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State of the art on miscanthus properties and its use in the building sector

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ABSTRACT

Due to the significant energy consumption and carbon emissions associated with the building sector, there is growing interest in developing sustainable and energy-efficient construction materials. This article presents the physicochemical properties of miscanthus, its cultivation and growth, its applications in the construction sector, and the challenges and limitations arising from its lignocellulosic chemical composition. The aim is to provide a comprehensive overview of miscanthus, offering a solid foundation for the development of plant-based thermal insulation composite materials for use in construction. Miscanthus, due to its low thermal conductivity (0.05 W/(m·K)), high porosity, lightweight nature, and environmental benefits such as renewability and sustainability, is a promising candidate for use in building insulation materials.

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1. Introduction

The Intergovernmental Panel on Climate Change (IPCC) predicts in its report in 2023 that the global warming of 1.1°C will become 1.5°C in 2030 and that the main cause is the greenhouse gas emissions resulted by human activity, referencing to the pre-industrial period. In order to reduce this risk, it is necessary to focus on the building sector because it is one of the most polluting and energy-intensive sectors.

For instance, the residential and tertiary sectors consumed over 700 TWh of energy in 2022, accounting for 47 % of the national energy use and representing the highest levels of energy consumption in France [1]. In addition, the tertiary sector accounts for one-third of greenhouse gas emissions from all French buildings and occupies 940 million m² or one-fourth of all existing buildings in France. [2]

The United Nations' 2030 Sustainable Development Goals and the European Union's 2020, 2030, and 2050 climate and energy packages and frameworks [3], emphasize the importance of building envelope design to improve energy performance. Using passive or active energy management technologies such as thermal insulation panels, lighting systems, automatic control devices for air conditioning/heating units or energy storage systems can contribute to overcoming environmental challenges. These systems cannot ensure year-round thermal comfort. As a result, many research activities focus on developing environmentally friendly materials that can improve energy performance and user comfort in future buildings [4]. Thus, eco-friendly insulation materials including plant fibers are becoming more popular. Miscanthus, a perennial plant, is a promising source to produce sustainable construction materials. International and national research programs began in the 1980s to examine miscanthus' biomass production potential and increase its feasibility in Southern Europe by improving plant understanding, harvest, and development [5]. Thus, miscanthus, and other sustainable biomaterials, have attracted interest in transitioning toward greener technologies and stricter energy standards.

In this work is reviewed the current information on the miscanthus cultivation, uses, and its physical and chemical properties that make it a promising resource for sustainable construction.

Since this paper is part of a thesis work conducted in France and using French miscanthus and tested under French climate, thus some values related to French miscanthus are mentioned in this manuscript.

Given its many applications, a clear understanding is necessary to have a foundational understanding of miscanthus, in order to support future research and practical applications in sustainable industries. This study focuses mainly on the potential of miscanthus in the building sector, specifically on the thermal insulation of buildings. Although this plant is gaining interest as a bioresource, literature still lacks a comprehensive analysis of its valorization, especially concerning its potential in thermal insulation. Thus, this work aims to present the state of the art of the current research and applications of miscanthus-based materials in the building thermal insulation section by analyzing its physicochemical characteristics, insulation performance, processing techniques and environmental impact within the construction industry.

2. Bibliometric analysis

The search query yielded 5,090 (July 2025) papers published between 1953 and 2025, representing approximately 30 % of the total number of publications on hemp 17,465 (July 2025) and flax 17,959 (July 2025) during the same period. These numbers are obtained by entering the respective biomass names - miscanthus, hemp, and flax - into the search bar. Hemp and flax were selected for comparison as they are considered relatively well-established bio-based materials in the building sector, with a mature research background. Hemp is a fibrous plant, known for its fast-growth rate and multiple applications, such as hemp-based thermal insulation contributing in sustainable construction due to its excellent thermal insulation properties and its ability to trap carbon. Also, the flax plant, in form of fibers, is used in thermal insulation due to its low thermal conductivity and biodegradability. Miscanthus, hemp and flax are all three fiber-rich, fast-growing plants and have the potential to be used in sustainable industrial applications such as bio-based insulation materials. Figure 1 highlights the growing interest of these bioresources, illustrated by the increasing number of publications over time – particularly for miscanthus raw material – compared to other natural fibers. In other words, the increase in the publications related to miscanthus is noticed starting 2009, with 103 papers published in only one year. On the other hand, only 372 publications were

made over 50 years (from 1953 to 2003), and 398 publications in just three years (from 2009 to 2011). It was only from 2016 that studies began to increase significantly. Although they are fewer in number compared to hemp and flax, this increase in publications reflects the growing interest in miscanthus research.

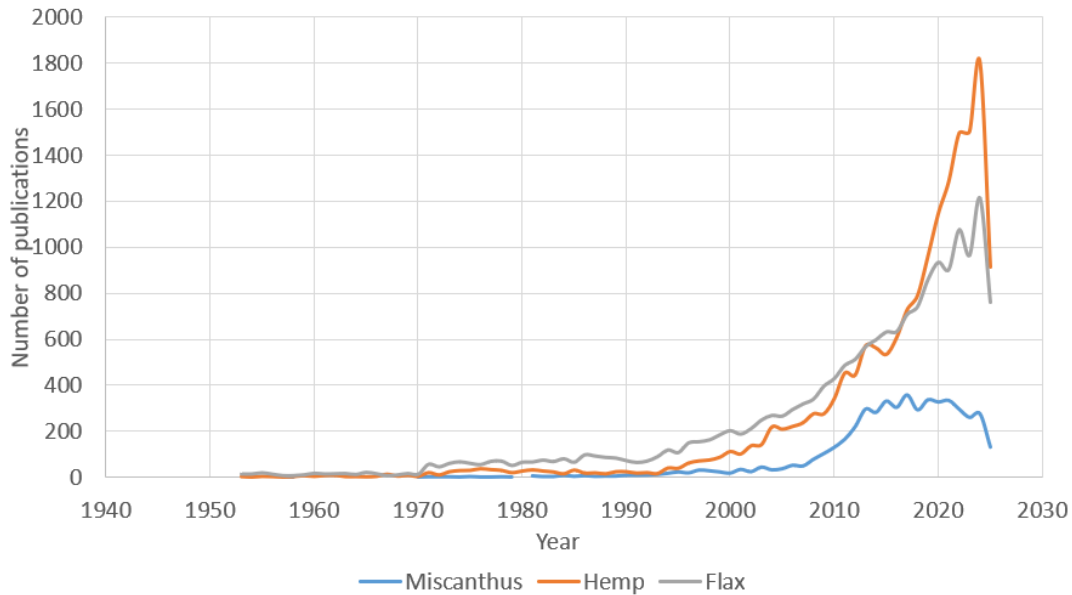


Figure 1: Evolution of the number of publications per year from 1953 and 2025 for (a) miscanthus, (b) hemp and (c) flax according to Scopus data.

In the construction sector, a total of 352 publications are found for miscanthus, which is considered a limited number in comparison to hemp with 3,473 publications and flax with 2,303 publications for the same period and sector. These numbers were obtained by refining the search to the 'construction' field for each plant. This divergence explains that miscanthus has not yet obtained the same level of attention in research and application in the construction field as other biomass. This reveals the need for further exploration of the potential of miscanthus in this field. Figure 2 presents the evolution of the studies on miscanthus, hemp and flax in the construction field between 1989 and 2025. The references are collected from the database of Scopus that is linked to the most important publishers, such as Springer, Elsevier, and Blackwell, among others.

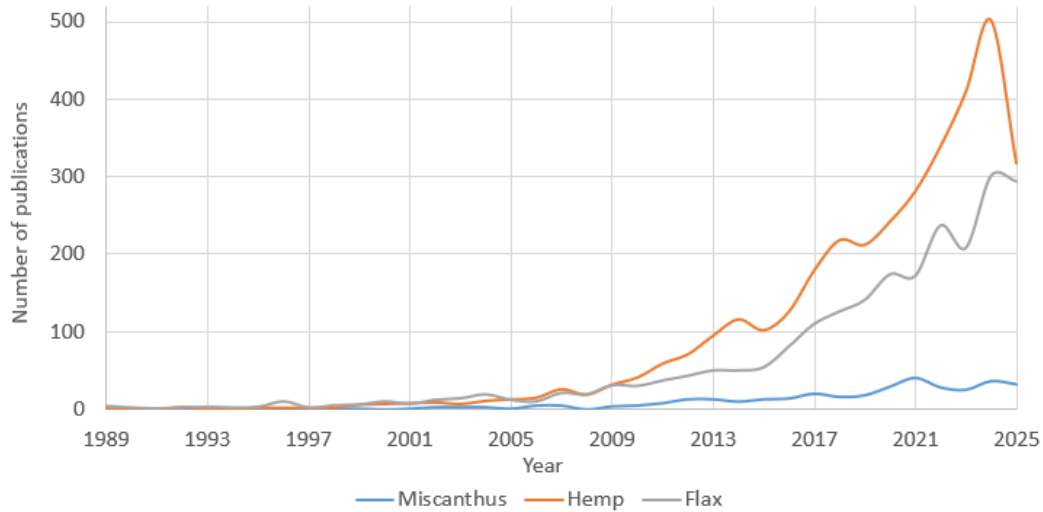


Figure 2: Evolution of the number of publications per year from 1989 and 2025 for (a) miscanthus, (b) hemp and (c) flax in the construction sector according to Scopus data.

3. Insulation materials

Building envelope thermal insulation is commonly used as passive solution to reduce excessive energy consumption. A wide variety of thermal insulation materials are currently available on the market [6]. The choice of the material follows an approach developed by Frasca *et al.* (2024) [7] called the TEnSE approach and rejoins the four domains: Technical (T), Environmental (En), Safety (S), and Economic (E). This technique is introduced in this review as a guiding approach to review available data on the performance of miscanthus: technically (thermal conductivity, density, and hygrothermal behavior), environmentally (renewability and carbon sequestration), considering safety aspects (fire resistance and health impacts), and analyzing economic factors (material availability, processing requirements, and cost competitiveness).

Alongside the selection procedure, multiple classifications of the thermal insulation materials are found in the literature. Durakovic *et al.* (2020) [8] generally divided the insulation materials into two categories - organic and inorganic - based on the used raw materials. Then, Hetimy *et al.* (2024) [9] refined the subdivision of inorganic materials into traditional and innovative, while both authors categorized the organic materials into petrochemical and natural materials. Figure 3 represents a detailed classification of these classifications.

