERIALS ALTERNATIVES TO REDUCE CARBON EMISSIONS IN PORTUGAL BY 2050

MIGUEL JOSÉ PRATES FERNANDES

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SUPERVISOR: PROF. DR. MANUEL MIRA GODINHO

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ABSTRACT

Nowadays, there is a progressive concern with a view to a sustainable future. In this context, the construction sector, one of the main sources of carbon emissions and resource consumption, is striving to find sustainable solutions to mitigate its ecological impact.

The present study explores the transition from traditional materials, concrete and steel, to sustainable materials, CLT and bamboo, in Portugal, by 2050, positioning the country in compliance with the decarbonization objectives of the Paris Agreement. The dissertation focuses on demonstrating the benefits of using and applying these materials, highlighting how they will minimize CO2 emissions, while simultaneously enabling faster and more efficient construction. Creative destruction will happen as traditional practices will be replaced by innovative solutions, with technological change helping to promote sustainability.

The advances will happen as the current state of art of building construction in Portugal is still very much concentrated on materials and typologies that have been rooted and unchanged for more than 80 years.

The quantitative and qualitative results of the research carried out addresses the main obstacles that will be faced in this trajectory of change, assessing whether the transition from traditional materials to sustainable materials will be possible in Portugal by 2050.

Keywords:

Sustainability; Environmental Sustainability; Sustainable Materials; CLT; Bamboo; Construction Materials; Renewable Resources; Innovation;

RESUMO

Nos dias de hoje, existe uma preocupação progressista com vista a obter-se um futuro sustentável. Neste contexto, o setor da construção civil, um dos principais responsáveis pelas emissões de carbono e consumo de recursos, empenha-se na procura de soluções sustentáveis para mitigar o seu impacto ecológico.

Este estudo explora a transição dos materiais tradicionais, betão e aço, para materiais sustentáveis, CLT e bambu, em Portugal, até 2050, com vista a permitir que o país se posicione em conformidade com os objetivos de descarbonização do Acordo de Paris. Concentra-se na demonstração dos benefícios da utilização e aplicação desses materiais, tanto por permitirem a redução de emissões de CO2, como por proporcionarem construções mais rápidas e eficientes. Nesta transição, a destruição criativa levará à substituição de práticas tradicionais por soluções inovadoras, proporcionando soluções de base tecnológica para a promoção da sustentabilidade.

O ponto de partida para esta mudança é o atual estado da arte da construção de edifícios em Portugal, ainda intrinsecamente baseado nos materiais e nas tipologias mais utilizadas no setor, numa situação enraizada e inalterada há mais de 80 anos.

Os resultados quantitativos e qualitativos da investigação desenvolvida, apesar dos principais obstáculos enfrentados, permitem discutir criticamente se a transição de materiais tradicionais para materiais sustentáveis é possível em Portugal até 2050.

Palavras-Chave:

Sustentabilidade; Sustentabilidade Ambiental; Materiais Sustentáveis; CLT; Bambu; Materiais Construção; Recursos Renováveis; Inovação;

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To my Ismarelos friends, for all the moments you've provided me, which I will remember forever.

And finally, to me, for never giving up.

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1. Introduction

The building construction sector, known for traditionally being a huge consumer of resources and consequently a generator of waste, is currently witnessing a transformation within the scope of growing concern with sustainability. The Paris Agreement triggered a transformation in global environmental policies. So, in order to limit climate change by achieving goals of cutting emissions down to netzero by 2050, stronger efforts are needed to reduce the whole life cycle emissions of buildings. The transition to sustainable construction materials represents a unique opportunity to transform the construction sector in Portugal, making it more competitive, efficient and aligned with the Paris Agreement objective.

In that regard, concrete and steel, the two dominant materials in building construction, are highly energy-intensive to produce and result in substantial carbon dioxide emissions making construction one of the most polluting activities. Therefore, there is an increasing demand for innovative, ecological and efficient solutions to shape the future of construction. As the global demand for sustainable construction practices continues to rise, innovative materials and renewable resources such as cross-laminated timber (CLT) and bamboo are gaining prominence due to their strength, durability, and low carbon footprint. CLT is one of the most propitious materials reassuring sustainable requirements (O'Ceallaigh, 2018) and, on the other hand, bamboo structures are becoming more in demand due to the increasing environmental problems (Maikol, 2020).

This investigation will address the adoption of new technologies as a solution to solving environmental problems, promoting sustainability in Portugal. Likewise, the benefits and advantages that exist in the application of sustainable solutions in the construction of buildings will be alluded. In this context, the current status of the use of materials and construction techniques for buildings currently most used in civil construction in Portugal will be analysed. Also, the results of this investigation will identify the current state of the construction sector and what the main obstacles to be faced in the transition in Portugal will be by 2050.

In sum, this dissertation will address how it is the transition in Portugal for more sustainable building and, what are the prospects for the diffusion of this new paradigm.

This dissertation has 8 chapters, this one being the introduction to the research. Chapter 2 focuses on the literature review of the main traditional and sustainable materials. Chapter 3 is designed as a definition of the civil construction sector in Portugal, the dominant typologies and the most used construction techniques. It also presents the existing housing crisis. In chapter 4, the data collection methodology and data analysis will be discussed. In relation to chapter 5, the discussion of results from the questionnaires carried out and the interview will be presented. Next, in chapter 6 the conclusions of the work will be introduced in relation to the previous chapter. Finally, bibliographical references, next to the appendices, chapters 7 and 8, will be presented.

2. LITERATURE REVIEW

This chapter will present a theoretical framework about the paradigm shift towards sustainable construction through Schumpeter's Theory of Destructive Creation and Everett's Theory of Diffusion of Innovation. Subsequently, the traditional materials and sustainable materials, along with their respective advantages and disadvantages, will be presented.

2.1 Framework

Creative destruction, a central concept in Schumpeter's theory, is fundamental to economic progress. According to the economist, this is a process that continuously revolutionizes the economic structure from within, constantly destroying the old one and creating a new one (Schumpeter, 1942). In other words, it is based on the introduction of new products, services or technologies that aim to replace old ones already on the market, creating new markets and business opportunities. The long-term survival of companies and economic agents depends on their ability to adapt to the emergence of innovations on the market. Those companies which are unable to adapt will be outplaced, resulting in their extinction. In this theory, Schumpeter argues that the entrepreneur is a driving force capable of challenging the *status quo* and foresting economic development through new ideas, products and processes (Tülüce & Yurtkur, 2015), playing the central role as the transformative agent responsible for promoting change through innovation.

The transition from traditional to sustainable materials in building construction may be perceived as an example of Joseph Schumpeter's theory of creative destruction, where innovation drives the development of sustainable materials, eventually leading to the decline of traditional ones.

The traditional materials used in building construction, which rely on non-renewable resources and polluting processes, have significant and growing implications for global material flows and emissions (Fishman, Mastrucci, & Peled, 2024). Nowadays, building construction accounts for approximately 39% of total CO_2 emissions related to energy consumption worldwide (Kovalchuk & Shcherbakova, 2024). Thus, the continuous process of creative destruction of traditional materials, such as concrete and steel, seeks to replace them with innovative sustainable alternatives that reduce resource consumption, minimize emissions to the atmosphere and enhance energy efficiency.

On the other hand, in building construction, its technologies and agents are part of the wider National Innovation Systems. NIS are established through the connection between various actors such as construction companies, universities, Government and investors, with the aim to promote innovation and contributions to the economic and technological development of the sector. Each actor plays a distinct but independent role in processes ranging from R&D to the implementation of new technologies and practices. In this way, the weight of culture and tradition in the behavior of actors is vital. In traditional sectors, the introduction of new technologies can be slow due to attachment to established practices. In contrast, in markets with a culture more open to innovation, exactly the opposite would be observed, with a tendency more conducive to innovation.

In the context of this dissertation, the construction sector is looking for sustainable alternatives, as well as the adoption of technologies to increase efficiency and reduce waste. Such changes may not only require the reconfiguration of production processes but also in consumption patterns. The shift to sustainable construction has been a significant driver of this transformation. With increasing awareness of the environmental impact of buildings and the use of renewable and low-impact materials such as CLT and bamboo, these materials align with society's broader demand for greener living and healthy environments. Thus, the role of public policies is considered vital to align the interests of different actors. These frameworks push industries to innovate while providing a pathway for consumers and developers to make more informed choices.

Consequently, Schumpeter can be considered the "grandfather" of innovation theories, as he highlights the role of creative destruction as a driver of economic progress. National innovation systems, in turn, can be seen as the "child", as they organize networks of actors and institutions to foster innovation on a macroeconomic scale. Finally, socio-technical transitions would be the "grandchild", focusing on evolution that integrates technological, social and cultural dimensions.

The Diffusion of Innovation Theory by Everett Rogers can be better understood under the light of the previously mentioned Schumpeterian Theory. Rogers focuses on the process of dissemination of innovations subsequent to their introduction into the market and which lead to the transformation of practices and behaviours on a large scale among the actors in an economic sector (McGrath & Zell, 2001). Also, this helps us understand how there can be a substitution of non-sustainable construction practices with sustainable ones, allowing the latter to gain greater momentum. Rogers argues that there are different adoption groups, classifying innovators as pioneers who do have less averse to financial risk, and are the first to try innovative solutions, paving the way for dissemination. On the other hand, laggards are those who resist the adoption of sustainable materials due to conservatism, high risk aversion or lack of R&D, ending up giving in to innovation only due to regulated obligations or discontinuity (Ssebalamu, 2024). In this context, diffusion is the process by which an innovation is communicated through certain channels over time among the members of a social system (Orr, 2003), highlighting the vital role of communication in promoting the application of changes and how the process of adopting to them can be accelerated to achieve more sustainable building construction in Portugal. Although this is not a dissertation adopting quantitative methods to estimate diffusion models, there is a particular interest in considering what could eventually facilitate or limit the diffusion of the new paradigm in Portugal.

2.2 Concrete

Concrete is a construction material made by adding sand and gravel to cement, whisking the mixture with water and pouring it into molds before it dries (Nature, 2021). This material possesses adaptability and enduring qualities that facilitate the construction of lasting buildings (Monteiro, Miller, & Horvath, 2017), and beyond its strength and resilience, it is also a staple of building construction because it is relatively cheap and simple to make (Nature, 2021). Concrete is the most widely used man-made material in existence (Rodgers, 2018), being used in different countries in their constructions. An impressive example and probably the most remarkable in the world is China which between 2011 and 2013 used more concrete than the United States did in the entire 20th century (Skinner & Lalit, 2023) due to the country's massive urbanization.

The typical composition of concrete, according to Industries (2023), consists of the following materials: cement, which comprises between 10% and 15% ; water, which represents between 15% and 20%; and aggregates, such as sand and gravel, which add up to between 65% and 75%, as visible in *Table 1* (in Appendices). The production method starts when cement and water interact chemically to bind the aggregate particles (sand and gravel) into a solid mass (Garcia, 2012) giving the mixture the workability that enables it to fill the forms. This chemical reaction is called hydration (Babor, Plian, & Judele, 2009). After placement it is vital the compaction step which is a process by which entrapped air is removed from the concrete's plastic matrix (Howes, Hadi, & South, 2019) with the goals of reducing permeability and hence increasing durability.