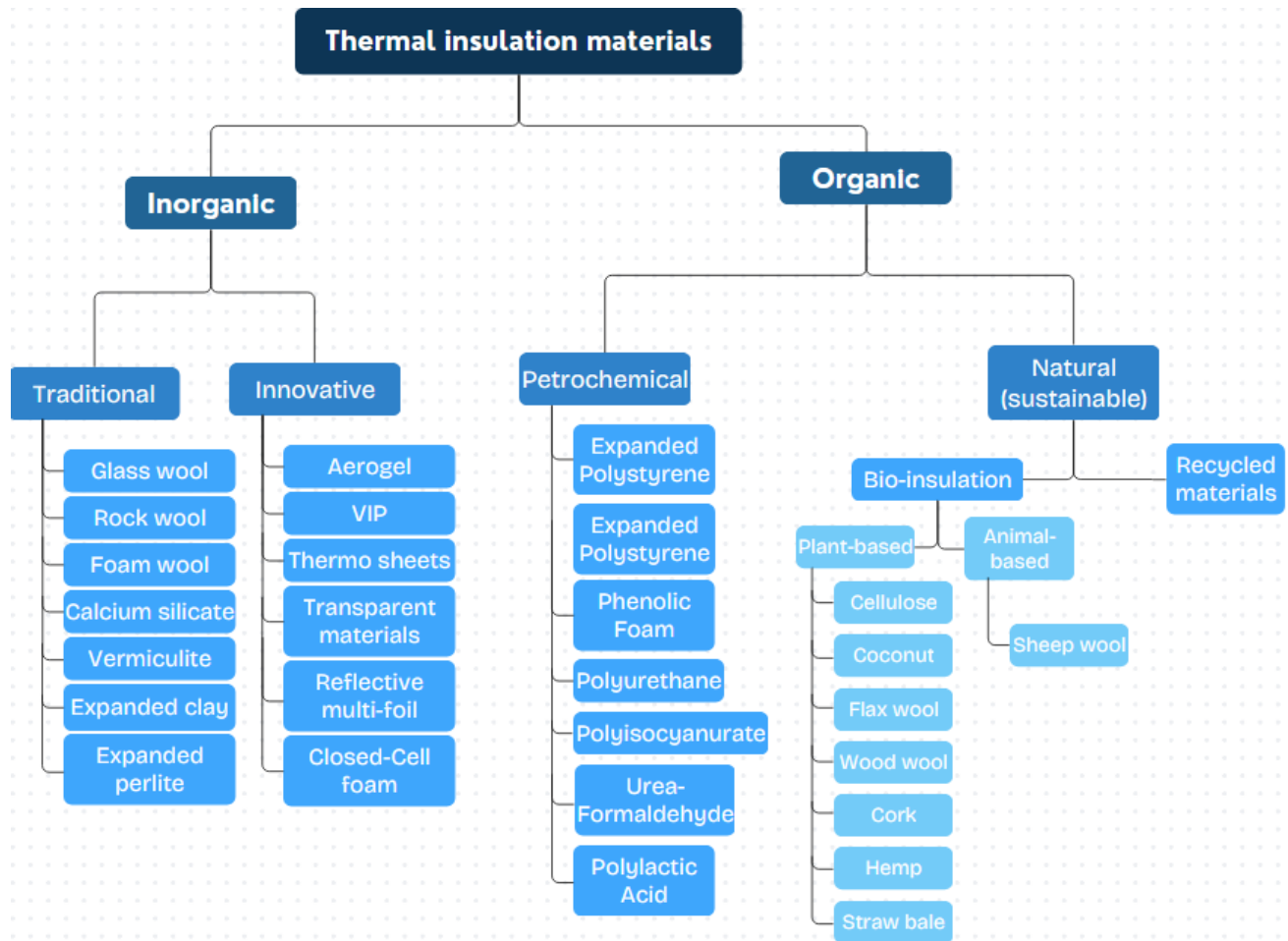


Figure 3: Classification of thermal insulation materials according to Hetimy et al. (2024) [9].

Badouard et al. (2023) [10] divided the insulation materials into four main families:

- mineral insulation from natural mineral material (glass wool, rockwool, perlite...),
- synthetic insulation from organic resources (expanded polystyrene EPS, extruded polystyrene XPS, polyurethane foam PU...),
- natural insulation from plant or animal resources (wood fibers, hemp wool, straw, cork, duck feather, sheep wool, cellulose wadding...),
- new generation insulation (vacuum insulation panel VIP, reflective, aerogel...).

Despite being very efficient in thermal insulation especially because of their consistent physical and chemical properties, inorganic thermal insulation materials often suffer from poor mechanical properties, high costs, and potential toxicity. Therefore, the development of renewable natural materials with the same thermal conductivity and minimum impact on the environment is thus a topic that researchers are following closely. The objective is to decrease the thermal insulation cost and CO₂ emissions as much as possible. In the upcoming sections and for the purpose of this review, a simplified classification of the insulation materials into synthetic and bio-based materials will be adopted based on whether natural resources are used or not. This classification best aligns with the focus of this review, which deals with natural plant-based materials such as miscanthus-based materials. This division into bio-based and synthetic simplify the comparison in terms of sustainability and environmental impact.

3.1. Synthetic insulation materials

Synthetic insulation refers to man-made thermal insulation materials, typically derived from petrochemicals, such as polystyrene, polyurethane, or polyethylene foams [11]. These materials use artificially created fibers rather than naturally occurring substances as in the case of natural insulation. The most common synthetic insulation products now in the market include expanded polystyrene (EPS), extruded polystyrene (XPS) and polyurethane (PUR). Inorganic materials such as mineral wool (glass and rock wool) are sometimes included due to their industrial production process, although they differ in origin and composition [11].

Synthetic insulation materials, particularly rigid polyurethane foams, exhibit high mechanical strength and resistance to damage, while remaining flexible enough for simple installation [12]. In addition, its widespread availability makes it easily accessible for most construction projects.

The typical insulation material with the lowest thermal conductivity is polyurethane (PUR), with a value of $20 \times 10^{-3} \text{ W/(m.K)}$. For the other materials, the range is between 30 and $40 \times 10^{-3} \text{ W/(m.K)}$ [13].

One of the drawbacks of synthetic insulation materials is their sensitivity to temperature and moisture explained by the increase of the thermal conductivity with the increase of temperature and especially the increase of humidity. While temperature increases (20–40 °C) lead to relatively small conductivity changes—typically under 8 %, except for EPS, which reaches 13.29 % at 40 °C, compared to values at 20 °C—humidity has a much stronger effect. When exposed to high humidity (up to 100 %), the maximum increase in thermal conductivity of the materials with time are 8.2–186.7 % compared to the dry state: phenolic foam (PF) shows a conductivity increase of 27.3 % at just 50 % humidity, and EPS shows a maximum increase of about 15 % while the increase rate in thermal conductivity of FG and XPS are less than 10 %. These results highlight the importance of choosing the appropriate insulation materials based on local climate conditions and point out the necessity for moisture-resistant solutions in humid climates. [14].

Some synthetic materials (such as phenolic foam) show notable increases in thermal conductivity when wet, but others (extruded polystyrene or Foam glass) perform quite well when moisture is present [14].

Biobased materials such as hemp concrete perform also well when wet: the increase in thermal conductivity is less than 20 % even at high humidity levels [15], [16]. Regarding the MBV, for instance, the moisture buffer value (MBV) of Expanded Polystyrene (EPS) is about $0.3 \text{ g/(m}^2 \cdot \% \text{RH)}$ [17] which is considered very low value of MBV, while the values of vegetable concrete are greater than $2 \text{ g/(m}^2 \cdot \% \text{RH)}$ which are considered very good moisture regulators [18]. Therefore, biobased insulation materials contribute much better to passive humidity regulation than conventional insulation materials.

Moreover, the carbon-based and mineral resources used for the production of synthetic insulations (EPS, XPS, PUR) cause serious environmental pollution and problems. For instance, EPS and PUR exhibit high greenhouse gas emissions—2.55 and 3.48 kg CO₂ per kg, respectively—with PUR also showing elevated human-toxicity potential (~3,444 kg DCB/kg) compared to mineral wool (~741 kg DCB/kg) [19]. Blowing agents in XPS (such as HFCs) further increase ozone depletion and global warming impacts. These materials are also non-biodegradable and often end up in landfills or combusted, releasing toxic substances (e.g., SO₂, NO_x) [20], [21].

3.2. Bio-based insulation materials

Biomass-based insulation materials are identified as low-embodied energy materials that reduce energy use and greenhouse gas emissions during their lifecycle, according to Rabbat *et al.* (2022) [22]. They are considered as environmentally friendly [8] because they use renewable resources including plants, animals, and microorganisms. Most research projects on this topic focus on renewable biomass resources and wastes, insulation material design and manufacture, testing, and building installation, but few papers have examined

durability and end-of-life management. In France for example, about 230,000 tons of biomass were used in construction in 2022, storing 1.8 tons of CO₂eq each ([23]). Adding plant-based elements to concrete, for instance, can lower its density and enhance both thermal and acoustic insulation properties due to the porous structure of biomass [15]. For Amziane and Arnaud (2017) [24], bio-sourced concrete is a "mixture of lignocellulosic plant matter granules, derived directly or indirectly from agriculture or forestry, which make up the bulk of the volume, and a mineral binder".

3.2.1. Classification of natural fibers

Natural fibers, which are biopolymers derived from or produced by living organisms, have been used for many centuries in different applications. This is due to their outstanding environmental properties, namely the non-toxicity, biodegradability, and biocompatibility, but they also have interesting mechanical properties including high strength and flexibility [25], [26].

The natural fibers are subdivided based on their origins: from plants, animals or minerals [27], [26], as shown in figure 4. Plant-based fibers are the most popular. Their structure consists mainly of cellulose, hemicellulose, and lignin. According to the most common classification of plant fibers, bast, leaf, seed, fruit, wood, stem, and grass/reed fibers are the seven basic types. For animal-based fibers, the main component is protein. [26]

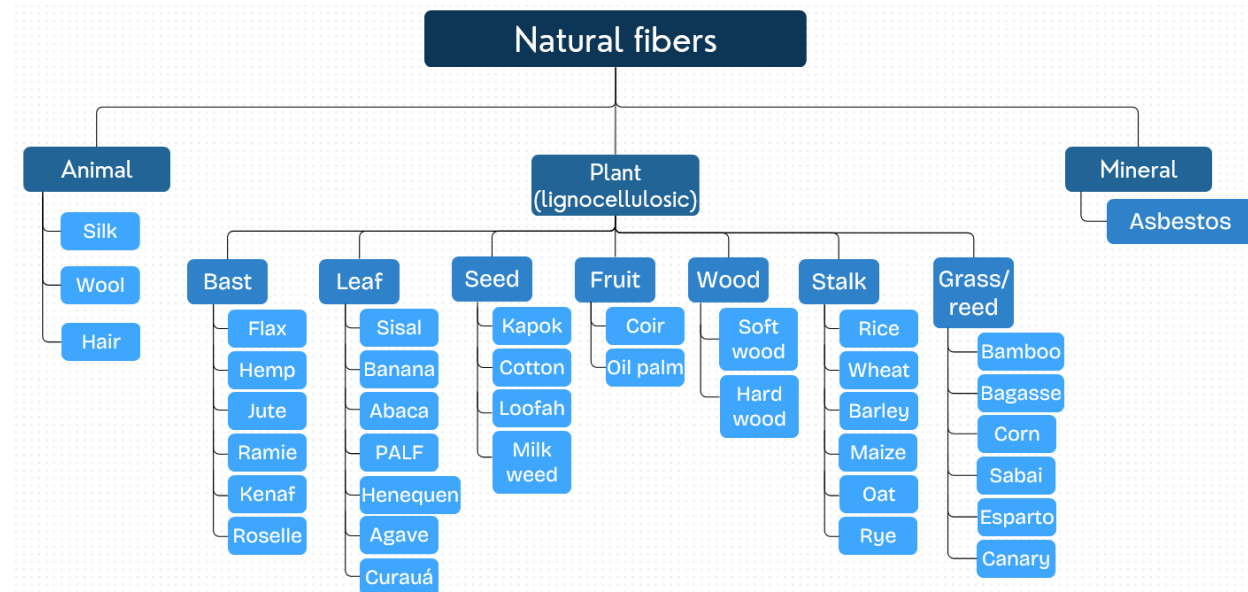


Figure 4: Classification of some of the most common natural fibers [27], [28], [29].