2.1.1 Advantages of Concrete

Concrete is characterized by being versatile and long-lasting (Nature, 2021) making it an indispensable material in construction.

Also, another advantage of concrete over other building materials is its inherent fire-resistant properties (Bilow & Kamara, 2008) which are considered exceptional. Concrete doesn't burn (Sustainable Concrete, 2018), it cannot be set on fire and does not emit any toxic fumes, acting as a thermal barrier preventing fire. However, it is fundamental to understand that if the material is not at 100% of its capacity it can sometimes be damaged or it can fail. This phenomenon may occur if there are cracks or chips (known as spalling) in the material due to prolonged exposure to intense heat (Fletcher, Welch, Torero, Carvel, & Usmani, 2007) resulting in structural failures.

2.1.2 Disadvantages of Concrete

The main environmental issue associated with cement production and consequently concrete production, is the high level of energy consumption. Cement production is one of the most energy-intensive industrial process (Babor, Plian, & Judele, 2009) making it a significant environmental challenge for the concrete and building construction industry. In 2022, the amount of electricity consumed per ton of cement produced reached around 100 kWh/t (IEA, 2023).

Apart from energy consumption, with the increasing reliance on concrete and ready-mix applications, countless gallons of water are used every day to mix concrete and clean equipment. These actions end up contributing to high water waste. Also, a significant challenge in concrete production is the highly alkaline nature of the wastewater it generates, with pH levels often exceeding 12 (ChemReady, 2020) it's classified as dangerous. This elevated pH complicates efforts to reuse or recycle the wastewater, contributing to water pollution concerns.

Also, concrete production has become a significant contributor to global greenhouse gas emissions. Forthwith, it accounts for at least 8% of all worldwide CO2 emissions (Tigue, 2022). The increased demand for concrete has led to a substantial rise in production. Nowadays, around 30 billion tons of concrete are used annually on a global scale, with each one emitting up to 622 kg of carbon dioxide (Brogan, 2021) contributing directly to greenhouse gas emissions to the atmosphere. From a production perspective, on a per capita basis that is 3 times as much as 40 years ago (Nature, 2021).

Besides being strong and resilient, concrete becomes vulnerable when it is exposed to chemicals, water or weather for long periods of time (Kaushal & Saeed, 2024). The exposure can cause material deterioration, which is a problem that can significantly compromise the integrity and consequently structural safety of the buildings which are built by concrete.

2.3 Steel

Steel is a metallic alloy and its composition consists of approximately 98% to 99% iron and 1% to 2% carbon, as visible in *Table 2Table* (in Appendices). In its pure form, iron is soft and is not normally practical as an engineering material. So, there is a need to reinforce it. Its transformation into steel is carried out by adding carbon (Nutting, Wente, & Wondris, 2023) which is crucial to increasing the strength and durability of the iron.

2.3.1 Steel Production: BOF vs EAF (CO2 emissions and cost comparison)

Nowadays, steel is chiefly created through two fundamental processes: the basic oxygen furnace (BOF) and the electric arc furnace (EAF).

In the BOF method, also known as Blast Furnace, coal is utilized as the primary carbon source for steel production. This technique is commonly used for large-scale steel manufacturing and results in higher CO2 emissions due to the use of coke and the overall scale of operations. The EAF technique produces steel primarily from recycled steel scrap. This approach is generally more adaptable and environmentally friendly, with lower CO2 emissions compared to the BOF method.

The difference between the two processes is enormous. Comparing the CO2 emissions, BOF production has cradle-to-gate (CTG) CO2 emissions of 1,990 kg per metric ton (MT) of steel contrasting with EAF process that has CTG CO2 emissions of 270 kg per MT of steel (Zang, et al., 2023). The difference is also noticeable in terms of prices. BOF production costs $439 per MT, while a typical EAF process has a cost of $365 per MT, offering better economic viability.

In 2023, global steel production reached 1,849.7 Mt (million tons) (WorldSteel, 2021). Despite that, adopting the EAF method to produce steel is producing less landfill waste, using less energy and generating fewer emissions from production (Charter Steel, 2024) raising awareness of the contribution of the circular economy.

2.3.2 Advantages of Steel

Steel is considered one of the most widely used material in the world due to the innumerable properties that make it useful in various industries (Ulma, 2023). In the building construction sector, steel structures are characterized by being consistent, having great elasticity and being ductile (Structural Community, 2020). These characteristics make steel ideal for buildings applications, as it meets the requirements for ensuring long-lasting and resilient structures.

In the United States and the United Kingdom, the use of steel is more popular due to its use in large structures, such as industrial structures and skyscrapers, and is widely preferred over reinforced concrete due to its ability to withstand tensile forces and extreme specifications (FedSteel, 2023). Steel also allows greater architectural freedom and is a preferred choice for large urban projects, particularly those that need to be completed in short deadlines.

Nevertheless, reinforced concrete is a technique that combines steel and cement to form a highly resistant and versatile structure. The combination of the two materials merges their respective qualities, providing efficiency and structural safety. This technique is widely applied in public and housing infrastructure in Portugal, and when properly designed, reinforced concrete provides durability and the ability to support large structural loads (Almeida, 2022). This characteristic is crucial for building infrastructures in a country located in a region susceptible to earthquakes.

2.3.3 Disadvantages of Steel

Water plays a vital role in the entirety of all steelmaking processes. It is used extensively especially for cooling purposes and to clean exhaust gases in blast furnaces, for removing scale in hot rolling mills and mainly as a resource for steam production. Aquatic ecosystems can be significantly affected by the discharge of cooling water. The average water intake of an integrated plant is 28.6 m^3 per ton of steel produced, with the average water flow being 25.3 m^3 (World Steel Association, 2011).

Steel, despite being a material considered homogeneous and uniform, is susceptible to corrosion when freely exposed to air and water. This proves that steel requires high maintenance and periodic inspections. If that is not carried out, exposed steel can lose weight by up to 35% during its useful life (Structural Community, 2020).

On the other hand, material presents a significant vulnerability due to its susceptibility to fire. When the material is exposed to high temperatures, it can go through a softening process, compromising the resistance and rigidity found in its normal state. Additionally, steel is capable to transmit enough heat from a burning compartment of a building to start a fire in other parts of the building (Structural Community, 2020), so it is counterproductive to fireproofing.

2.4 Cross Laminated Timber

Cross Laminated Timber (CLT) is an innovative structural composite panel product developed in the early 1990s in Germany and Austria. CLT production has grown globally in recent years, with Europe leading the charge in its widespread adoption. In 2017, around 70% of global CLT production originated in Europe, with countries such as Germany, Switzerland and Austria making the most significant contributions (Ilgın, Karjalainen, & & Mikkola, 2023). On the other hand, in the markets of North America and Australia, although still at an embryonic stage, the introduction of CLT technology has been well received (Mallo & Espinoza, 2016). Expanding into these markets is expected to contribute to an increase in the material's use worldwide. Nowadays, the global CLT market is flourishing, with its value expected to reach 3.7 billion dollars by 2030, compared to its current value of 1.4 billion dollars, in 2024 (Analysts, 2024). As concerns about climate change and sustainability continue to grow, builders are increasingly turning to CLT as a greener alternative to traditional construction materials.

Cross-laminated timber (CLT) is made from multiple layers of kiln-dried lumber and commonly used wood species include pine, spruce and larch (WIGO, 2024). Each layer is bonded with high-strength adhesives to ensure durability and structural integrity. Then, layers are fitted perpendicular to the adjacent one. This method aims to follow a sustainable design which is surging in popularity fueled by consumer preferences, technological advancements and environmental conscious building practices (Albee, 2019). Afterwards, layers are pressed together under significant pressure to form a single, solid rectangular panel. Once the adhesive has set, the large CLT panels are cut to precise dimensions allowing to meet specific design requirements, being possible to manufacture panels up to 4.8m tall, 30m long and 60-500 mm thickness (Swedish Wood, 2019). This way of fitting offers new CLT application features such as be used as room dividing of construction such as walls, roofs and ceiling boards (Holzleimbau, 2010).

2.4.1 Advantages of CLT

The surge in popularity of CLT for construction likely stems from its many benefits, particularly its positive environmental impact. During its life time , CLT has the capability to store carbon dioxide (Younis & Dodoo, 2022) and at the end of its service time it can be used as biofuel replacing fossil fuel (Swedish Wood, 2019). Comparing to concrete production, if approximately 10% of cement were replaced with CLT, carbon emissions could be reduced by up to 750 million tons each year, which is a reduction of 2% of global emissions (Czigler, Reiter, Schulze, & Somers, 2020). So, it can be used as a concrete substitute, replacing a highly carbon-intensive resource with a renewable, low-carbon similar. In this process, wood acts as a carbon sink, sequestering carbon dioxide and helping to reduce greenhouse gas levels, making CLT crucial for mitigating climate change and promoting sustainable building practices.

Moreover, the production of CLT requires less energy contrasting with steel (McCutcheon, 2024). In a study was found that mass timber structures have a lower carbon footprint than steel structures. The mass timber structure has a carbon footprint of 2853 tons of CO2 which has a significant less environmental impact compared to a steel structure with a carbon footprint of 4478 tons of CO2 (Hemmati, Messadi, Gu,, Seddelmeyer, & Hemmati, 2024). CLT panels can also compete with other traditional structural materials (Swedish Wood, 2019), such as steel and concrete (D'Amico, Pomponi, & Hart, 2021), in the construction of buildings due their excellent stiffness and strength properties. Nevertheless, these characteristics also provide an excellent seismic response (Sandoli, D'Ambra, Ceraldi, Calderoni, & Prota, 2021), positioning CLT as a sustainable structural alternative.

In addition, CLT innovation offers the unique possibility of prefabricated 3D modules (Scalet T. , 2015) in addition to the standard 2D panels (also achievable with concrete), changing dramatically the paradigm and playing a critical role in project economics and competitiveness. Construction prefabrication is revolutionizing the sector by reducing construction times and on-site labor needs, transferring production to a more efficient factory assembly line and consequently minimizing the risk of accidents (Scalet T. , 2015). In this innovative construction model, CLT panels have structural performance like concrete but have a significant advantage due to their significantly lower weight (Swedish Wood, 2019). Notwithstanding, the lightweight nature of CLT provides cost savings across the entire building construction process, including foundation work, on-site handling and assembly (Falk, 2013) which translates to a more economical building approach. While concrete prefabrication is also common, CLT is becoming more popular due to its advantages in weight, sustainability, and ease of transportation (Melton, 2024). This popularity is further enhanced by the speed with which CLT buildings can be raised (Albee, 2019), resulting in economies of scale.

When exposed to fire, cross laminated timber panel chars on the surface to create a protective layer (Swedish Wood, 2019) demonstrating fire resistance. However, CLT's fire performance can be improved by incorporating fire retardant treatments into the material, such as plasterboard or a suspended ceiling flooring (Swedish Wood, 2019), which act as a complement.

Cross-laminated timber (CLT) offers a win-win solution across the construction sector. Lumber producers find new markets for their materials, while CLT manufacturers capitalize on the mass timber trend. Designers and builders benefit from CLT's design flexibility and strong performance, leading to faster construction and more project possibilities. Finally, occupants enjoy the livability and potential health benefits of living in a CLT structure as visible in *Table 3* (in Appendices).

2.4.2 Disadvantages of CLT

Transporting CLT material from production sites to the construction site may generate significant costs, especially when the locations are remote (Green Building, 2022). However, these shipping costs, although still high, become more bearable in large-scale orders. Therefore, ordering only a few units is a disadvantage, as the order ends up being relatively expensive.

On the other hand, CLT panels must be properly protected during installation, as any absorption of water by the boards can result in mold and rot (Green Building, 2022), although the glue on CLT boards is waterproof.

2.5 Bamboo

Bamboo is an all-natural and renewable resource (Fahim, Haris, Khan, & Zaman, 2022) and a type of grass that grows from its roots, which regrow quickly when cut, and does not require pesticides or herbicides to grow well. Some species can even grow at a staggering rate of five centimeters per hour, reaching a towering height of 18 meters in just three months (Emamverdian, Ding, Ranaei, & Ahmad, 2020). On the other hand, compared to conventional trees that take around 20 years to mature, bamboo only needs 3-5 years. The plant typically reaches its maturation phase in approximately 3-4 months and then reduces its growth in order to survive. Despite during the initial stages it exhibits rapid growth, as shown in *Table 4* (in Appendices), the deceleration occurs due to the difficulty to draw nutrients and water up from the soil to support the aerial parts of the plant (PlantIn, 2024). This plant which is used as construction material is reputed by being the fastest-growing plant on Earth (PlantIn, 2024), boasting a rich history as a building material dating back to ancient times. However, during the 1980s, there was a renewed interest in this multifaceted construction material (Manandhar, Kim, & Kim, 2019).

Bamboo forests represent 3.2% of the world's total forest area, covering a vast 36 million hectares across the world (Bose, 2019). Globally, there are approximately 1,500 different species of bamboo which grow in subtropical regions including China, South

America and Africa (Elliot, 2021). Furthermore, from an economic perspective, bamboo is a significant player in international trade, with an estimated value of 2.5 billion dollars in business carried out every year (Emamverdian, Ding, Ranaei, & Ahmad, 2020).

Bamboo's composition is characterized by having parallel fibers that act as bundles, while the high lignin content glues them together, distinguishing bamboo as a trump card (Stkikwood, 2020). This dense structure resists impacts and its flexibility bends under tension, absorbing the pressure and emerging unharmed. This construction material is commonly used as a substitute for steel due to its tensile strength, if it is protected from moisture penetration (Shine, 2023). In addition, the use of bamboo in building construction has twice the compression resistance of concrete (Zhao, Yu, Xu, & Guo, 2023). Due to its characteristics, from foundation to finish, bamboo can be used throughout a house building process, including structural walls, columns, roofs, doors and windows (Manandhar, Kim, & Kim, 2019) . This material offers sustainable and versatile construction material, being a viable alternative to the traditional building materials (Tan, et al., 2011).

2.5.1 Advantages of Bamboo

Bamboo swanks impressive environmental credentials playing a crucial role in regulating atmospheric oxygen and carbon dioxide (Bioproducts, 2022) being distinguished as an energy saver. Annually, a single hectare of bamboo can be a carbon-sequestration powerhouse, absorbing up to 17 tons of carbon dioxide (Bose, 2019) helping combat climate change. Also, processing bamboo only requires 1/8 of the energy that concrete needs and barely 1/50 of the amount of energy used in steel’s production (Roach, 1996) to create a building material with similar capacity. Besides, it has a remarkable versatility making it a popular choice for production of fuels like ethanol with a smaller footprint than fossil fuels (Bioproducts, 2022).

Furthermore, the material possesses thermal insulation characteristics, which implies it can assist in maintaining the temperature. This results in a cooler atmosphere during the summer and a warmer, more comfortable setting in the winter (Li & Yao, 2017). This is vindicated by its cellular structure that concedes exceptional thermal insulation properties due to its cavity filled with entrapped air (Bonivento & Vieira, 2017), a low thermal conductor.

Favorable elastic properties and resistance make bamboo a highly suitable building material in seismic and disaster-prone areas (Paudel, 2008). This attributes offers highly earthquake resistance, withstanding up to 7.6 on the Richter scale (Jayanetti, 2005). Also, bamboo has high-water content, so it possesses natural fire resistance. When it's treated with organic compounds, the resistance is slightly enhanced, allowing bamboo to withstand temperatures up to 400 degrees Celsius (van de Heuvel, 2023), showing durability abilities to withstand.

2.5.2 Disadvantages of Bamboo

In its natural state, bamboo has a disadvantage as it becomes a buffet for insects and fungi. Furthermore, direct contact with the ground can lead to the decomposition of the material within approximately one year (Jayanetti & Follett, 2008) realizing its greatest weakness (Silverman, 2024). Therefore, protection by design is crucial to unlock the full potential of this material. This includes the application of measures such as keeping the bamboo dry, out of the ground contact and ensuring good air circulation and visibility (Jayanetti & Follett, 2008).

On the other hand, while bamboo has a competitive price compared to other hardwoods, the sustainable material continues to be more expensive than traditional ones, such as steel or concrete (Coastal Custom Products, 2023).

3. PORTUGAL: CURRENT STATUS OF TRANSITION TO SUSTAINABLE BUILDING

The objective of this chapter is to provide an overview of the indicators and evidence that shape the construction sector in Portugal. This includes a close look into the sector's current state, the dominant materials used in building construction and the status of the adoption of sustainable building materials such as CLT and bamboo.

3.1 Overview of the Building Sector: Some Major Indicators

Domestic Material Consumption (DMC), a metric gauging a nation's total resource utilization allows to evaluate the efficiency of materials use. Portugal reached 162.7 million tons in 2022. This means a decline of 10.5% compared to 2021 and a 0.9% dip relative to the average value for the 2012-2021 decade. Non-metallic minerals, which are heavily used in construction, account for the largest share of DMC, at around 60.7% in 2022, as observed in *Graphic 1* (in Appendices). Despite the overall decrease in DMC, Portugal's per capita DMC still contains higher than the Horizon Europe 2027 objectives average as its visible in *Graphic 2* (in Appendices). In 2022, Portugal's per capita DMC was 15.8 tons, while the EU-27 average was 14.4 tons per capita. The difference between the two variables under study means that there was a greater expenditure of resources in Portugal contributing to a lower efficiency compared to the EU-27 (REA, 2024).

In Portugal, the Construction Production Index observed a rise of 2% in 2022, following a 3% increase in 2021 and a 3.3% decline in 2020. The two components of the index, Civil Engineering and Building Construction, demonstrated trends aligned with the aforementioned index, as illustrated in *Graphic 3* (in Appendices). Both segments exhibited growth rates of 2.0% and 2.1%, respectively. This trend indicates that the construction sector is on a steady path to recover from the decline observed, after the early COVID-19 impact.

In Portugal's territory, 20% of national energy resources and 6.7% of water consumption stems from residential buildings and services uses (CCDR LVT, 2019). This shows that this sector is a huge consumer of these resources in the country. The percentages observed are intrinsically linked to the main materials used, which are concrete and steel. Consequently, its large-scale production and use, reinforces the need to prioritize resource efficiency in the Portuguese building sector.

3.2 Portugal Construction Sector

The construction sector in Portugal obtained positive values compared to the previous year. This is proven mainly in the Construction Production Index whose increase was 2%, perhaps employment increased by 3.5%, GVA increased by 0.7% and investment was 0.8% higher compared to 2021, visible in *Table 5* (in Appendices).

In addition, this economic sector represented 6.4% of total employment in 2022 in Portugal. Since 2013, the GVA variation rates were negative until 2015, when the rate was zero. In the following years, only positive values were recorded until 2020, when the zero value was recorded again and from then on, the values remain positive, revealing a large oscillation in the last decade, as perceived in *Graphic 4* (in Appendices). Regarding quantitative data at the end of 2022, the number of valid licenses for construction activities increased by 4002 and the number of valid certificates increased by 1605 compared to 2021 (IMPIC, 2023).

Analysis of the construction sector from a production perspective is, therefore, essential to understand the existing and historical economic dynamics of the sector. It’s possible to notice that the construction sector shows a decrease of more than double the percentage value of GDP from a production perspective between 1982 and 2022 (11% and 4.4%, respectively), by observing *Table 6* (in Appendices).

The sharp decline is justified by the various economic crises throughout the aforesaid period that severely affected the construction sector, especially with the financial crisis of 2008. This had a huge impact on the Portuguese economy, which ended up resulting in a drop in financing and investment in the sector. Furthermore, the Portuguese economy has diversified over the years. There has been an increase in the importance of sectors such as tourism, technology and services. Another plausible justification is the changes in buildings construction policies that increased the costs and consequently the complexity of new construction projects, discouraging new investments in the sector, reducing the need for new construction. Furthermore, in 2021, the construction sector presents a total of 8,620 million euros compared to the 9,166.2 million euros recorded in 2022, as can be seen in *Table* 7 (in Appendices).

In Portugal, demographic census studies, known as *Census*, are carried out every ten years. The last study was executed in 2021. Therefore, we take now a longer perspective, taking in consideration these 10 years periods. There was a peak in construction in Portugal between 1961 and 1980 where 967,182 buildings were built (approximately 27.1% of the total) visible in *Table 8* and *Table 9* (both in Appendices). This period had the highest number of constructions, indicating a significant boom in civil construction, which in turn reflected urban expansion in Portugal. From 1981 onwards, a steady slowdown in the number of new buildings constructed in each subsequent decade is notable. The period 2011-2021 was the one with the lowest number of constructions (representing just 3.1% of the total). The visible decrease in the number of new building constructions in Portugal in recent decades is naturally related to what was previously mentioned. Next, it is clear to notice that the total of existing buildings in Portugal, more than 99% are residential, 3,572,128 contrasting with only 1,288 non-residential, after viewing *Table* (in Appendices).

3.3 Portugal's Dominant Materials Used in Civil Construction

There has been a constant evolution over the centuries in civil construction, observable in *Table* (in Appendices). The development of different typologies in house construction in Portugal mirrors the nation's toughness and resourcefulness throughout requirements and markable events. After the 1755 earthquake, profound changes occurred. In the past, the materials used were primitive and did not provide safe and livable conditions for people. After that huge disaster, there was not only a change in materials but also in structures. In fact, a housing transformation took place as a result of the use of different materials as anti-seismic prevention. Although used in different ways, stone is a traditional material that has been one of the most used in Portugal for more than 200 years. Meanwhile, in Portugal, materials such as stone, wood and earth have been replaced by materials like industrial iron (component of steel), cement, concrete and glass (Andrade, Aleixo, & Faustino, 2019). This transition started to occur during the 1940s not only with a change in the building materials but also in structural systems and construction typology. Despite the constant development once envisioned, the introduction of concrete created a huge sensation in Portugal. Very quickly, it became the preferred material used, standing out for its ability to increase the speed and stability of construction levels. The importance of the material was such that it is dubbed as the material of the 20th century (Nero, 2022). This constituted an increase never seen in the construction of buildings in Portugal perceived in *Table 8* and *Table 9* (both in Appendices). The importance of concrete in Portugal is still visible today, with 65% of the total concrete produced being used for the construction of residential buildings (APEB, 2024), and as a result, it is the most used construction material in the country.