3.2.2. Properties

Exploring methods to improve the long-term durability, ease of production, mechanical, and thermal properties, environmental impacts, preparation procedures and biomass treatments for bio-cementitious products and agro-materials are the current focus of different research groups [30].

Environmental properties and impact

Compared with traditional building materials, plant-based bio-composites offer long-term benefits for infrastructures (biodegradability, waste reduction, energy efficiency, lower health risks, etc.) enabling a considerable reduced environmental impact. These materials present many advantages. First, the biomass used in producing bio-composites is, in most cases, agricultural wastes and residues, therefore made from renewable carbon, cheap and widely available. Second, they produce relatively low levels of greenhouse

gases emissions throughout their life cycle because they are renewable materials and require less energy in production compared to conventional resources. Third, using insulation material results directly in reducing heating and cooling needs, which reduce the energy consumption, especially the biobased materials because of their natural insulating properties. Finally, natural fibers can regulate humidity and improve air quality by absorbing excess moisture during high humidity periods, reducing the risk of mold and allergens, and releasing it during very dry periods, thus improving domestic comfort [31], [27].

Hygro-thermal properties

Generally, the moisture content of thermal insulation material is expressed as a function of relative humidity during the moisture absorption phase at room temperature. Numerous researchers have studied these phenomena and the impact of moisture absorption and desorption on materials, specifically those of biological origin [32]; [33]; [34]; [35]. Multiple studies have shown that adding plant fibers to cementitious mortars improves the water retention and moisture storage capacity [36], a property known as hygroscopicity. This is due to the presence of many hydroxyl groups of cellulose, hemicelluloses and other polysaccharide materials present in the biomass [30]. In particular, the addition of plant fibers results in a high moisture absorption and storage capacity due to the microporous structure and hydrophilic nature of cellulosic plant fibers. Conversely, the presence of hydrophobic lignin may limit moisture absorption and delay water from entering the cell wall [30].

Plant fibers have remarkable thermal insulation properties, making them suitable for building applications. Lignocellulosic fibers such as hemp [37], flax [22], sunflower [38], grown in France, or date palm [39] grown in Morocco, were used as insulating materials. The thermal conductivity of insulation materials is often influenced by density, with the lowest thermal conductivities typically found in low-density materials. For example, for sunflower pith boards [40], [41] thermal conductivity values are $(38\text{--}41 \times 10^{-3} \text{ W}/(\text{m}\cdot\text{K}))$ at 25°C with density of around $0.036 - 0.047 \text{ g}/\text{cm}^3$; perfectly comparable to those of conventional insulation materials such as expanded polystyrene ($37 \times 10^{-3} \text{ W}/(\text{m}\cdot\text{K})$ with a density of $0.05 \text{ g}/\text{cm}^3$), rock wool ($36 \times 10^{-3} \text{ W}/(\text{m}\cdot\text{K})$ with a density of $0.115 \text{ g}/\text{cm}^3$), and glass wool ($35 \times 10^{-3} \text{ W}/(\text{m}\cdot\text{K})$ with a density of $0.026 \text{ g}/\text{cm}^3$).

Table 1 compares the density and thermal conductivity of various natural fibers, highlighting that miscanthus can be a competitive and sustainable insulation material with properties comparable to widely used fibers like hemp and flax.

Table 1: Natural fibers thermal conductivity [42], [43]

| Fiber | Bulk density (g/cm^3) | Thermal conductivity ($\times 10^{-3} \text{ W}/\text{m}\cdot\text{K}$) | Reference |
|------------|--|--|------------|
| Oil palm | 0.02 – 0.12 | 94.66 – 57.82 | [42] |
| Cotton | 0.032 – 0.053 | 36 – 34.5 | [43] |
| Coconut | 0.04 – 0.09 | 57.58 – 50.09 | [42] |
| Miscanthus | 0.04 - 0.128 | 40 – 60 | [44] |
| Sugarcane | 0.07 – 0.12 | 50.94 – 49.64 | [42] |
| Flax | 0.019 – 0.038 | 51.6 – 38.8 | [43] |
| Sisal | 0.109 | 38.5 | [43] |
| Hemp | 0.043 – 0.046 | 49.3 – 49 | [43] |
| Jute | 0.014 – 0.197 | 53.2 – 41.4 | [43] |
| Bagasse | 0.03 – 0.228 | 36.2 – 48.9 | [43] |
| Bamboo | 0.6 – 1.1 | 58.2 – 81.2 | [40], [45] |

Mechanical properties

Because of their high lignocellulose content, plant fibers can serve as effective reinforcement in wood-polymer composites (WPCs) [27], which are used as outdoor terrace slats or wall cladding. Additionally, lignocellulosic by-products from agriculture or agro-industry can also be used as bio-aggregates to produce biobased insulating concretes [46]. Most studies show that plant fibers reduce compressive strength in cementitious composites. This reduction is usually attributed to the following main factors: the mortar's density, which decreases with porosity and fibers' low density, the fibers' negligible mechanical properties compared to other components, and the plant fibers' low compatibility with the cement matrix. The type of plant fibers, mortar fiber content, and fiber preparation also have an impact on overall compressive strength, which is more important than tensile and flexural strength. Depending on fiber size and type, bio-sourced composites may have higher flexural or tensile strength than reference mortars. [47], [48]. Table 2 presents the main mechanical properties of the commonly used natural fibers.

Table 2: Natural fibers mechanical properties[29], [49], [50], [51].

| Fiber | Absolute density (g/cm ³) | Tensile strength (MPa) | Elastic modulus (x 10 ³ MPa) | Elongation at break (%) | Reference |
|------------|---------------------------------------|------------------------|---|-------------------------|------------|
| Cotton | 1.6 | 400 | 5.5 – 12 | 7 – 8 | [18], [36] |
| Pineapple | 1.56 | 170 – 1627 | 60 – 82 | 2.4 | [36] |
| Flax | 1.5 | 345 – 1500 | 27.6; 50 – 70 | 2.7 – 3.7 | [18], [36] |
| Sisal | 1.5 | 228 – 1002 | 9.4 – 26.7 | 2 – 5.1 | [18], [36] |
| Hemp | 1.47 | 690 | 70 | 2 – 4 | [18], [36] |
| Kenaf | 1.45 | 930 | 53 | 1.6 | [18], [36] |
| Abaca | 1.5 | 400 – 980 | 6.2 – 20 | 1 – 10 | [18], [36] |
| Jute | 1.3 | 393 – 773 | 26.5 | 1.5 – 1.8 | [18], [36] |
| Banana | 1.3 | 500 | 12 | 1.5 – 9 | [18], [36] |
| Bagasse | 1.25 | 222 – 290 | 17 – 27.1 | 1.1 | [18], [36] |
| Bamboo | 0.6 – 1.1 | 140 – 800 | 11 – 32 | 2.5 – 3.7 | [18], [36] |
| Miscanthus | | 2 – 8 | 0.5 – 6.6 | | [38] |

4. Overview on miscanthus

In this section are elaborated the cultivation process of the miscanthus plant along with the properties of the miscanthus in form of aggregates (bulk) not the properties of the final product made partially or totally of miscanthus in form of composite, this section will be the interest later on in the paper not in this section specifically.

4.1. General introduction on miscanthus

Miscanthus, one of the two leading second-generation perennial energy crops in Europe and parts of Asia (alongside switchgrass [52]), belongs to the *Poaceae* grass family, and more specifically the *Andropogoneae* tribe [53]. It is a heterogeneous gramineous plant that hybridizes interspecifically and hence has a complex genetic background [54]. It is expected to play a key role in the development of the future bioeconomy.

The term “miscanthus” derives from the Greek "mischos" referring to the peduncle which carries the inflorescence, and "anthos," meaning flower [5]. The miscanthus genus includes 14-20 of the C₄ perennial species native to eastern Asia, northern India, and Africa [55], [53]. It is a type of lignocellulosic agricultural

resource, primarily composed of cellulose (27–50 wt.% dry basis) and lignin (it is considered to have a high lignin content, compared to woody biomass [56]). Hemicelluloses and pectins are also found in the plant stem.

4.1.1. Parts of the miscanthus

As shown in figure 5, miscanthus has two primary parts: the underground and the aerial. The underground section consists of a rhizome, which is a series of modified stems, along with the roots. When recycled, the rhizome stores nutrients for a long time, reducing the need for nitrogen fertilization. In the aerial section, during flowering, 25 to 75 leafy stems produce a panicle-type inflorescence. The genotypes and locations affect the panicle emergence and flowering [5]. The biochemical structure and composition of each component of the plant varies depending on its function [30]. Even the stem's composition is not homogenous over its length and varies from genotype to another where sections from the bottom of the stem are stiffer than those from the top [57]. The high cellulose content and highly lignified cell walls help plants resist lodging, a common phenomenon in agriculture that occurs when tall crops bend or collapse. Figure 5 (b) represents a microscopic lateral cut of a miscanthus stem where two main divisions are clear: the parenchyma in the middle and the sclerenchyma all around.

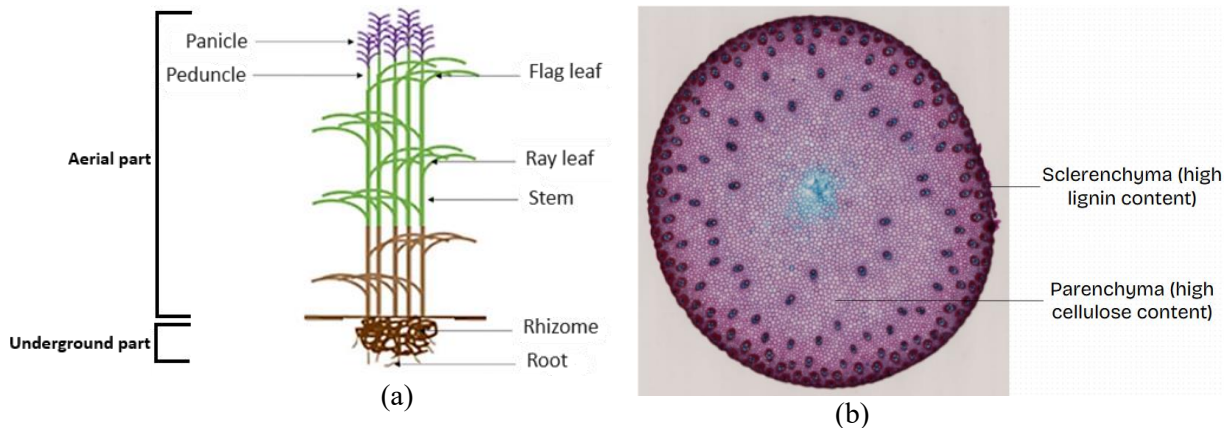


Figure 5: (a) Representation of a miscanthus plant during flowering [5], (b) microscopic cut of a miscanthus stem [58].

4.1.2. Species

Miscanthus has widespread inter- and intraspecific hybridization, resulting in genetic diversity and heterosis. Due to its complex genetic background, phylogenetic relationships in this genus are challenging to study. Miscanthus hybrids, which have higher biomass yields and better climate tolerance than their parents, have been created using genetic variety. Chen et al. (2022) [54] found that the polyploid *Miscanthus lutarioriparius* generates more biomass and is more adaptive than any other miscanthus species, including the most known diploid *M. sacchariflorus*. The taxonomy review of Sun et al. (2010) [59] lists six miscanthus species: *M. floridulus*, *M. sinensis* (Msin), *M. sacchariflorus* (Msac), *M. nepalensis*, *M. paniculatus*, and *M. nudipes* [60]. These species differ in height, stem diameter, and panicle features [61], [5]. Each genotype has a different density due to its leaf amount [62], and a unique yield and features that affect the final material produced using this biomass [63].

Miscanthus sinensis 'Giganteus', now known as *Miscanthus x giganteus* (Mxg) is a sterile triploid hybrid resulting from several spontaneous crosses between tetraploid *M. sacchariflorus* (Msac) and diploid *M. sinensis* (Msin). The type of miscanthus used in the composite [64] affects its properties and the final result. Multiple studies have evaluated the effect of different miscanthus genotypes in concrete. Table 3 is part of

a study done by Jury *et al.* (2022) [64] where is compared the compressive strengths of concrete made with different miscanthus genotypes called in their study: H5, GiGB, Flo, Mal, Sac, and Gol. They are divided as follows: two genotypes *M. x giganteus* interspecific hybrids (GiGB and *floridulus* Flo) ornamental variety, two other genotypes from the *M. sinensis* (*goliath* Gol and *malepartus* Mal). and two from the *M. sacchariflorus* species (H5 and Sac).

Table 3: Compressive strength of concrete prepared with six genotypes of miscanthus [64].

| Genotype | H5 | GiGB | Flo | Mal | Sac | Gol |
|-----------------|------|------|------|------|------|------|
| Leaf/stem ratio | 0.04 | 0.04 | 0.05 | 0.22 | 0.31 | 0.08 |
| Strength [MPa] | 1.67 | 1.51 | 1.50 | 0.90 | 0.46 | 0.32 |

De Vega *et al.* (2021) [65] compare the physiological and molecular responses of different miscanthus species under excessive (flood) and insufficient (drought) water conditions in greenhouses. The results showed that miscanthus species react differently to water stress, depending on their origin and cultivation location. The most common species - Mxg - showed a smaller reduction in biomass yield under drought conditions studied in a soil without ash, and is known for its efficient and sustainable production of lignocellulosic biomass, with minimal environmental impact and minimal fertilization and management [66], [67]: water consumption: 80 to 300 g/g of dry matter [68] [56]; nitrogen intake: 50 kg N/ha, phosphorus input: 10 Unit/ha, potash intake: 50 U/ha [69], [70]. It has also a relatively high yield, producing 19 to 24 t/ha/year of aboveground biomass for four consecutive years on fertile and deep soil in the Northern France, which is higher than the yields of switchgrass, fescue, alfalfa or even triticale (10 to 15 t/ha/year). Another decade-long trial in Europe showed that Mxg produced up to 40 t/ha/year of DM after 2 years of establishment [65].

Another interesting species is the *Miscanthus sinensis* (Msin) with its high stress tolerance, enabling it to grow in colder regions such as Sweden. For instance, while the lethal temperature of Mxg and Msac rhizomes during implantation is between -2.6°C and -3.4°C, some Msin genotypes showed frost resistance of down to -6.5°C. Its salt exclusion mechanism allows it to grow on salty soil, unlike Mxg. Msin also has thinner stems, which increase chloride and potassium leaching while increasing leafiness [5], [71]. Growing miscanthus can enhance soil carbon, aiding in land restoration and climate change mitigation [72]. For instance, the project CE-CARB for energy crops and carbon storage in France reported an important increase in soil carbon stocks, with the lowest levels of net greenhouse gas emissions, in comparison with the annual or multi-annual crops. Miscanthus contributes to soil improvement by surface decomposition and underground degradation that store carbon in the soil. For example, a cultivated area of miscanthus harvested in March and eliminated after 20 years will have stored the equivalent of 1.3 to 3.3 tons of CO₂/ha/year, compared to annual crops. Considering the greenhouse gas emissions emitted during miscanthus planting and harvesting, this leads to an average net storage of around one ton of CO₂/ha/year in France.

These findings demonstrate that miscanthus, particularly the *M. x giganteus* species, has a big genetic diversity, with an ability to adapt to different conditions and is durable. Hence, it's a promising material in the green construction including in low-carbon insulation and bio-based composites.

4.2. Cultivation of miscanthus

The cultivation of miscanthus is an effective and common option worldwide for sustainable agriculture and landscaping projects because of its ecological and economic benefits, durability, ease of use, and aesthetic value.

4.2.1. The cycle

The miscanthus vegetative cycle begins each year in early spring with the growth of the rhizome, where nutrients are stored. During this period, nutrients are transported to the aerial parts until late summer. Nutrients reach aerial portions until the end of summer. At that point, the stems reach three meters, then, senescence begins in late summer and lasts until late winter. At this stage, the leaves fall off and nutrients return to the rhizome. Figure 6 depicts this cycle [73].

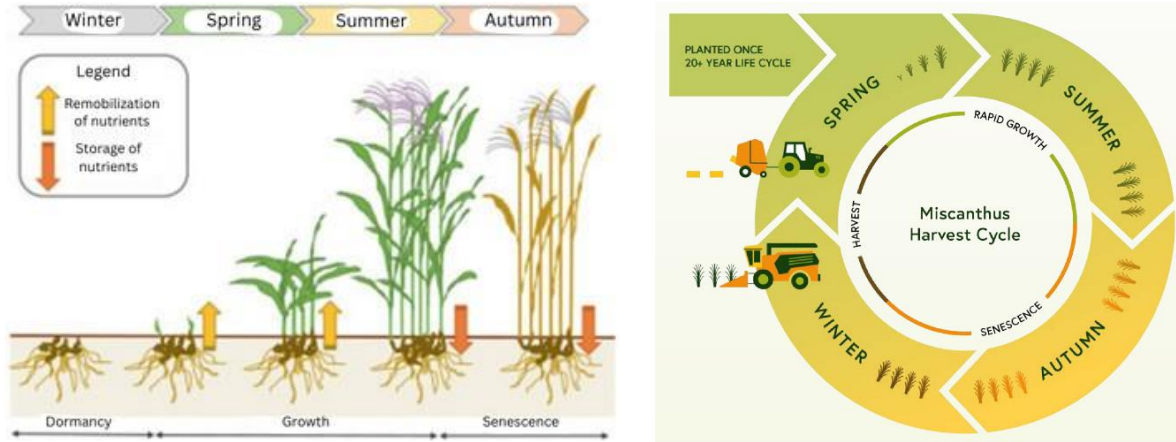


Figure 6: The vegetative cycle of miscanthus [53].

Miscanthus is typically planted for about twenty years, with the recommended planting period being in the spring (April-Mai) when the soil is dry, warmed to 8°C, with a pH between 5.5 and 7.5. However, successful establishment can also occur in the fall (RMT Biomasse, 2012). In figure 7, the vegetative cycle in function of the plant's height is presented for the first three cycles (two years) of its lifetime. It can be seen that it does not reach its highest yield from the first cycle and is returned to the soil at the end of this year. It is at the end of the second growing season (December year 1) that it achieves its maximum height.

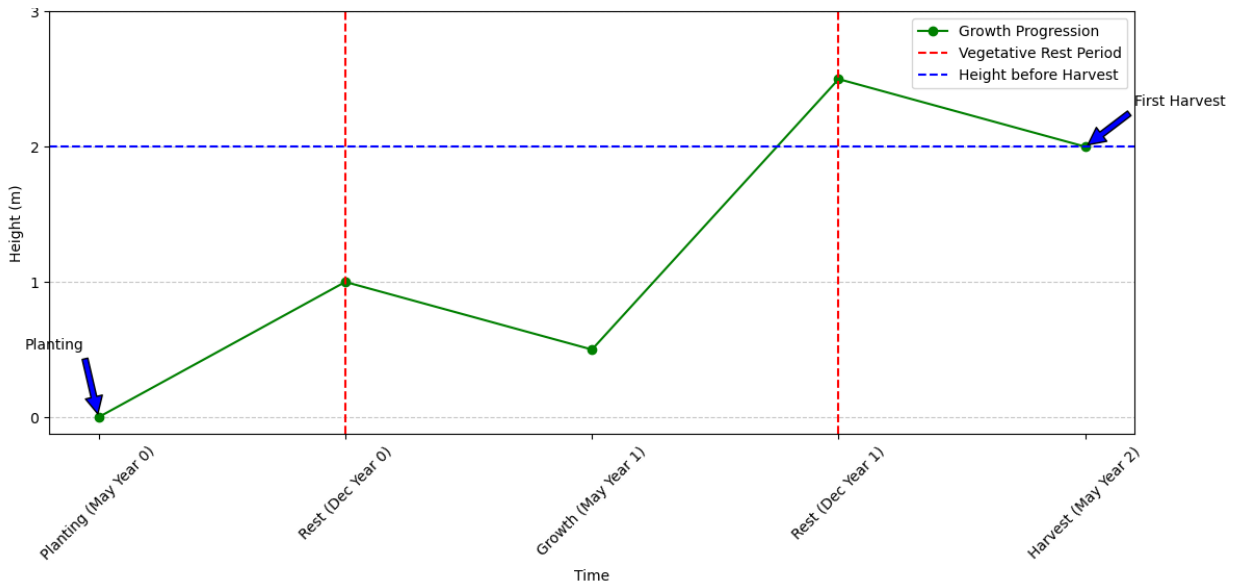


Figure 7: Vegetative cycle of miscanthus (data from: Promisc Belux [74]).

4.2.2. Soil and care

Since miscanthus can be grown directly on unworked soil by removing only pre-existing vegetation, energy crops on marginal lands have been proposed to avoid competition with food crops for soil, water, and other natural resources [75], [76], [77], [78] and [79], and this cultivation is expected to increase in the coming years. MAGIC, the EU project, forecasts 45 million hectares (449,901 km²) of marginal land suitable for Mxg crops in the EU (2023 Terravesta report).

Mulching reduces weed in lands and improves the fertility of soil. A 2023 AgrexConsulting study found that miscanthus mulch is more affordable than wood barks and coconut fibers, costing 6 €/m² (figure 8). In addition, miscanthus is the cheapest raw fiber used in construction, followed by hemp, flax, and bamboo. According to Gbekou et al. (2023) [4], miscanthus can adapt to different climates and soil types and it requires few or no pesticides, water, and fertilizers. Namoi et al. (2024) [70] found that nitrogen fertilization rates (0, 56, 112, and 168 kg N/ha) affected yield components (tiller height, density, and weight) for aging miscanthus, although the best rate depends on site, environmental circumstances, and management history. The impact of nitrogen fertilizer on Mxg appears to be enhanced by irrigation (Cadoux et al., 2014) [80]. For the same biomass, miscanthus needs 18 % less nitrogen than corn or sorghum (Zapater et al., 2016) [81]. Witzel et al. (2016) [82] also noted that soil and harvest type affect fertilizing. In the first year of

cultivation, most researchers recommend irrigating and fertilizing the crops to help rhizome formation as the root system is still developing.