Currently, there are three techniques that dominate the construction of houses in Portugal, which are masonry, LSF and CPRC, as shown in *Table 12* (in Appendices). These techniques incorporate concrete, confirming the thesis that Portugal's buildings are mostly built by concrete, apart from LSF, which is an alternative to the use of this material (Idealista, 2024), using steel. These techniques used in Portuguese construction and the materials applied in building construction since 1940 contributed significantly to ensuring that the architectural heritage remained practically unchanged for 80 years. In an era that is increasingly moving towards sustainable construction through the use of innovative technologies, there are no significant disruptive changes in civil construction in Portugal.

3.4 Portugal's Housing Crisis

The movement of a considerable part of the Portuguese population to the large urban centres, Lisbon and Porto, also known as rural exodus, culminated in a severe depopulation of towns and villages, leaving behind a large number of abandoned houses in the interior of the country (Rodrigues, 2022). Currently, Portugal faces criticism of its housing shortage, which has worsened in recent years due to the imbalance between the explosion in demand, in the big cities for housing and the anaemic supply (Martins, 2024). That said, in Portugal there aren't houses in the urban centres at affordable prices and compatible with family salaries (Oliveira, 2024), even though some are deteriorating and are in unsafe conditions. Therefore, the concept of technology fix emerges as a possible answer to this problem. Instead of building new houses or demolishing the abandoned ones, the rehabilitation of these properties using sustainable materials and sustainable construction techniques can be a more efficient alternative, increasing the supply of housing, promoting the rehabilitation and even reducing the price of houses (Sousa, 2024). Possible solutions in order to mitigate housing crisis are the investment in different construction materials, cheaper and more efficient, and resorting to prefabrication (Construir, 2024), thus CLT and bamboo are correspondences.

3.5 CLT in Portugal

The use of the CLT construction method in Portugal is relatively recent and it was once seen as an expensive and uncommon option due to the need to import wood from long distances and its associated high prices (Guerreiro, 2023).

Although CLT has intrinsic qualities and a lower environmental impact compared to concrete and steel, in Portugal, until then it was a primitive method that was only available in a very restricted segment, without any significance in the Portuguese market. In recent years, despite the emergence of new companies in the sector and consumers becoming increasingly more informed and no longer limited to traditional materials (steel and concrete), but also recognizing the advantages of the sustainable construction material, the numbers are not relevant at a national level. Only in 2023 was reported that the construction of CLT houses 100% produced in Portugal began in Portuguese territory in 2023 (Diário Imobiliário, 2023), in what could be the first big step towards establishing this material in the Portuguese market. The pioneering companies sought to innovate with a view to sustainability in order to fill a gap in the market. Therefore, its insertion into the Portuguese market aims to change the productivity of CLT construction in Portugal, which is still considered very low. On the other hand, through the use of this material, a house takes an average of two years to build, with CLT technology it reduces the average time to around five to six months (Figueiredo, 2023), reducing time and costs.

In this way, awareness and an increase in local wood production accompany greater accessibility to the resource transforming it into a more affordable construction option, mitigating possible high transport costs and external dependence. More, the vast forest area that covers Portugal, with around 36% of the national territory and totaling more than three million hectares, places the country above the global average in terms of the proportion of territory covered by forests (Florestas, 2022). The development of the timber construction sector not only demonstrates its potential, but also highlights its significant ability to influence sustainable forestry practices in the face of a heritage that can translate into a competitive advantage. Portugal faces the challenge of, if the paradigm changes to the increased use of CLT, harmonizing environmental preservation with needs that include the demand for wood for construction. This scenario also reflects a growing interest in the use of national raw materials (FLORESTAS, 2024), contributing to the valorization of local resources and promoting a more sustainable construction sector that is less dependent on exports.

3.6 Bamboo in Portugal

In temperate climates, such as Portugal, there are less favorable conditions for the development of fungi (previously referred as a disadvantage to the use of bamboo) compared to tropical ones. Furthermore, the degradation of the material is also not as serious because the relative humidity of the air is considerably lower, resulting in a competitive advantage for Portugal. Besides that, bamboo as a construction material, has no significance in the Portuguese market.

Related to this, Portugal does not have relevant resources of this material. This leads that countries that have local bamboo resources are the few that have legal bases for construction with the material. An engineer or organization in a country without bamboo resources is considered mandatory to rely on legislation adapted to the conditions and characteristics of a country other than their own (Pereira, 2017). Currently, Portugal does not have specific national standards that exclusively regulate the use of bamboo as a construction material. However, a set of international standards and local guidelines adapted to the national reality are followed to ensure adequate use. Portugal operates within the following framework of international economic and commercial standards:

- ISO 22156:2004 - establishes requirements to ensure the safety and efficiency of bamboo constructions;
- ISO 22157-1:2004 & ISO 22157-2:2004 - define the methods used to evaluate the physical and mechanical characteristics of bamboo;

However, ISO standards are still the first step in the construction sector needing to be updated and improved (Pereira, 2017) so that they can be implemented in Europe and serve as support for engineers.

Although Portugal is ruled by international standards, there are also local guidelines adapted to the national reality that come from results obtained by academic studies (still considered embryonic) and by organizations, such as the Portuguese Environment Agency (APA) (Pereira, 2017). These local standards essentially seek to promote the use of sustainable materials through the adaptation of international standards to the Portuguese context (Soares, 2013).

3.7 Portugal and Sustainable Construction

Portugal's duty to sustainability is aligned with the global objectives established by the Paris Agreement, having been the first nation in the world to make this commitment (Silva & Fernandes, 2016), aiming for carbon neutrality by 2050. To meet the goals of the Paris Agreement, Portugal developed the National Energy and Climate Plan 2021-2030 (PNEC 2030), which establishes objectives for an energy transition and a reduction in greenhouse gas emissions, as the sector of civil construction, responsible of 20% of national energy resources, is considered one of the main contributors to energy consumption. Furthermore, Portugal also adopts the European Standard EN 15804, which provides a framework for the Life Cycle Assessment (LCA) of construction materials. This standard is crucial for sustainability in building construction, as it allows the environmental impact of the materials used to be assessed and reduced.

4. METHODOLOGY

The objective of this thesis is to analyze the transition from traditional materials to sustainable materials in the construction of buildings in Portugal. For this, the time horizon defined was 2050 as it is a sufficient period for possible major changes to occur in the sector. In this context, 2050 also marks the year of the end of the Paris Agreement to achieve carbon neutrality, a goal that Portugal is committed to.

Given the complexity of the topic and the diversity of actors involved, a methodological approach that incorporates both qualitative and quantitative data collection for subsequent analysis was employed. This dissertation adopts an exploratory perspective in an attempt to answer to our initial research questions. Therefore, the present study was carried out using two different questionnaires to evaluate two different views. The questions were closed-ended, with easy-to-understand language to be understood by all respondents (Barnett, 1991).

The first questionnaire **(Q1)** was aimed at companies that are included in the sector, operate in the construction market and have experience in building construction projects in Portugal. The scope of its preparation focused on understanding the perceptions and opinions of companies on the forecast and challenges of the transition to a more sustainable construction model, by using materials like cross-laminated timber (CLT) and bamboo by 2050. The questionnaire was created online (via *Word*). First, a telephone call was made to the companies using the contacts that are available online. Then, the objective was presented and subsequently their availability to participate in the questionnaire was asked. Contacts were made to the companies that are included in the Ranking of Companies list in the building construction sector (residential and non-residential) from *Dinheiro Vivo* website. Then, the questionnaire was sent by email. In the end, 120 emails were sent, obtaining a total of 20 responses, with the response rate from companies recorded at 16.67%.

Type of enterprises surveyed

Micro Enterprise	0
SME	18
Large Enterprise	2

Table 13 - Type of enterprises surveyed (source: own elaboration)

The sample is mainly made up of SMEs, with 18 interviewees, leaving the focus of the investigation on these types of companies. On the other hand, only 2 large companies participated in the survey, indicating that these types of companies may have been less accessible or less interested in participating. Thus, no micro enterprises were included in the sample.

Geographic location of the companies surveyed

Lisbon	8 (40%)
Porto	4 (20%)
Setúbal	5 (25%)
Aveiro	2 (10%)
Guimarães	1 (5%)

Table 14 - Geographic location of the companies surveyed (source: own elaboration)

In terms of geography, most companies are based in the districts of Lisbon, Porto and Setúbal. Even though there is a concentration in the aforementioned regions, the research included companies from other districts, such as Aveiro and Guimarães, which contributes to a greater geographic coverage of the investigation. However, the study has the following limitations: only 20 companies responded to the questionnaire and only companies from 5 of the 18 existing districts were included. In other words, the sample is considered small and doesn't allow generalizing the results to all Portuguese companies.

The second questionnaire **(Q2)** was directed at the general community. This was carried out with the aim of measuring the interests of the community related to sustainable construction, recognizing the flip side of the coin by understanding the "consumers" preferences. The questionnaire was created online (via *Google Forms*) and has 217 responses. The respective link was sent to family, friends and acquaintances. However, the means of dissemination used was social media, namely *Instagram* and *Youtube*, in order to increase its reach.

To conduct the interview, an informal telephone interview was previously scheduled with engineer Jorge, from the company *Imperalum*. The questions were asked while answers were recorded using notes in real time.

5. Discussion of results

5.1 Results of Q1

Q1Q1 - Has the company ever been involved in construction projects that use bamboo and CLT?

Yes	3 (15%)
No	17 (85%)

Table 15 - Has the company ever been involved in construction projects that use bamboo and CLT? (source: own elaboration)

After analyzing the answers of the first question it is possible to observe that only 15% (3 companies) have already carried out their activities with a view to the sustainability of buildings, not using traditional materials. On the other hand, and in contrast, 85% (17 companies) have never had any contact with sustainable materials, nor when including them in building construction projects. Through this sample, it is understandable that despite their benefits presented in the literature, they are not yet widely disseminated in the Portuguese market.

Q1Q2 – What are the main obstacles in changing to sustainable materials?

Option	Obstacle	Number of times mentioned	
A	Lack of specific legislation	3	
B	Lack of know-how	10	2nd & 3rd Place
C	Lack of specialized labor	10	2nd & 3rd Place
D	Lack of economies of scale	5	
E	Lack of consumer knowledge	9	
F	Resistance to changes	14	→ 1st Place
G	Supply limitation	4	
H	Little investment	4	
I	Change in assets	0	
J	Aesthetic requirements	1	

Table 16 - What are the main obstacles in changing to sustainable materials? (source: own elaboration)

Regarding question 2, the three main obstacles identified were: firstly, resistance to change with 14 references. Then, lack of specialized labour and lack of know-how are the other two obstacles identified, having obtained the same references equally, 10 each. The choice made by companies is extremely relevant because it reflects the existing reality in the building construction sector. This reality is characterized by being rooted in habits and practices that have been consolidated for years or decades. It also indicates the need for a continuous effort to educate and raise awareness of everyone involved in the construction process about the benefits of material transition through sustainability. The lack of know-how highlights the need for investment in R&D and insufficiency of knowledge dissemination in the construction sector. On the other hand, the lack of specialized labor reveals a gap in the supply of existing human resources. Through this question, is clear that there is a deficit of professional training courses and programs that address the specificities of sustainable construction materials and techniques.

Q1Q3 - Which material performs best as a thermal insulator?

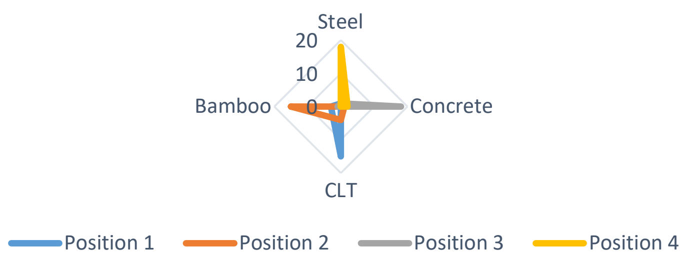

Table 17 - Which material performs best as a thermal insulator? (source: own elaboration)

Through the answers to question 3, it is possible to highlight that the material considered the most insulating is CLT. Subsequently, bamboo occupies the second position and in third and fourth place were concrete and steel, respectively. Therefore, it is interesting to highlight that according to the results, for companies, sustainable materials are considered more thermal insulators than traditional materials.

Q1Q4 - Which material has the best seismic performance?

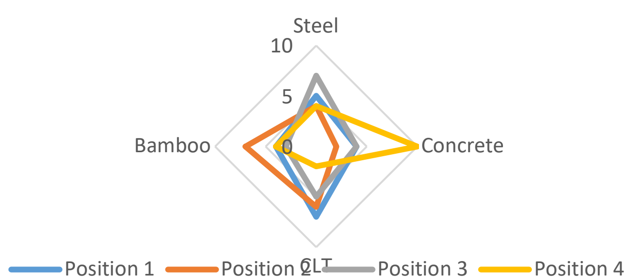

Table 18 - Which material has the best seismic performance? (source: own elaboration)

Addressing question 4, for companies the least vulnerable material is CLT. In the next position is bamboo, followed by steel in third place, and concrete in fourth place. According to the results presented, it is possible to note that, for companies, sustainable materials were classified as the least vulnerable to earthquakes compared to traditional materials.

Q1Q5 – Can the transition to sustainable materials mitigate the existing housing crisis in Portugal?

Invalid	0 (0%)
Partially Invalid	8 (40%)
Neutral	5 (25%)
Partially Valid	7 (35%)
Valid	0 (0%)

Table 19 - Can the transition to sustainable materials mitigate the existing housing crisis in Portugal? (source: own elaboration)

Regarding question 5, there were no definitive responses from companies, as neither "Invalid" nor "Valid" answers did not have any votes, being represented by a rate of 0%. Furthermore, 25% of companies (5 companies) chose the "Neutral" option, admitting a paucity of sufficient information revealing a lack of strategic vision on the part of these companies. The remaining responses were quite balanced, with a division. On the one hand, 35% (7 companies) admit that this scenario is partially invalid, believing that although there are benefits, such as reduced costs and construction time, they are insufficient to solve the housing crisis. On the other hand, 40% (8 companies) believe that the scenario may be partially valid. Thus, companies admit that the problem of the housing crisis is broad but that sustainable construction through the transition of materials can really be a tool or a starting point.

Q1Q6 - Can sustainable materials compete with traditional ones in terms of performance to fire?

Agree	3 (15%)
Partially Agree	11 (55%)
Neutral	3 (15%)
Disagree	3 (15%)

Table 20 - Can sustainable materials compete with traditional ones in terms of performance to fire? (source: own source)

Observing the table, only 15% (3 companies) disagreed with the question asked and another 15% (3 companies) abstained, giving a neutral response. However, 70% (14 companies) positively defend the question asked, as they agree or partially agree that bamboo and CLT have intrinsic properties that can compete with concrete and steel. Through these results, it is possible to understand that there is agreement on the part of companies with the literature. In an individual analysis, the vast majority partially agree, 55% (11 companies) meaning that they recognize the fire resistance of sustainable materials, such as CLT and bamboo, but that more R&D is needed, particularly in the treatment of materials to achieve more competitive results.

Q1Q7 - Can the competitive advantages of bamboo and CLT facilitate the expansion of the use of these materials in civil construction?

Yes	7 (35%)
No	13 (65%)

Table 21 - Can the competitive advantages of bamboo and CLT facilitate the expansion of the use of these materials in civil construction? (source: own elaboration)

Considering question 7, it is possible to verify that 35% (7 companies) responded positively arguing that Portuguese forests together with its temperate climate offer a solid basis for innovation and the use of local materials in civil construction. In turn, these factors end up driving a cycle of economic development and environmental conservation until 2050. On the other hand, 65% (13 companies) highlight the fact that facilitating the use of materials is negative. In this way, they legitimize that the competitive advantages listed, although significant and relevant, may not be sufficient to overcome the obstacles presented in Q1Q2 by 2050.

Q1Q8 - Do you believe that in 2050 there will be a model that favours sustainable materials over traditional ones, through the use of CLT and bamboo, in Portugal?

Impossible	1 (5%)
Little Possible	12 (60%)
Possible	5 (25%)
Very Possible	2 (10%)

Table 22 - Do you believe that in 2050 there will be a model that favors sustainable materials over traditional ones, through the use of CLT and bamboo, in Portugal? (source: own elaboration)

As shown in the previous table, 60% (12 companies) consider this transition to be little possible, explaining that it could increase usage but maintain a completely secondary role. Subsequently, 5% (1 company) claim that it will be impossible for a transition model that favors sustainable materials over traditional ones. However, 25% (5 companies) believe it is possible and 10% (2 companies) believe it is totally possible to exist a model that favors sustainable materials by 2050. Based on these results and performing a percentage agglomeration, 65% of companies are not convinced about the transition from traditional to sustainable materials while 35% of companies are convinced or partially convinced.

5.2 Results of Q2

Looking at the *Table 23* (in Appendices), it is understandable that 13% (28 people) have no interest in living in houses built with sustainable materials. In contrast, 12% (26 people) showed a lot of interest. In the middle term, 29% (63 people) chose option 3, which can be considered an average interest. Furthermore, 19% (41 people) and 27% (59 people) rated this issue as little interest and some interest, respectively. By agglomerating percentages between interest 3 and interest 4, this represents 56% of the total, meaning more than half of the samples collected. Thus, it is possible to understand that community interest can be qualified as medium/some interest, which is considered positive. Their answers to this question emphasize that they are predisposed to live in a building or house built with sustainable construction materials, such as CLT and bamboo.

Regarding *Table 24* (in Appendices), is clear that the least voted option belongs to thermal insulation, which represents only 13% (28 people). Nevertheless, fire resistance constitutes 14% (31 people) while seismic performance represents 17% (37 people). On the other hand, rapid construction accounts for 30% (65 people) and the reduction in construction costs represents 26% (56 people). These last mentioned characteristics are visibly highlighted by the community, offering results completely different from the other choices presented, being the community's preferred options.

Examining the results of *Table 25* (in Appendices), it is conceivable to infer that 63% (137 people) answered yes while 37% (80 people) replied no. In this way, it can be emphasized that the community strongly believes in the transition from the use of traditional materials to sustainable materials in the construction of buildings in Portugal by 2050.

5.3 Engineer Jorge Interview

In the first question (I1Q1) it was questioned if it is realistically achievable that most building construction projects in 2050 could be made from sustainable materials such as CLT and bamboo. According to the interviewee's response, it can be understood that in building construction sector, in Portugal, the companies have moved towards sustainability only in terms of complying with legislation and inspections that have been increasingly stricter over the recent years. Even so, the transition of materials by Portuguese companies appears to be a slow process, and therefore, the deadline of 2050 is characterized as short due to the involving complexity that characterizes the transition.

Respecting the second interrogation (I1Q2), the engineer mentions that the expansion of large-scale production and the use of forest materials in construction could deplete resources from existing forest areas, compromising biodiversity and coming into conflict with agriculture. Despite this, engineer Jorge suggests that forests could be replaced by monoculture tree plantations for timber purpose, offering great potential for forest materials, but considering a careful and holistic approach to the environment. The interviewee thus proposes that the production of forest materials for construction could reach a maximum limit, restricting their availability and consequently production. He also advocates the development of public policies that legislate the sustainable use of forestry materials in construction in order to boost this competitive advantage.

The engineer's answer to the third question (I1Q3) states that the transition from traditional materials to sustainable materials is not enough to mitigate the housing crisis in Portugal. He also refers to the fact that the existing crisis is a complex problem that is entirely influenced by other sectors of activity. Even if construction costs using sustainable materials show an increase in demand, it is not necessarily the solution to the problem of affordable housing. Pombo highlights that to face the housing crisis, it is essential to adopt a multidimensional approach, like a combination of efforts involving policies aimed at different sectors of the economy and society. Engineer Pombo also emphasizes that the transition to sustainable materials, due to their characteristics, can be an important piece, but there is a puzzle that is the housing crisis.

Concerning the fourth question (I1Q4), engineer Pombo analyzes the differences of opinion (visible in Q1Q8 and Q2Q3) that occurred between companies and the community regarding the transition to sustainable materials in the construction sector in Portugal by 2050. Although the community expresses belief in this transition, as awareness about sustainability is increasingly implemented in society, the execution of this transition on a large scale by 2050, for the interviewee, is considered premature, as the community does not consider all the existing complexities of the process. Therefore, engineer Pombo also reports that the transition to a model of using sustainable materials in the construction of buildings is a complex process that requires significant changes in several aspects. These include the companies themselves, construction methods, qualified professionals and training. Even though there is an argumentative difference, for the engineer, the opinion of the companies prevails, as it is based on the obstacles faced daily and on realistic facts.

6. CONCLUSION

This chapter attempts to provide answers to the initial research questions – which were: how it is the transition in Portugal for more sustainable building; and, what are the prospects for the diffusion of this new paradigm –looking at the main conclusions of the previous chapters, trying to integrate them now. As highlighted before, this dissertation was not based on quantitative methods, rather it is essentially exploratory study on the perspectives of diffusion of the new paradigm.

The Paris Agreement endeavor is to achieve a net zero level of emissions by 2050. As it was seen in this dissertation, the materials used in the construction of buildings have enormous implications for global emissions of harmful gases. The transition to the use of sustainable materials in the construction of buildings aims to minimize the environmental impact throughout the life cycle of the building, contributing to the achievement of the 2050 net zero emissions objective, with which Portugal is aligned. It must be pointed out that this transition to more sustainable materials can be perceived as a Schumpeterian process of creative destruction. By replacing traditional materials with sustainable alternatives, it generates new business opportunities and boosts economic growth, while at the same time the companies that don't have the capacity to adapt to the new innovations will get out of business.