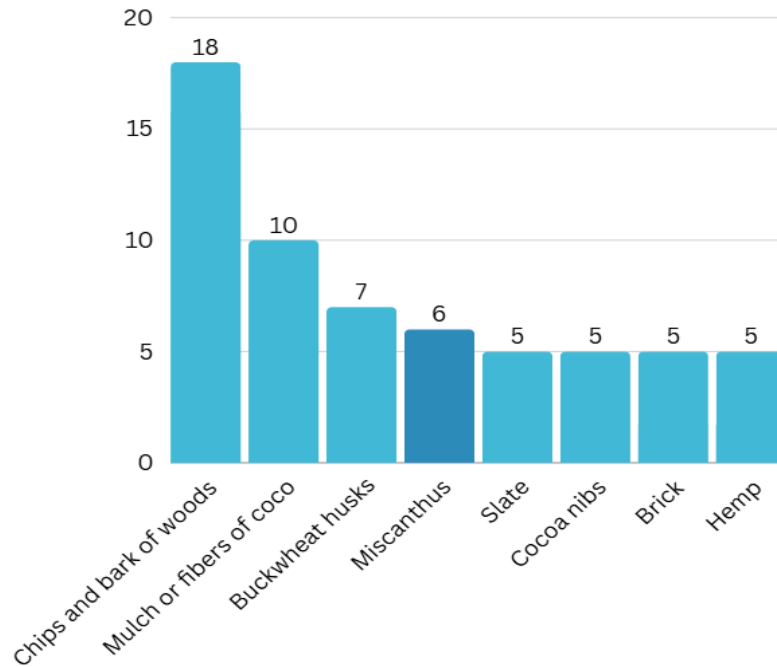


Figure 8: Miscanthus development study in the Seine-et-Marne department (France), cost of installing mulch in €/m² (data from: AgrexConsulting, 2023)

4.2.3. Establishment cost and propagation

The Mxg species requires higher establishing costs than seeds due to its vegetative spread by rhizome cuttings (figure 9) or micropropagation. Establishment costs range from 0.19 to 0.6 €/m². According to the Dordogne Agriculture chamber, a rhizome costs 0.13 to 0.16 € (2021 price), or 0.3 €/m² for 20,000 plants/ha or 2 plants/m² (excluding transport and planting cost). According to Xue *et al.* (2015) [83], miscanthus is best established in Europe by planting rhizome cuttings in a greenhouse in March and moving them to the field in May. Cutting density is usually 16,000 to 20,000 cuttings/ha or 1.6 to 2 cuttings/m².



Figure 9: Miscanthus rhizomes (Source: Novabiom [84]).

4.2.4. Harvest period

Miscanthus can regenerate annually for almost twenty years, except in the first year when it is crushed and returned to the soil in February or March. The true harvest begins in the second year of cultivation, with "green" and "dry" harvests. The "green" harvest is in October, whereas the "dry" harvest takes place at the end of winter (March, April). The "green" harvest yields 15–25 t/ha/year with 40–50 % dry matter (DM).

The "dry" harvest has 70–85 % DM and yields 5–30 t/ha/year. This plant takes three to five years to reach its peak output. Therefore, plant age directly impacts biomass yield. Gismatulina *et al.* (2017) [85] examined Miscanthus grown in Siberia as a function of planting age for the first five years. Table 4 summarizes the main results. The study found that miscanthus biomass yield rises from 2.1 to 14.9 t ha⁻¹ with aging planting.

Table 4: Biomass yields of five miscanthus harvests from different-aged plantation [85].

| Miscanthus age [years] | 1 | 2 | 3 | 4 | 5 |
|------------------------------------|-------------|-------------|-------------|-------------|-------------|
| Biomass yield [kg/m ²] | 0.21 ± 0.01 | 0.45 ± 0.01 | 0.82 ± 0.01 | 1.28 ± 0.01 | 1.49 ± 0.01 |

Gismatulina *et al.* [85] also investigated the effect of the harvesting period and type on the chemical composition of the biomass. In the “dry” harvest also known as late harvest, the cellulose, hemicellulose, and lignin content are 40 to 50 % DM, 25 to 35 % DM, and 7 to 11 % DM, respectively. The harvest period depends on the applications. An early harvest – typically in October- is more favorable for methanization because the biomass has relatively high levels of water and nutrient, while a late harvest- in April- results in dry biomass with a water content below 15 %, which helps lower drying costs, and is more favorable for combustion [86].

These findings present the importance of taking into consideration the planting age and harvest timing of the plant in order to optimize biomass yield and adapt it to specific applications.

4.2.5. Cartography of miscanthus and statistics

Miscanthus, a plant native to Eastern Asia (Japan and China) and originating from Africa, Eastern Asia, and India, thrives across a wide climatic range in warm temperate regions [63]. It is also found in other severe continental climates, such as North America and Siberia [85].

In Europe, miscanthus was first cultivated in Denmark in the 1930s, then cloned and distributed to other European countries. Since 1983, extensive field experiments of Mxg have been conducted in northern Europe, specifically in Denmark, Germany, Ireland and the UK with the JOULE research project [68]. Mxg cultivation then spread to southern European countries such as Italy and Spain with the launch of the European AIR program in 1993. Other European countries interested in cultivating this plant, namely Denmark, Netherlands, Germany, Austria and Switzerland, supporting researches on its propagation, establishment, management, harvest, and handling [87]. In Belgium, about 100 hectares are established, according to Promisc, a leading miscanthus cultivation company in Belgium [74].

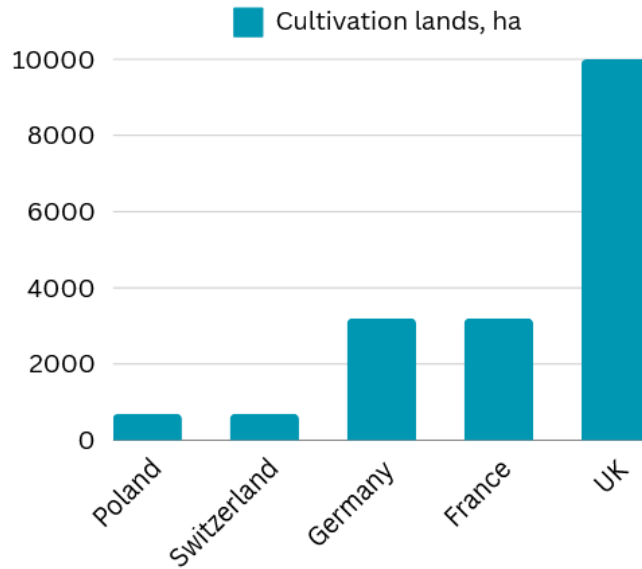


Figure 10: The distribution of miscanthus plantation in the European union countries (2016) [88], [89].

In France, miscanthus was cultivated since 2000 and is mainly grown in northern regions of the country, but it can also be found in other regions. The most important regions for this cultivation are Pays de la Loire (1,800 ha cultivated in 2022), Normandy (1,200 ha), Centre Val de Loire (1,200 ha) and Hauts de France (1,200 ha). Till now, French miscanthus cultivation is based on the use of a single clone of Mxg. Novabiom [84], a renowned French miscanthus cultivator, provided the table 5 below - whose source is France Miscanthus [90] - showing the number of farms and hectares cultivated with miscanthus in France between 2015 and 2023. (Source: France Miscanthus [90]).

Table 5: Evolution of areas cultivated with miscanthus in France in the past 9 years.
(Source: France Miscanthus [90]).

| Year | 2015 | 2016 | 2017 | 2018 | 2019 | 2020 | 2021 | 2022 | 2023 |
|--------------------------------------|------|------|------|------|------|------|------|------|--------|
| Area cultivated with miscanthus [ha] | 4008 | 4555 | 5079 | 5433 | 6440 | 7200 | 8426 | 9577 | 10,581 |
| Number of farms growing miscanthus | 951 | 1088 | 1220 | 1348 | 1629 | 1807 | 2124 | 2327 | 2467 |

The surface area and number of farms growing miscanthus have doubled since 2017. In the next section are presented the main outlets and utilizations of miscanthus, specifically in France.

4.3. Applications

Miscanthus has numerous sustainable applications, reducing waste by repurposing its biomass across various industries. As illustrated in figure 11, nearly all parts of the plant - leaves, stems, and rhizomes - are utilized, especially in bioenergy, soil improvement, and construction.

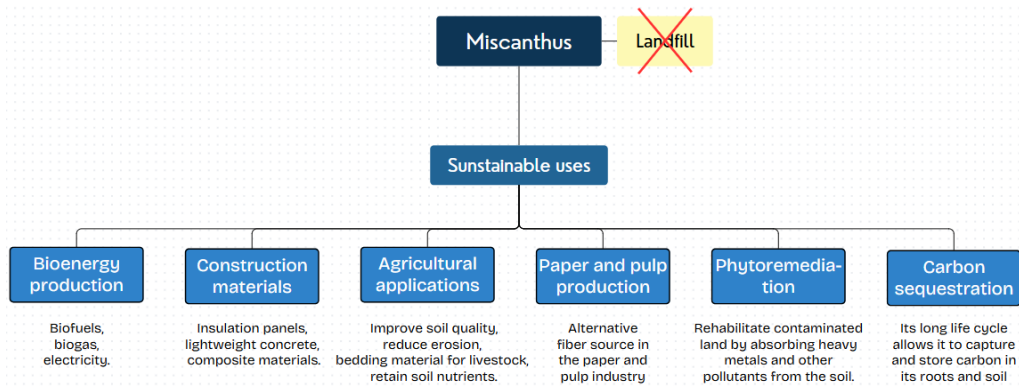


Figure 11: Sustainable valorization pathways for miscanthus.

Historically, over 10,000 years ago, miscanthus is native to Eastern Asia – Japan, Korea, China and extending to southeast Asia – where it has been used in house construction, particularly for lightweight concrete and fiberboard [5]. Stewart et al. (2009) [91] frame *Miscanthus sinensis* as a culturally and ecologically significant grass in East Asia—especially Japan—where it has shaped landscapes and traditional architecture for millennia. They note that *Miscanthus sinensis* has been used in semi natural grasslands maintained for centuries in Japan, where local communities traditionally harvested it for constructing thatch roofs and lightweight wall cladding in farmhouses, temples and shrines. Thatched roofs made from susuki (*M. sinensis*) were known to last 50–70 years in traditional practice. They further explain that in regions such as Kumamoto, these grasslands have been managed via controlled burning for over 10,000 years, indicating a very long history of human utilization of *M. sinensis* in domestic and communal structures.

Today, the high productivity, energy ratio, and lignocellulosic content of miscanthus make it a promising resource for sustainable cement mortars where mineral aggregates are partially or totally replaced with renewable plant fibers such as miscanthus, which results in reducing density, improving thermal insulation and lowering embodied carbon [4]. While cement is commonly used as a binder in these composites, some studies also explore partial substitution with supplementary cementitious materials such as fly ash or metakaolin to enhance sustainability. Compared to lightweight concrete, these mortars are typically used for non-structural applications such as insulating renders, plasters, or partition elements [4]. For example, cement-miscanthus mortars with 20–40 % miscanthus volume fraction have demonstrated thermal conductivity reductions to ~0.07–0.10 W/m·K, while maintaining compressive strengths between 0.5 and 3 MPa, depending on the binder-to-aggregate ratio and pre-treatment of the fibers [92], [4]

In the energy sector, miscanthus is used as solid fuel with higher energy value than wood (4,700 kWh/t and 3,300 kWh/t respectively)[5]. It is also used to make bioethanol with half the environmental impact of switchgrass-based bioethanol [66], [93]. The obtained biofuel has a moisture content of around 15 %, making it simple to market and transport.