The transition to sustainable technologies is happening very fast in the renewable energy sector, which is intrinsically linked to photovoltaic panels that are extensively used in residential buildings. The rapid diffusion of these technologies is essentially due to the economic advantages inherent to their use (Lovegrove, 2023). Once positioned, these can remain on the roofs of buildings for decades without wasting resources, costing almost nothing, and generating power (The Economist, 2024) capable to make buildings self-sufficient. In sum, this revolution leads to the adoption of more sustainable technologies in the construction of buildings.

The research results reveal that in addition to being economically viable for business companies, CLT and bamboo are considered superior to traditional ones offering greater resistance to seismic activities, presenting less vulnerability to the fire with the appropriate treatments and having better thermal insulation. This perception indicates that companies believe what was reported in the literature review, that the intrinsic properties of these materials can compete with concrete or steel in terms of performance and application in building construction.

Through the research carried out, it's corroborated that the members of the target community express medium/some interest in living in a house built with sustainable materials, providing a good indication of social acceptance for the transition to occur.

Despite the numerous benefits of sustainable construction materials, is clear that the change towards sustainable building will not be enough to solve the problem of the housing crisis in Portugal, being considered just one piece of a puzzle.

The research also revealed that construction companies expressed skepticism and resistance to change in relation to the transition to more sustainable materials. The companies showed aversion to risk, preferring solutions with short-term results and maintaining their *modus operandi* by not adopting innovative and sustainable solutions. The difficulty of the transition also stems from the fact that the Portuguese construction sector is deeply rooted in decades of established habits and practices. In a broader approach, the most used building construction materials in Portugal remained unchanged for 80 years, with concrete and steel still dominating up to the present. On the other hand, in Portugal, the use of sustainable materials is still in an embryonic phase and therefore is considered unimportant at a national level. Despite there being a potential for growth in the bamboo and CLT market, combined with the existence of sustainable benefits in their adoption and associated with the competitive advantages that Portugal has, the 2050 deadline is considered short and premature.

In conclusion, through the characterization of Portuguese companies and the current *status quo* of the building construction sector in Portugal, the transition from traditional materials to sustainable materials looks like that will not happen by the target date of 2050.

This dissertation leaves points that remain open. As a result, a suggestion for future investigations is that there is the need for more systematic and detailed studies, namely collecting appropriate statistical data with the purpose of carrying out a quantitative analysis in order to estimate diffusion models.

Based on the deep-rooted characteristics of the building construction sector and the resistance to change identified in this dissertation, it is recommended that companies adopt a holistic strategy to raise R&D, knowledge and instruct their employees to implement sustainable practices. On the other hand, it is suggested that public policies be aimed at offering tax incentives and financial support in order to create a culture of change that can be observed in the long term in Portugal.

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8. APPENDICES

Table 1 – Concrete Composition

Concrete Composition

Material Type	Cement	Water	Aggregates (sand & gravel)
Value (~%)	(10 – 15 %)	(15 – 20 %)	(65 – 75 %)

Table 1 - Concrete Composition (source: Chart Industries)

Table 2 – Steel Composition

Steel Composition

Material Type	Iron	Carbon
Value (~%)	(98 - 99 %)	(1 - 2 %)

Table 2 - Steel Production [source: ((Britannica, 2024)*]*

Table 3 – Benefits of CLT use from stakeholders

Benefits of CLT use from stakeholders:

Stakeholder	CLT Producer	Designer	Builder	Occupants
Advantages	• Flourishing market • Environmental performance • Construction speed • Structural performance	• Design flexibility • Market opportunity • Cost competitiveness	• Construction Speed • Cost competitiveness • Environmental performance • Design flexibility	• Cost competitiveness • Cost speed • Livability

Table 3 - Advantages of CLT use from stakeholders (source: (Albee, 2019))

Table 4 – Bamboo’s Growth Rate

Bamboo’s Growth Rate

Time	Growth
per minute	~ 0.6 mm (0.025 inches)
per hour	~ 4 cm (1.5 inches)
per day	~ 89 cm (35 inches)
per week	~ 6 m (20 feet)
in a year	~ 30 – 45 m (100 – 150 feet)

Table 4 - Bamboo’s Growth Rate - (PlantIn, 2024)*)*

Table 5 – Portugal Construction Sector in 2022

Portugal Construction Sector in 2022

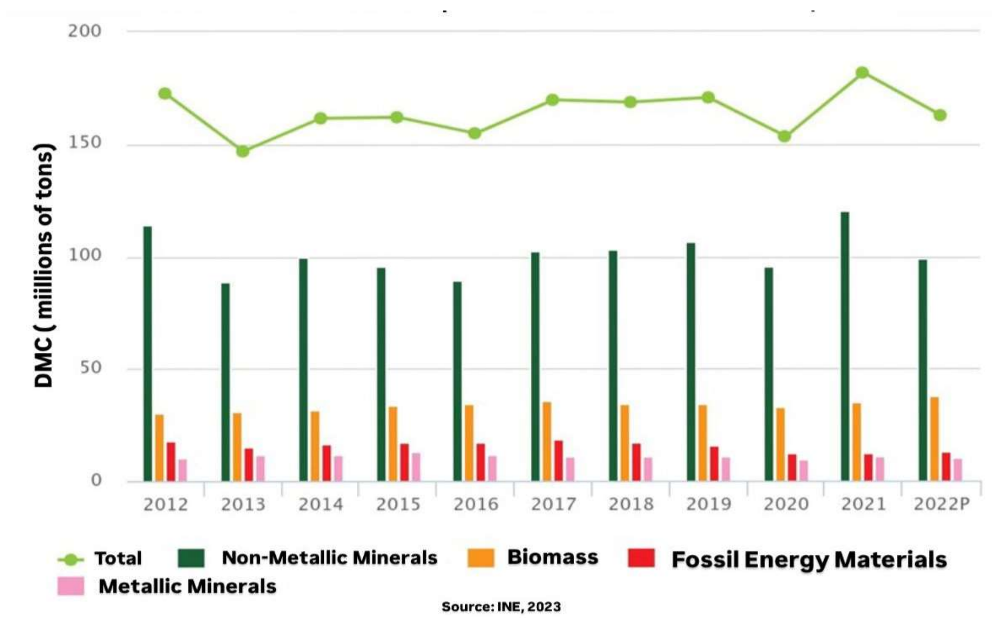
Construction Production Index	Investment	Gross Value Added (GVA)	Employment	Qualifying Titles	Valid Permits
⬆ 2 % *	⬆ 0,8% *	⬆ 0,7% *	⬆ 3,5% *	⬆ 7,1% *	⬆ 7,8% *

*- variation referring to the previous year (2021)

Table 5 - Portugal Construction Sector in 2022 (source: ((IMPIC, 2023)*)*

Graphic 1 - Evolution of DMC - total and main components

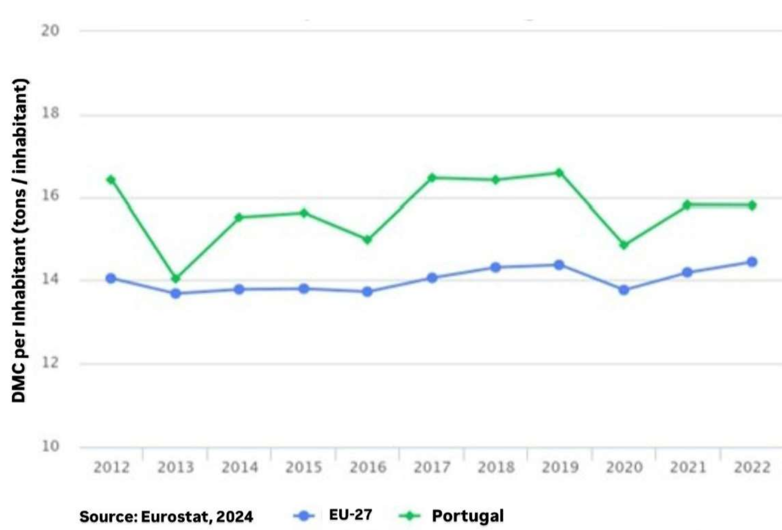
Evolution of Domestic Materials Consumption - total and main components



Graphic 1 - Evolution of Domestic Materials Consumption - total and main components (source: INE)

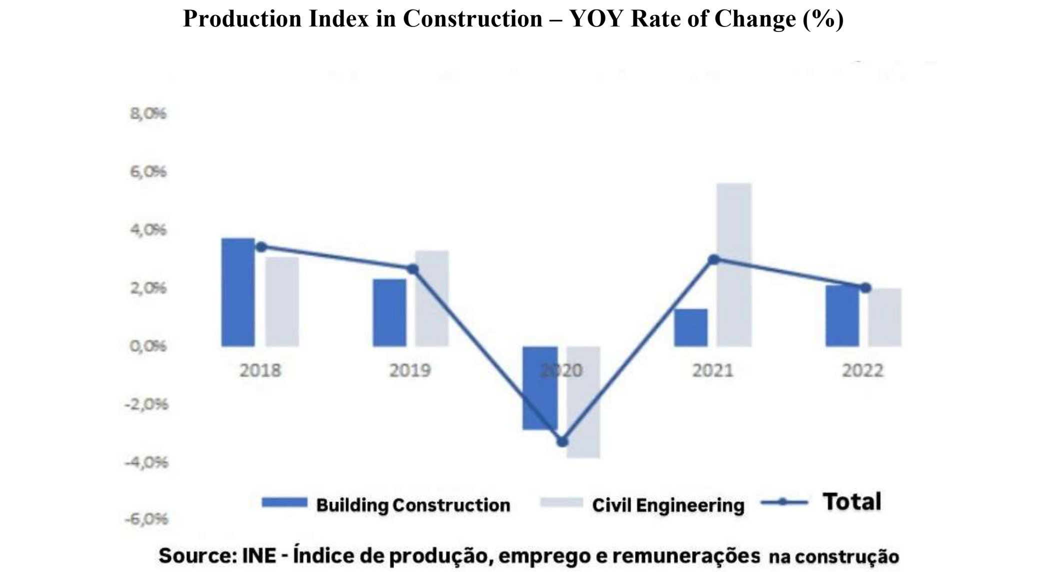
Graphic 2 - Evolution of DMC per inhabitant – Portugal and EU-27

Evolution of DMC per inhabitant – Portugal and EU-27



Graphic 2 - Evolution of DMC per inhabitant – Portugal and EU-27 (source: Eurostat)

Graphic 3 - Production Index in Construction – YOY Rate of Change (%)



Graphic 3 - Production Index in Construction – YOY Rate of Change (%) (source: INE)

Graphic 4 - GVA of the Construction Sector – Annual Rate of Change (%)

Graphic 4 - GVA of the Construction Sector – Annual Rate of Change (%) (source: INE)

Table 6 - GDP from a production perspective (values in percentage)

Years	GDP from a production perspective										
	Total	Gross Value Added									Taxes net of product subsidies
		Total	Agriculture, forestry and fishing	Industry	Energy, water and sanitation	Construction	Vehicle sales and repair, accommodation and catering	Transport and storage, information and communication	Financial, insurance and real estate activities	Other service activities	
1980	100,0	100,0	9,5	26,4	1,3	9,7	18,3	6,0	8,9	19,9	9,1
1981	100,0	100,0	9,7	23,9	1,2	10,9	18,3	6,3	9,9	19,9	8,8
1982	100,0	100,0	9,8	22,1	1,5	11,0	18,0	6,6	11,1	19,8	10,2
1983	100,0	100,0	9,8	22,4	2,3	10,2	18,2	7,0	10,8	19,4	10,6
1984	100,0	100,0	9,4	23,9	2,9	8,0	18,6	7,5	10,2	19,5	9,0
1985	100,0	100,0	9,3	23,9	3,1	7,1	18,7	8,0	10,2	19,7	9,9
1986	100,0	100,0	8,8	24,3	2,9	6,6	19,2	7,8	9,9	20,7	12,1
1987	100,0	100,0	8,0	25,1	2,9	6,9	18,0	7,8	10,7	20,7	11,7
1988	100,0	100,0	7,0	25,5	3,0	6,8	17,8	7,4	11,0	21,5	11,9
1989	100,0	100,0	8,2	24,3	2,6	6,1	17,8	7,0	11,6	22,4	11,3
1990	100,0	100,0	7,8	23,7	2,7	6,4	17,5	6,7	12,7	22,6	11,0
1991	100,0	100,0	6,4	21,4	2,9	6,6	18,1	7,1	13,3	24,3	11,0
1992	100,0	100,0	5,2	20,2	3,0	7,1	18,8	7,1	12,7	25,8	11,2
1993	100,0	100,0	4,5	19,5	3,0	6,6	19,7	7,0	13,1	26,6	10,8
1994	100,0	100,0	4,9	19,0	3,0	6,6	19,4	7,1	13,8	26,2	11,4
1995	100,0	100,0	5,4	18,8	2,9	6,5	18,8	7,2	13,8	26,6	11,9
1996	100,0	100,0	5,2	19,5	2,9	6,6	18,4	7,3	13,2	26,9	12,2
1997	100,0	100,0	4,4	19,4	2,7	7,1	18,8	7,4	13,3	26,9	12,0
1998	100,0	100,0	4,1	18,9	2,8	7,3	18,8	7,4	13,5	27,2	12,6
1999	100,0	100,0	3,8	18,5	2,7	7,3	18,4	7,7	13,7	27,9	12,9
2000	100,0	100,0	3,5	17,7	2,5	7,6	18,5	7,7	13,4	28,8	12,4
2001	100,0	100,0	3,4	17,3	2,5	7,7	18,5	7,8	13,8	29,0	12,3
2002	100,0	100,0	3,1	16,7	2,6	7,6	18,6	7,9	14,0	29,5	12,5
2003	100,0	100,0	3,0	15,8	2,9	7,2	18,4	7,9	14,6	30,2	12,6
2004	100,0	100,0	3,0	15,4	2,9	7,1	18,4	8,0	14,8	30,4	12,5
2005	100,0	100,0	2,7	15,0	2,8	6,9	18,3	7,9	15,2	31,3	13,3
2006	100,0	100,0	2,6	14,9	2,9	6,7	18,2	8,1	16,1	30,5	13,7
2007	100,0	100,0	2,3	14,6	3,0	6,8	18,0	8,3	16,8	30,2	13,3
2008	100,0	100,0	2,3	14,0	2,6	6,7	17,9	8,2	17,5	30,8	12,8
2009	100,0	100,0	2,2	13,0	3,1	6,3	18,4	8,3	16,8	31,9	11,3
2010	100,0	100,0	2,2	13,6	3,2	5,8	18,1	8,3	17,2	31,5	12,0
2011	100,0	100,0	2,1	13,4	3,2	5,5	18,9	8,3	17,8	30,7	12,5
2012	100,0	100,0	2,2	13,5	3,5	4,9	19,8	8,4	18,1	29,6	12,5
2013	100,0	100,0	2,4	13,5	3,4	4,5	19,8	8,3	17,9	30,1	12,1
2014	100,0	100,0	2,4	13,9	3,7	4,2	19,9	8,2	17,9	30,0	12,7
2015	100,0	100,0	2,4	14,3	4,0	4,1	19,8	8,3	17,6	29,5	12,9
2016	100,0	100,0	2,4	14,3	3,9	4,0	19,9	8,3	17,7	29,5	13,1
2017	100,0	100,0	2,4	14,6	3,4	4,0	19,7	8,5	17,5	29,8	13,4
2018	100,0	100,0	2,4	14,5	3,6	4,2	19,4	8,5	17,4	30,1	13,5
2019	100,0	100,0	2,4	14,1	3,3	4,4	19,2	8,9	17,4	30,3	13,5
2020	100,0	100,0	2,5	14,1	3,4	4,7	16,7	8,4	18,7	31,5	12,8
2021	100,0	100,0	2,5	14,7	2,9	4,6	17,0	8,7	18,0	31,6	13,4
2022	100,0	100,0	2,1	14,5	2,7	4,4	18,8	9,4	17,2	31,0	13,5

Table 6 - GDP from a production perspective (percentage) (source:PORDATA)

Table 7 - GDP from a production perspective (millions of euros)

Years	GDP from a production perspective										
	Total	Gross Value Added									Taxes net of product subsidies
		Total	Agriculture, forestry and fishing	Industry	Energy, water and sanitation	Construction	Vehicle sales and repair, accommodation and catering	Transport and storage, information and communication activities	Financial, insurance and real estate activities	Other service activities	
1980	8 356,8	7 594,4	719,6	2 007,6	101,5	736,2	1 389,3	459,0	672,8	1 508,4	762,4
1981	10 058,2	9 176,4	887,5	2 197,7	107,5	998,4	1 682,3	574,3	906,9	1 821,7	881,8
1982	12 147,0	10 910,1	1 071,5	2 415,2	166,9	1 198,3	1 962,3	717,0	1 215,6	2 163,5	1 236,9
1983	15 440,0	13 808,0	1 356,4	3 088,1	312,4	1 401,7	2 511,0	965,5	1 487,6	2 685,4	1 632,0
1984	18 948,9	17 235,7	1 613,8	4 124,6	496,4	1 386,0	3 207,6	1 285,8	1 764,0	3 357,7	1 713,2
1985	23 226,6	20 930,8	1 941,7	5 005,6	655,7	1 487,8	3 915,9	1 670,4	2 126,4	4 127,2	2 295,8
1986	28 332,5	24 903,3	2 181,7	6 055,3	728,0	1 634,3	4 771,4	1 935,1	2 453,9	5 143,7	3 429,2
1987	33 508,4	29 581,8	2 374,6	7 432,0	845,2	2 033,8	5 328,9	2 303,6	3 154,0	6 109,6	3 926,6
1988	40 045,8	35 273,4	2 472,1	9 011,3	1 068,2	2 381,8	6 273,4	2 597,0	3 868,8	7 600,8	4 772,4
1989	47 221,2	41 876,4	3 454,4	10 173,5	1 084,6	2 569,4	7 444,2	2 914,4	4 854,6	9 381,2	5 344,9
1990	56 691,9	50 471,9	3 920,3	11 958,0	1 338,5	3 208,1	8 835,8	3 388,6	6 397,0	11 425,6	6 220,0
1991	65 005,2	57 857,4	3 685,3	12 362,9	1 704,3	3 824,9	10 467,7	4 092,4	7 689,1	14 030,9	7 147,8
1992	72 957,5	64 795,7	3 345,9	13 114,8	1 931,6	4 623,1	12 193,9	4 631,0	8 258,4	16 697,1	8 161,8
1993	76 065,1	67 836,5	3 067,1	13 220,1	2 053,2	4 483,2	13 380,1	4 745,7	8 868,3	18 018,8	8 228,5
1994	82 468,7	73 051,8	3 612,5	13 880,6	2 205,8	4 830,8	14 174,1	5 173,7	10 045,8	19 128,5	9 416,9
1995	89 028,6	78 452,6	4 273,8	14 741,1	2 241,1	5 109,9	14 739,2	5 668,4	10 825,8	20 853,4	10 575,9
1996	94 351,6	82 876,8	4 331,4	16 126,5	2 416,8	5 459,2	15 241,8	6 056,4	10 938,0	22 306,7	11 474,8
1997	102 331,0	90 046,3	3 920,4	17 485,9	2 471,8	6 357,3	16 944,6	6 669,3	12 019,2	24 177,9	12 284,6
1998	111 353,4	97 354,5	3 943,8	18 408,6	2 744,8	7 059,6	18 348,2	7 228,4	13 107,7	26 513,3	13 998,9
1999	119 603,3	104 225,1	3 934,0	19 294,2	2 832,2	7 616,7	19 199,7	7 978,7	14 306,6	29 063,1	15 378,2
2000	128 414,4	112 521,7	3 993,4	19 954,3	2 855,1	8 602,8	20 855,0	8 693,8	15 123,9	32 443,4	15 892,8
2001	135 775,0	119 098,2	4 020,0	20 578,6	2 976,2	9 226,6	22 052,1	9 304,9	16 405,7	34 534,3	16 676,8
2002	142 554,3	124 721,5	3 881,6	20 814,6	3 201,9	9 479,4	23 218,8	9 831,9	17 447,0	36 846,2	17 832,7
2003	146 067,9	127 734,3	3 872,5	20 220,5	3 676,4	9 157,8	23 440,7	10 129,7	18 671,7	38 564,9	18 333,6
2004	152 248,4	133 144,8	3 961,7	20 481,3	3 909,1	9 465,0	24 488,0	10 599,2	19 741,2	40 499,3	19 103,6
2005	158 552,7	137 485,7	3 652,3	20 582,9	3 782,6	9 538,3	25 108,8	10 915,7	20 930,4	42 974,7	21 067,0
2006	166 260,5	143 562,1	3 746,1	21 325,1	4 153,0	9 682,1	26 074,0	11 613,0	23 154,1	43 814,7	22 698,4
2007	175 483,4	152 166,0	3 506,4	22 289,6	4 539,8	10 291,2	27 374,1	12 615,6	25 632,2	45 917,0	23 317,4
2008	179 102,8	156 158,2	3 517,2	21 924,2	4 059,4	10 528,8	27 922,0	12 785,5	27 273,8	48 147,3	22 944,6
2009	175 416,4	155 546,5	3 421,7	20 175,5	4 889,3	9 767,9	28 563,1	12 981,5	26 198,7	49 548,7	19 869,9
2010	179 610,8	157 970,8	3 479,2	21 551,1	5 056,5	9 224,9	28 565,4	13 151,9	27 219,1	49 722,7	21 640,0
2011	176 096,2	154 128,2	3 229,6	20 624,8	4 976,6	8 464,3	29 166,3	12 864,3	27 422,3	47 379,9	21 967,9
2012	168 295,6	147 214,8	3 238,2	19 811,5	5 187,1	7 168,6	29 101,8	12 349,8	26 712,6	43 645,2	21 080,7
2013	170 492,3	149 802,3	3 572,6	20 254,2	5 147,0	6 767,1	29 728,5	12 423,9	26 856,6	45 052,5	20 689,9
2014	173 053,7	151 135,8	3 592,8	20 935,3	5 537,5	6 298,0	30 066,5	12 331,6	26 999,0	45 375,1	21 917,9
2015	179 713,2	156 517,3	3 773,0	22 315,4	6 273,3	6 391,4	31 009,1	13 008,9	27 563,8	46 182,5	23 195,8
2016	186 489,8	161 993,3	3 852,5	23 198,2	6 323,1	6 523,4	32 193,6	13 451,5	28 597,4	47 853,7	24 496,5
2017	195 947,2	169 642,3	4 106,8	24 793,5	5 801,9	6 864,3	33 366,4	14 396,3	29 704,7	50 608,3	26 305,0
2018	205 184,1	177 465,9	4 178,6	25 763,8	6 371,5	7 463,8	34 371,6	15 048,2	30 870,8	53 397,6	27 718,2
2019	214 374,6	185 536,3	4 477,3	26 077,7	6 207,8	8 087,2	35 619,3	16 549,5	32 315,9	56 201,7	28 838,3
2020	200 518,9	174 768,0	4 359,2	24 645,0	5 958,2	8 298,3	29 159,1	14 687,9	32 693,3	54 967,0	25 750,9
2021	216 053,2	187 070,1	4 645,9	27 509,0	5 445,4	8 620,0	31 742,0	16 330,3	33 745,2	59 032,2	28 983,1
2022	242340,8	209790,7	4494,9	30400,1	5559,5	9166,2	39356,1	19747,4	36029,6	65036,9	32680,6