Other uses of this plant include: animal bedding (due to the spongy core of the stem which makes it highly absorbent), feeding, yellow dye manufacture, bags for charcoal transportation and organic fertilizer, methanization, green chemistry used in food or pharmacology [94], bio-sourced plastics (automotive industry, flower pots, etc.), paper production and cotton fabric [95], biodegradable geotextiles, phytoremediation or even for the use of biochar from pyrolysis of biomass as an amendment [96].

Table 6 compares the energy input and output of different biomass, including miscanthus that it presents the highest energy yield, with an energy output/input ratio of 32.52. This high energy efficiency explains its potential for use in renewable energy systems.

Table 6: Energy Input and Output for various crops [63]

| Cultivation | Energy-in [kWh/ha] | Energy-out [kWh/ha] | Ratio |
|-------------|--------------------|---------------------|-------|
| Canola oil | 5.386 | 20 | 3.71 |
| Hemp | 3.692 | 31.25 | 8.47 |
| Miscanthus | 2.561 | 83.333 | 32.54 |
| Wheat | 5.964 | 52.594 | 8.82 |
| Willow | 1.667 | 50 | 29.99 |

The graphs in figure 12 below present the main outlets of miscanthus plant in France: combustion, animal bedding, horticultural mulching, and bovine rumination. Also, they compare the primary usages of miscanthus in France between years 2014 and 2021 (data from Novabiom company). The usage of miscanthus in combustion decreases from 60 % to 20 % while the animal bedding increases by 22 % and the horticultural mulch by 15 %. This considerable shift indicates the shift in the priorities in the biomass and sustainable energy.

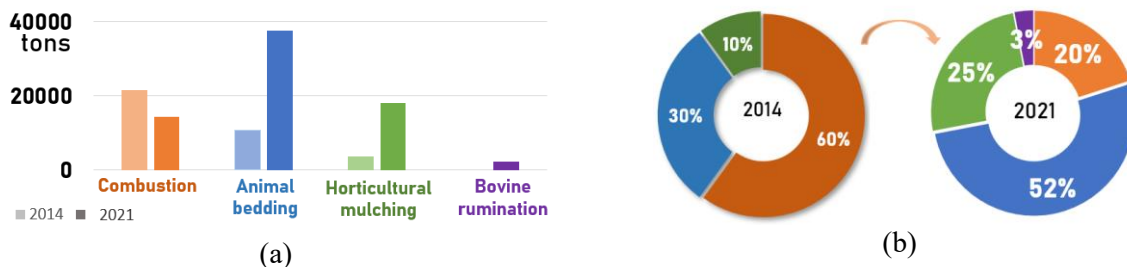


Figure 12: Comparison of the miscanthus outlets in 2014 and in 2021; (a) Quantity (in tons) (b) percentage; (Source: Novabiom [84]).

The following map (figure 13) shows some miscanthus-based projects in France. As can be seen, the crop is mainly cultivated in the northern regions, with ongoing efforts to establish and develop an efficient value chain from farm to industry.

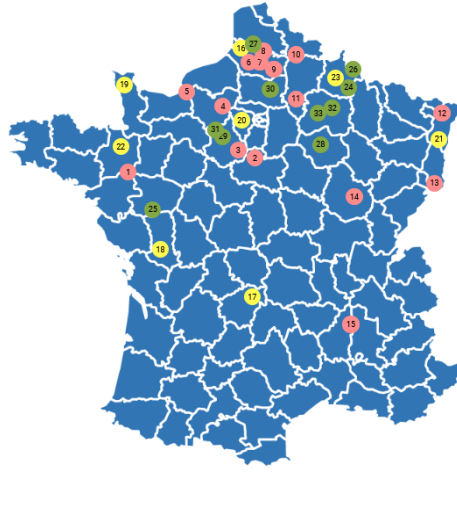


Figure 13: Map of France indicating projects made by miscanthus (source: France Miscanthus) [90].

Map legend and primary informations:

- 1- SCI La Dionnais in Noyant-la-Gravoyère, heating 580 m² of buildings, hot water production, 4 hectares of miscanthus planted in 2015, heating savings enabling boiler investment and plantation to be amortized in 10 years.
- 2- Champhol, Heating the Château de Vauventriers (8 homes), 230 linear meter heating network, 6.5 ha of marginal land planted with miscanthus 1 km from the boiler, annual savings of €23,600, return on investment in 30 months.
- 3- Thimert-Gatelles, Heating 300 m² of homes and domestic hot water, 1 ha of miscanthus planted in 2008, annual savings of €3,450 compared with fuel oil.
- 4- Tilly, Heating of 700 m² of buildings and domestic hot water, 7.5 ha of miscanthus planted in 2008, annual savings of €8,000 compared with fuel oil.
- 5- Conteville, heating for the farm, domestic hot water, 6 ha of miscanthus planted in 2015, miscanthus used for a variety of mulch and bedding applications, considerable time savings compared with heating with wood.
- 6- Hangest-sur-Somme, heating a 240 m² house, offices and domestic hot water, promoting the miscanthus heating solution on a regional scale and helping to promote miscanthus sector in France, 245 ha planted between 2007 and 2011.
- 7- Hangest-sur-Somme, heating of 1,000 m² of communal buildings (town hall, school complex, canteen), 6 ha of miscanthus planted on communal land, annual savings of €13,000.
- 8- Allaines, heating of a 5,000 m² building and domestic hot water, 4 ha of miscanthus planted between 2010 and 2012.
- 9- Omiecourt, heating of a 400 m² castle, two 320 m² gîtes, two swimming pools, jacuzzi, sanitary water, 7 ha of miscanthus planted in 2014, annual savings of €40,000 compared with the fuel oil situation.
- 10- Herleville, heating for 8 rental dwellings (500 m²), housing for farmers, camping area, hosting an educational farm, a total of 760 m², 2.7 ha of miscanthus planted in 2012.
- 11- Ourscamp, Heating the entire abbey, 10 hectares of miscanthus planted in 2015-2016, annual savings of €60,000, with a return on investment of less than 5 years.
- 12- Brumath, solving recurrent problems of sludge flows, preserving water resources within the catchment area, increasing heating capacity to heat 7,055 m² of municipal buildings, 15 ha of miscanthus planted in 2012, return on investment in 7 years thanks to subsidies (ADEME, FEDER, region...).

- 13- Ammertzwiller, improving water quality, which had been deteriorating for 20 years, using the harvest as fuel to heat 60 homes and public buildings, 27 hectares of miscanthus planted in 2009-2010, Reduction in nitrate levels in Ammertzwiller wells by more than 18 % between 2009 and 2013, slowing of sludge flows, atmospheric emissions meeting current standards.
- 14- 100 % miscanthus heating at Bourgogne Pellet, since 2011, (Aiserey) heating with miscanthus, including radiators, floors and the bagging line in the warehouse, Guntamatic Powercorn boiler – 50 kW, boiler feed: 100 % miscanthus pellets produced on site, consumption: 8-10t of pellets.
- 15- Montéléger, heating a 200 m² house and domestic water, reducing the CO₂ footprint, 0.9 hectares planted 60 m from the silo.
- 16- Turkey farm at Saily Flibeaucourt, 2.8 flocks of 20,000 turkeys per year, miscanthus litter since 2014, 100 t/year, 7 ha planted in 2015-2016 for litter autonomy, improved health (legs) and better cleanliness.
- 17- Duck farm at Riouzal, Sexcles, 3.5 flocks of 10,700 IGP Sud-Ouest ducks per year, miscanthus litter since 2016, 100 t/year, less lameness and brush problems, cleaner animals, less dust and therefore fewer respiratory problems.
- 18- Turkey farm at Neuil les Aubiers, 2.4 batches of 21,000 turkeys a year, a few batches of chickens, miscanthus litter since 2016, 4 ha of miscanthus planted in 2016 for litter autonomy, reduced dust, aspergillosis problems, pododermatitis, less mortality and veterinary costs.
- 19- Pony Club and equestrian center in Nicorps, 24 stalls of 16 m², 12 of which are mulched with miscanthus, miscanthus litter dusted (1 to 5 cm) since 2010, 2.5 ha planted in 2009 for litter autonomy, reduction in allergy cases and improvement in the health of feet, no cases of colic since switching to miscanthus.
- 20- Western Equestrian Centre in Grosrouvres, 22 12 m² stalls, miscanthus pellets on concrete floor since 2015, 15 t/year, cleaner horses, less odours and no colic, stalls mulched twice as quickly as with straw, drastic reduction in manure volume, recycled through vermicomposting.
- 21- Veterinary clinic in Truchtersheim, approximately 20 cubicles of 6 to 9 m² mulched with miscanthus, miscanthus litter since 2014 (50 t/year pellets, 3 t/year shavings), annual savings of 10 % on litter compared with wood shavings, more regular quality and easy supply, miscanthus manure spreadable without soil acidification.
- 22- Dairy farm in Le Tiercent, 700,000 L of milk produced per year, miscanthus litter in straw bedding since 2016, 11.5 t/40 days for 110 dairy cows, fewer cases of mastitis, cleaner cows, extra cost of €12/day offset by 1h15 less work for a worker who would cost €25.
- 23- Dairy farm at Auboncourt-Vauzelles, 64 Prim'Holsteins in cubicles, 45 suckling dams and 70 bullocks, miscanthus litter in crumbled granules since 2013, 9 t/year for 64 cubicles, saves maintenance time, litter more absorbent and less sticky to the cubicles, extra cost of €2.5/day compared with straw meal, offset by daily savings of €5 in labour.
- 24- Horticultural mulching in Hubert Fontaine's Garden (Coulommès and Marquény), Hubert Fontaine, a well-known gardener in the Ardennes, uses miscanthus mulch over several hundred m², the aim being to protect plants (from heat and frost) and nourish the soil, mulch thickness: between 7 and 10 cm in the first year.
- 25- Horticultural mulching at Château Colbert (Maulévrier), large vegetable garden of 8,000 m² + 7,000 m² of floral park, objective: to enhance the gardens and vegetable plots without inputs, aesthetic, hard-wearing mulching that enriches the soil, thickness chosen: between 5 and 10 cm, renewed every 6 months miscanthus mulch.
- 26- Horticultural mulch in Rethel's flower beds (Champagne Ardennes), the town uses miscanthus mulch since 2009, with the aim of implementing the national "Zéro Phyto" regulation as an alternative to chemical weedkillers, a local, easy-to-use and cost-effective product (4 times cheaper than cocoa

beans), thickness chosen: between 5 and 8 cm, renewed every year in April, results: effective weedkiller, water savings.