Table 7 - GDP from production perspective (millions of euros) (source: PORDATA)

Table 8 - In which decade were houses, apartment buildings and other buildings built for housing or other purposes in Portugal? (in percentage)

Year	Construction time								
	Total	Before 1919	1919 - 1945	1946 - 1960	1961 - 1980	1981 - 1990	1991 - 2000	2001 - 2010	2011 - 2021
2021	100,0	4,9	7,8	10,5	27,1	16,3	15,6	14,8	3,1

Table 8 - In which decade were houses, apartment buildings and other buildings built for housing or other purposes in Portugal? (in percentage) (source: PORDATA)

Table 9 - In which decade were houses, apartment buildings and other buildings built for housing or other purposes in Portugal? (exact values)

Year	Construction time								
	Total	Before 1919	1919 - 1945	1946 - 1960	1961 - 1980	1981 - 1990	1991 - 2000	2001 - 2010	2011 - 2021
2021	3 573 416	174 200	277 571	375 353	967 182	581 768	557 048	529 510	110 784

Table 9 - In which decade were houses, apartment buildings and other buildings built for housing or other purposes in Portugal? (exact values) (source: PORDATA)

Table 10 - Types of Buildings in Portugal

Year	Building type		
	Total	Residential	Non-Residential
2021	3 573 416	3 572 128	1 288

Table 10 - Types of Buildings in Portugal (source: PORDATA)

Table 11 - Evolution of Dominant Typologies in Civil Construction in Portugal

Evolution of Dominant Typologies in Civil Construction in Portugal

Type of construction	Masonry Structure	Masonry Structure from the Pombaline Period	Gaioleiro Buildings	Reinforced Concrete Buildings
Construction Period	< 1775	1755 -1880	1880 - 1930	~1940 - present
Used Materials	-Stone; -Earth; -Sand;	-Stone; -Iron; -Wood;	-Stone; -Brick; - Iron;	-Concrete; -Steel; -Brick;
Characteristics	-High density of walls; - No corridors; -No sanitary facilities;	- Pombaline cage; - Resists earthquakes and is anti-seismic; - 3 to 4 floors	-Structural continuity Lack; -Balconies usage; - 5 to 6 floors;	-Mixed used buildings; -Multiple apartments per floor; -9 to +20 floors;
Observations	- the 1755 earthquake destroyed most of the buildings; - surviving ones were heavily damaged;	-Portuguese architecture landmark; -UNESCO World Heritage;	-Quality decline compared to Pombaline period; -Vulnerable to earthquakes and structural failures;	-Complex & taller buildings; -Advancement in construction technology; -Development of new architectural styles and forms;

Table 11 - Evolution of Dominant Typologies in Civil Construction in Portugal (source: (LNEC, 2005)*)*

Table 12 - Most Used Construction Techniques for Houses in Portugal

Most Used Construction Techniques for Houses in Portugal

Construction Type	**Masonry**	**Light Steel Frame**	**Cast-in-Place Reinforced Concrete**
Envolved Materials	-Concrete blocks; - Stone; - Bricks;	- Steel;	- Concrete; - Steel;

(Eurostat, s.d.)	- Architectural freedom; - Durable; - Strong;	- Faster construction; - Lightweight materials; - More cost-effective;	- Resistant to weather conditions; - Quick to construct;
Disadvantages	-Time-consuming construction process; - Homes that retain less heat;	- Unstable for buildings with extreme height; - Structural inefficiencies for large spans;	- Poor thermal insulation; - Poor acoustic insulation;

Table 12 - Most Used Construction Techniques for Houses in Portugal (source: (SPM, 2019))

Table 23 - On a scale of 1 to 5, with 1 being "no interest" and 5 "very interesting", how would you rate your willingness to live in a house built with CLT or bamboo in Portugal?

Q2Q1 - On a scale of 1 to 5, with 1 being "no interest" and 5 "very interesting", how would you rate your willingness to live in a house built with CLT or bamboo in Portugal?

1	28 (13%)
2	41 (19%)
3	63 (29%)
4	59 (27%)
5	26 (12%)

Table 23 - On a scale of 1 to 5, with 1 being "no interest" and 5 "very interesting", how would you rate your willingness to live in a house built with CLT or bamboo in Portugal? (source: own elaboration)

Table 24 - What's the best opportunity in the construction of buildings with sustainable materials?

Q2Q2 – What's the best opportunity in the construction of buildings with sustainable materials?

Seismic performance	37 (17%)
Fast construction	65 (30%)
Fire resistance	31 (14%)
Reduced construction costs	56 (26%)
Thermal insulation	28 (13%)

Table 24 - What's the best opportunity in the construction of buildings with sustainable materials? (source: own elaboration)

Table 25 - Do you consider that construction using sustainable materials, and their inherent characteristics could replace the traditional model (use of concrete and steel) in Portugal by 2050?

Q2Q3 - Do you consider that construction using sustainable materials, and their inherent characteristics could replace the traditional model (use of concrete and steel) in Portugal by 2050?

Yes	137 (63%)
No	80 (37%)

Table 25 - Do you consider that construction using sustainable materials, and their inherent characteristics could replace the traditional model (use of concrete and steel) in Portugal by 2050? (source: own elaboration)

8.3 Interview (I1)

The interview was carried out with Engineer Jorge Pombo, whose company is *Imperalum*.

I1Q1 - *Do you think it is realistic that by 2050 the majority of construction projects in Portugal will be made with sustainable materials? Do you think the sector's problems will hinder this change?*

JP – "Over the years there has been more and more legislation, more rules and more awareness regarding the environment and I am not surprised that sustainability is the future of the sector. Answering the first question, I believe that the sector will move towards sustainability as a whole and obviously there will have to be a transition in materials but being characterized by its slowness over the years. Now, in my opinion it may not be possible is to occur by 2050. Unfortunately, it should happen, but that transition is still little compared to the much that needs to be done at national level."

I1Q2 - *Portugal has a competitive advantage by making sustainable use of its forests, which correspond to 36% of its territory, minimizing the need for imports and valuing local resources. Furthermore, it has a competitive advantage since the climate is considered temperate and reduces the deterioration of the material (seen as the biggest disadvantage). Do you believe that these competitive advantages can facilitate the expansion of the use of these materials in civil construction?*

JP – "I think there would be a lack of forest areas that would be necessary if the vast majority of construction started to use these materials. It is worth remembering that they would no longer be truly forests representing a diversity of flora and fauna, but would become a monoculture area, competing with agricultural areas, making agricultural land and all the food grown on it more expensive. What could eventually occur is an area solely destined for production, but with a production ceiling. Therefore, modelling, repetition and standardization, which allow for an effective industrialization of construction, must be the focus according to a previous legislation. Then we must diversify materials, and, in this sense, it will be positive to reduce the hegemony of traditional materials in Portugal (neither steel nor concrete) and diversify towards more hybrid constructions."

I1Q3 – *Do you consider that the transition from traditional to sustainable materials can mitigate the existing housing crisis in Portugal?*

JP - "The housing crisis is a problem that is quite general and is linked to many sectors of activity. In the event of a transition from the so-called traditional materials to sustainable materials, it is necessary to understand that this transition alone may not generate major changes. I think that the housing crisis is a problem that is spreading across sectors of both the economy and the social sectors, which really makes this problem a bit complex. Obviously, civil construction has some impact on this, but there are much greater impacts, such as inflation and irregularities in demand and supply at affordable prices. Now, if there is an adoption of sustainable materials due to the lower costs they offer, I believe that it could also raise another problem, which is the high demand and which only satisfies a very small percentage of people in relation to the generality. Having said that, I think that the transition of materials can be a measure but there are many other measures, particularly in terms of other sectors of activities that can complement so that the housing crisis can be absolved or even reduced."

I1Q4 - *Two different questionnaires were carried out. The first aimed at companies and the second for the community in general. The question: What would be the accreditation of a transition to sustainable materials compared to traditional materials in Portugal by 2050, was asked from both perspectives and the different perspectives under study. Surprisingly or not, the answers were different. Companies argued that they would not believe in this transition, and, in contrast, the community admitted that they believe in this transition. What is your opinion?*

JP - "Well, first, I have to tell you that this contrast is actually interesting to observe, but if it is better analysed I believe that there could actually be a justification. In my opinion, when companies argue that they do not believe in this transition, I believe it is a rational response. In other words, it is a response from someone who is involved in the field and who knows about the sector's difficulties because they face them every day and who is aware of what is around them. Therefore, I believe it is an answer that can shed light on what could happen by 2050. The community telling you that it believes in this transition may be a somewhat premature response because there is increasingly an induction towards sustainability in all sectors of activity and in all aspects of personal and professional life. I think people are increasingly familiar with the topic of sustainability, but in this specific case I think it ends up being a little early. I say this because when people to give this answer it is clear that they are not aware of the reality of the construction sector and what this transition will entail. Not only at the level of builders, at the level of companies, at the level of construction methods, at the level of professionals and at the level of training. I believe that companies can start to make some changes in their environment and that they can start to be noticeable in 2050, on the deadline date. Even though there is this divergence of opinion, the opinion of the companies ends up prevailing. Companies are aware of the environment, implications, difficulties and obstacles."