- 27- Horticultural mulching in Amiens' flowerbeds, Amiens and the 38 surrounding municipalities have been using miscanthus mulch since 2013, objective: to implement the national "Zero Phyto" regulation, a local product, easy to use and economical (transport costs), thickness chosen: between 5 and 7 cm to start with, then 2/3 cm when necessary, results: effective weedkiller, savings and no nitrogen hunger problem.
- 28- Horticultural mulching in Aube vineyards, project since 2014, nearly 1.5 ha mulched, i.e. 11 tons of miscanthus, objective: sustainable alternative to chemical weeding, thickness chosen: around 10 cm, renewed every 2 years, results: effective weedkiller, no fungus.
- 29- Horticultural mulching in Chartres, several thousand m² mulched with miscanthus = 300 m² of bulk / year, Project in existence since the early 2000s, thickness: layers of 8 to 10 cm renewed every year in February/March, an economical mulch (the cheapest) and very easy to use, miscanthus is excellent for retaining moisture and allows the plant to breathe.
- 30- Horticultural mulching in Compiègne, several thousands of m² of beds mulched with miscanthus, a project still ongoing since 2015, thickness: ~10 cm and renewed every 2 years, limits weed growth, trap moisture and contribute in esthetic contrasts.
- 31- Horticultural mulching at Digny, several thousand m² of beds mulched with miscanthus since 2012 in order to reduce maintenance, respect the zero pesticide policy known as "zero phyto", thickness adopted: ~10 cm and re-adjusted every year with elimination of weed, healthy mulching for gardening teams, sustainable and effective.
- 32- Horticultural mulching in vineyards in the Marne, around thirty acres mulched with miscanthus since February 2018, a quality mulch compatible with organic farming, 2 to 6 cm sprigs, a 5 cm layer laid on 15 cm of straw.
- 33- Horticultural mulching in vineyards in the Marne, twenty acres mulched with miscanthus in October 2018, a 10 cm layer, mulched between rows with clover, or directly under the plants, convincing results: elimination of quackgrass, gives new life to the soil: during the heatwave of 2019, the soil remained cool.

All these mentioned works and others demonstrate that miscanthus is being used in different ways especially in the building activity across France and focused mainly in the northern region where it's mostly cultivated.

4.4. Chemical composition of miscanthus

Various researchers have studied the chemical composition of miscanthus; findings are summarized in table 7. Miscanthus has a high holocellulose content (combined content of cellulose and hemicellulose) where cellulose is responsible for its structural strength. Cellulose fibers can swell to some extent in water or aqueous alkaline media, which can pose a problem when used in concrete or bio-based construction materials. Lignin renders the cell wall hydrophobic and helps to protect lignocellulosic materials from microbial degradation. The mineral content of miscanthus is lower than wheat straw, but higher than for willow/ poplar coppice. Miscanthus stores nitrogen in proteins and amino acids, and carbon in starch and sucrose. Phosphorus is stored as inorganic or polyphosphate, while potassium and magnesium are stored as ions. Calcium is not stored [97]. Note that late harvesting (February, March) reduces moisture and mineral content of miscanthus [68], [98].

Table 7: Chemical composition of miscanthus. Remark: Units are homogenized for better comparability; the values of moisture in the table are weight percentages of the biomass.

| Type | Cellulose (%) | Hemicellulose (%) | Lignin (%) | Ash (%) | Other (%) | Reference |
|---|---------------|-------------------|------------|-----------|--|-----------|
| Mxg (Picardie, France) | 45.5 | 22.19 | 21.89 | | | [57] |
| <i>M. sinensis</i> (Picardie, France) | 49.38 | 25.16 | 22.7 | | | [57] |
| <i>M. sacchariflorus</i> (Picardie, France) | 54.03 | 24 | 20.92 | | | [57] |
| Mxg (Larsen, Denmark) | 52.13 | 25.76 | 12.58 | 2.74 | Moisture: 4.9 | [98] |
| <i>M. sinensis</i> (Brander, Denmark) | 45.52 | 33.83 | 10.32 | 3.04 | | [98] |
| <i>M. sacchariflorus</i> (Deuter, Germany) | 50.18 | 28.11 | 12.13 | 2.16 | Moisture: 4.1 | [98] |
| <i>M. sinensis</i> (Deuter, Germany) | 45.36 | 32.99 | 9.7 | 2.71 | Moisture: 4.5 | [98] |
| <i>M. sinensis</i> (Andersson, Sweden) | 52.2 | 30.56 | 9.34 | 2.22 | 4.5 | [98] |
| <i>M. floridulus</i> | 66.98 | 13.86 | 6.97 | | Wax: 4.38 Pectin: 1.99 | [99] |
| Miscanthus (not specified) | 40 | | 16.2 | | Si: 1.8 | [69] |
| Miscanthus (not specified) | 36.5 ~43.3 | | 9.3 ~ 16.3 | 0.4 ~ 3 | | [51] |
| Miscanthus (not specified) | | | | 1.6 ~4.02 | N: 0.2 ~ 0.6; K: 0.5 ~ 1.3; Cl: 0.1 ~ 0.5; | [63] |
| Miscanthus (not specified) | 51 | 28 | 11 | 1 | Solubles: 9 | [100] |
| Miscanthus (not specified) | 45.7 | 22.8 | 20.2 | 2.8 | Moisture: 8 C: 48.3 H: 6 N: <0.3 O: 45.7 | [101] |

The table shows that the chemical composition of the miscanthus studied is affected by its location of origin and its species. The cellulose content varies between 36.5 % and 54.03 %, the hemicellulose content between 16.2 % and 33.83 % and the lignin content between 9.7 % and 22.7 % for the different species. In general, *M. sacchariflorus* tends to have higher cellulose and lower lignin compared to other species, while *M. sinensis* shows variable cellulose and hemicellulose content, but generally higher lignin content

compared to *M. sacchariflorus*. Also, Mxg from Denmark have higher cellulose and hemicellulose contents and lower lignin content compared to Mxg from France. These variations likely result from a combination of favorable environmental conditions, agricultural practices, and possibly genetic or harvest timing differences. These factors highlight the importance of location-specific studies when optimizing biomass crops like miscanthus for different applications.

In addition, the chemical composition of miscanthus varies within different parts and cell walls of the plant, according to Ntimugura *et al.* (2020) [102]. Pre-pulse vegetation measurements performed by Briones *et al.* (2023) [67] revealed that leaves, stems, and rhizomes had higher carbon contents compared to roots. The Mxg species exhibited the lowest carbon content in its roots relative to the other carbon pools.

Thermogravimetric analysis TGA:

Different research groups have examined the thermal stability of miscanthus stem fragments. In 2020, Chupin *et al.* (2020) [103] used Thermogravimetric Analysis (TGA) to evaluate six miscanthus genotypes from 25 °C to 400 °C at a rate of 10 °C/min and 400 °C to 800 °C at 50 °C/min for various particle sizes (100 and 200 µm). They found a strong correlation between miscanthus fragment size and biochemical and structural features. The first mass loss, up to 120 °C, corresponds to the evaporation of residual water in the samples. The main components of the stem pieces—cellulose, hemicellulose, lignin, and other non-cellulosic components—depolymerized and decomposed by oxidative pyrolysis at 180 °C –360 °C, resulting in the second mass loss. The final mass loss occurs between 360 °C and 540 °C due to thermal decomposition of lignin aromatic rings and the residue from the first degradation stage. As for the effect of the particles size, it was found that when the fragments size decrease, the mass loss between 180 and 360 °C increases. The weight loss of miscanthus is 71.2 % corresponding to a peak temperature of 331.17 °C based on a study conducted by Sergio Pons Ribera *et al.* (2023) [100] who noticed that miscanthus presents the largest weight loss percentage compared to bamboo (68.42 % at 328.42 °C), hemp (41.06 % at 352.93 °C), and flax (40.24 % at 352.44 °C). This is due to the higher lignocellulosic content in the miscanthus aggregates.

M. sacchariflorus (Msac) showed a main degradation peak on the Derivative Thermogravimetric (DTG) curve with a secondary peak at 300 °C, indicating hemicellulose disintegration, according to Kim *et al.* (2014) [104]. Heating and pretreatment conditions greatly affect thermal deterioration. Cortés and Bridgwater (2015) [105] increased the heating rate from 2.5 to 25 °C/min, raising decomposition temperatures by 50 °C: the peak decomposition passed from 310 °C to 364 °C. The shift of the TGA curves to higher temperature values with the increase of the heating rate is due to the increasing effect of heat transfer limitations.

This section demonstrates that the thermal stability and decomposition behavior of miscanthus are influenced by its lignocellulosic composition, particle size, and heating conditions. These properties, particularly its thermal degradation profile and high lignocellulosic content, make it a promising candidate for bioenergy applications such as combustion, pyrolysis, and gasification. In addition, the chemical composition of miscanthus leads to good thermal insulation properties. This composition includes a high cellulose and hemicellulose, improving porosity and structural cohesion. Also, the lignin content enhances rigidity and moisture resistance.

4.5. Microstructure of miscanthus

The external surface of miscanthus aggregates presents high roughness zones and smoother surfaces. The rough areas contain waxes as metabolites while the smooth surface presents an elongated honeycomb structure. This lamellar structure constitutes the remains of the stem's water and mineral transportation system. As with most biomass, miscanthus is highly porous. Compared to hemp, it has larger, more closed pores and pitted vascular tracheary sections [106], [107]. Larger interior cavities are ~20 µm wide and ~40 µm long. Their surface is lined with small pores spaced approximately ~10 µm apart in a relatively regular

pattern. This porosity enhances the thermal, hygroscopic, and acoustic properties of the incorporated material. The figures below show the smooth aspect of miscanthus from the outside (figures 14 (a) and (b)) and its porosity from the inside (figures 14 (c) and (d)). Micrographs were taken using the KEYENCE VHX 970 numerical microscope with various magnifications (x20 to x200) by the authors.

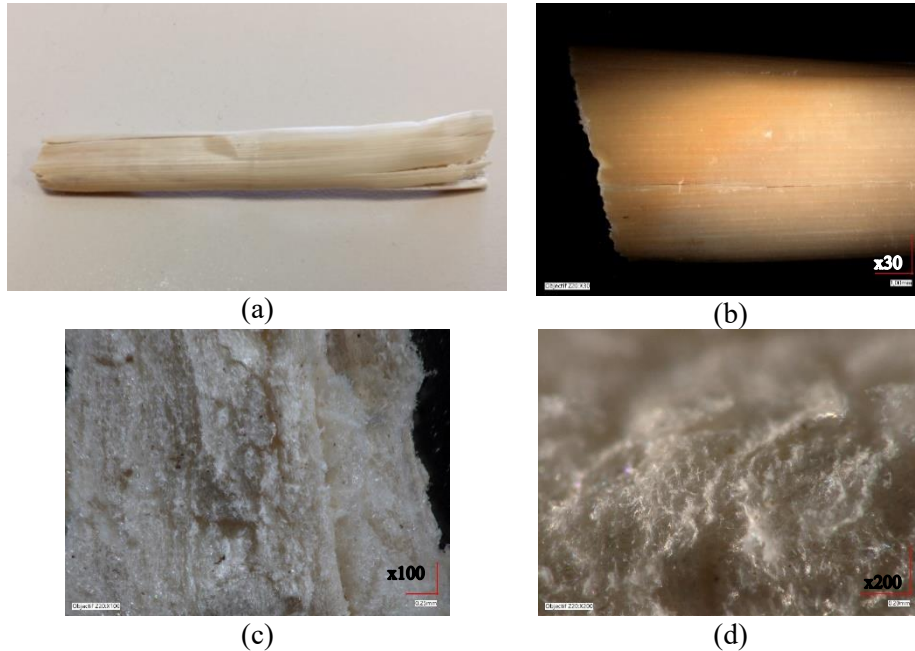


Figure 14: Picture of a miscanthus aggregate (a) from the outside without microscope and (b) microscopic view of miscanthus from the outside x 30 and (c) from the inside x 100 and (d) x 200.

Effect of the microstructure on the construction materials

In the work done by Hamdi et al. (2015) [108] they tested two techniques including the X-ray tomography and the 2D scanning to study the morphology of miscanthus and other natural fibers. They found many large bundles and fibers with high porosity ratios. This microstructure and heterogeneity of miscanthus particles affect the performance of the obtained construction material. For instance, the thermal conductivity is highly affected by the increased porosity of miscanthus and the compaction factor as well as the microstructure. The thermal conductivity of loose, open structure varies between 0.04 and 0.06 W/m.K [44], and of densified and poorly processed miscanthus, between 0.09 and 0.11 W/m.K [109]. As for the mechanical properties, the fiber length, cell wall thickness and aspect ratio affect directly the mechanical strength where relatively short and untreated fibers reduce the flexural strength from a range of 0.6~1.2 MPa with alkaline treatment to 0.15~0.3 MPa for untreated fibers [110].

4.6. Physical properties of miscanthus

Biomass in general presents good thermal properties, which are highly influenced by moisture content and relative humidity of the surrounding atmosphere thus understanding the physical and chemical properties of miscanthus helps to determine its behavior and potential applications, particularly in the construction.

4.6.1. Density of miscanthus

The bulk and particle densities of miscanthus were studied by Chen *et al.* (2017) [111] for different sizes of aggregates. Table 8 summarizes the results showing that both densities increase with the aggregates size (0-2 mm and 2-4 mm). This increase in density appears contradictory because when the particles are smaller in size, the packing becomes more efficient (better settlement) and results in higher bulk density. In the case presented by Chen *et al.*, the increase in the bulk and particle densities may be due to the fact that larger aggregates may have allowed for more stable structural packing and reduced inter-particle void due to particle morphology. The skeletal density of all sizes of miscanthus aggregates are almost the same (around 1.4 g/cm³) because they have the same chemical components: cellulose, hemicellulose and lignin of densities 1.559 g/cm³, 1.52 g/cm³ and 1.26 g/cm³, respectively [75]. This skeletal density of miscanthus can be justified by considering the weighted average of the structural components of Mxg: assuming average mass fraction of 45 % for cellulose, 30 % for hemicellulose and 20 % for lignin, and using the densities just mentioned, the theoretical skeletal density of miscanthus is approximately 1.41 g/cm³. This aligns well with experimental values reported in table 8 below. As per the authors [111], the bulk density is the particles mass of a material divided by the total volume it occupies, while the particle density in [111]- is the density of material that particles are composed of, excluding the inter-particle void volume (open pores). Finally, the skeletal density is the density that excludes both the inter- and intra-particle void volume.

However, in the study by Sergio Pons Ribera (2023) [100], as seen in table 8, the opposite trend was observed: a decrease in the absolute density of miscanthus fibers with an increase in their size.

Table 8: Bulk and particle densities of miscanthus aggregates.

| Size of miscanthus aggregates | Species of miscanthus | Bulk density [g/cm ³] | Particle density [g/cm ³] | Absolute (or specific or skeletal) density [g/cm ³] | Reference |
|-------------------------------|---------------------------------|-----------------------------------|---------------------------------------|---|-------------|
| Powder | Mxg | 0.1556 | 0.174 | 1.41 | [111] |
| 0 - 2 mm | Mxg | 0.0776 | 0.222 | 1.406 | [111] |
| 2 - 4 mm | Mxg | 0.1194 | 0.25 | 1.4 | [111] |
| 5 mm | Mxg | | | 1.297 | [100] |
| 15 mm | Mxg | | | 1.1263 | [100] |
| > 5 mm | <i>M. floridulus</i> upper part | - | 0.53 | 1.027 | [103] |
| > 5 mm | <i>M. floridulus</i> lower part | - | 0.63 | 1.157 | [103], [21] |
| > 5 mm | <i>M. sinensis</i> upper part | - | 0.665 | 1.172 | [103] |
| > 5 mm | <i>M. sinensis</i> lower part | - | 0.443 | 1.039 | [103] |

The difference in density values observed in the table is related to the size of the studied aggregates and the species of miscanthus.

In addition, Chen *et al.* (2017) studied the porosity of the same materials and found that both the inter- and intra-particle porosities decrease with the particle size. Smaller aggregates of 0-2 mm have 65.1 % inter-particle porosity, while 2-4 mm have 52.2 %. As for the inter-particle porosity, 0-2 mm aggregates have a 58.1 % porosity while 2-4 mm aggregates have a 38.3 % porosity [111]. Aggregates are characterized by a high porosity and low density. Chupin *et al.* (2020) [103] revealed how miscanthus stem fragment genotypes and position (upper and lower parts of the plant) affected absolute (specific) density (between 1.027 and 1.157 g/cm³), particle density (between 0.53 and 0.63 g/cm³), and volume porosity (between

0.911 and 0.724 cm³/g). Mxg clones had specific densities of 1125–1157 kg/m³ for the lower part of the stem and 1.027–1.089 g/cm³ for the higher part. The lower section of *M. sinensis* clones had a higher specific density of 1.172 g/cm³ and the upper part 1.039 g/cm³. However, the particle density of Mxg is still lower than *M. sinensis* for the lower part of the stem (average of 0.6335 g/cm³ and 0.665 g/cm³), while the opposite is true for the upper part (average of 0.4925 g/cm³ and 0.443 g/cm³, respectively). The pore volume of *M. floridulus* varies between 0.724 and 0.911 cm³/g and between 0.65 and 1.296 cm³/g for the *M. sinensis*, as per Chupin et al. [90]. The volume porosity ϕ is calculated based on the apparent ρ_{app} and specific densities ρ_{spe} for *M. floridulus* according to equation (1) below:

$$\phi = 1 - \frac{\rho_{app}}{\rho_{spe}} \quad (1)$$

Thus, the porosity of *M. floridulus* varies between 45.5 % and 48.4 %, and the porosity of *M. sinensis* between 43.3 % and 57.4 %.

Potential of miscanthus in thermal insulation:

It has already been proven that miscanthus fibers have relatively high thermal insulation capacity and it can be used in passive noise when subjected to treatments. Notably, inclusion of 30 % in volume of 2–4 mm miscanthus fibers in concrete showed outstanding dual performance, achieving optimal thermal conductivity of 0.09 W/(m.K) and 90 % acoustic absorption at 841 Hz of the obtained bio-based concrete [112].

Regarding the fire protection properties of miscanthus, untreated miscanthus exhibits relatively high flammability, with a peak heat release rate (pHRR) of 178 W/g and a total heat release (THR) of 12.4 kJ/g, indicating intense and continuous combustion, based on the work of Khalaf et al. (2025) [113]. The pHRR occurs at a relatively high temperature of 381 °C with minimal char formation. This contributes to a complete burning process of the material. These characteristics highlight the necessity of chemical treatment—specifically treating with phytic acid and urea—to significantly improve fire resistance. Before using it in the production of particle panels, miscanthus had never undergone fireproofing treatment [113].

From the ecological point of view, the study of Witzleben and al. (2022) [114] revealed that the global warming potential (GWP) of an insulation system made from miscanthus fibers, meeting current thermal insulation standards, results in a 95 % reduction in CO₂ emissions compared with conventional systems. This offers an eco-friendly option for thermal insulation in buildings because miscanthus stems possess special properties, particularly in terms of strength and elasticity, making them effective materials for insulation.

Additionally, the hygroscopic behavior of the bio-based fibred materials allows moderate moisture buffering (up to ~3.6 g/m²·%RH) by adsorbing temporarily excess water vapor when air is humid, which can help regulate indoor humidity and slightly stabilize thermal conditions. However, excess moisture can reduce insulation performance by increasing thermal conductivity [115].

4.6.2. Thermal conductivity

In this section the thermal conductivity of miscanthus aggregates is presented based on different works present in the literature. The thermal conductivity is estimated at 0.051 W/(m. K) for original unfractionated samples at 10°C [116]- measured with a lambda-meter according to EN 12667 (2001) [117] - but its specific heat is often absent despite being essential for assessing the material's thermal behavior [118]. The unfractionated miscanthus straw in the work of Schnabel et al. [116] refers to the bulk straw material as

shredded, without any separation into specific size ranges, that will after be air-dried, shredded using a customary shredder and subjected to steam explosion [103], [116], [111].

Studies of thermal conductivity is typically reported on dry-state of the raw aggregates since the thermal conductivity increases with the moisture content due to the high absorption capacity of miscanthus (up to 525 % by weight) [119]. For the same size of aggregates, conductivity increases with relative humidity: for the 15 mm aggregates for instance, a thermal conductivity at 15 % RH is $53.2 \times 10^{-3} \text{ W/(m.K)}$ and increases till reaching $63.7 \times 10^{-3} \text{ W/(m.K)}$ at 80 % RH. However, this thermal conductivity decreases with the increase of the aggregates size because larger aggregates create more void spaces (higher porosity) in the material, reducing the solid-to-solid contact needed for heat transfer, which results in lower overall conductivity. Higher porosity means more air pockets, which are poor conductors of heat.

There is still little data published in the literature on the thermal conductivity of miscanthus in its raw form, although more information is available on composites and by-products made from it.

Compared to other lignocellulosic materials, miscanthus exhibits a similar thermal conductivity - comparable to hemp shives ($0.05\text{--}0.10 \text{ W}\cdot\text{m}^{-1}\cdot\text{K}^{-1}$) [15] and straw ($0.04\text{--}0.08 \text{ W}\cdot\text{m}^{-1}\cdot\text{K}^{-1}$) [120] - making it a promising raw material for insulation.

Mason *et al.* (2016) [121] studied the thermal conductivity of miscanthus pellets used as biomass fuel, after being milled and crushed to below $90 \mu\text{m}$ size, they were then compressed into pellets of 13 mm diameter. The thermal conductivity obtained is 0.157 W/(m.K) for a so called by the authors miscanthus a and 0.15 for the so called miscanthus b. Miscanthus a and b differ slightly by the density, percentage of moisture, volatile matter, ash and fixed carbon. The corresponding densities for miscanthus a and b are 1.137 g/cm^3 and 1.172 g/cm^3 , respectively.

4.6.3. Mechanical properties

The elastic modulus (also known as Young's modulus E) for grasses, including miscanthus aggregates, varies between 5,000 and 10,000 MPa according to Kaack *et al.* (2001) [122]. It is measured using an Instron apparatus equipped with 50 kg load cell and a thin metal plate with a plunger pressed with a velocity of 10 mm/min until breaking. Two years later, in 2003, the authors reduced the range of the Young's modulus of miscanthus between 500 MPa and 6,600 MPa, giving a value of 4,270 MPa for the sterile hybrid Mxg [51]. Then, Chen *et al.* (2017) [111] presented a range between 2,000 and 8,000 MPa of the elastic modulus for Mxg and Msin. These values of Young's modulus are comparable to those of sisal (530MPa) [123] measured using the same methodology. Bourmaud *et al.* (2008) [124] measured the mechanical properties of miscanthus stem fragments using the nanoindentation technique. The results obtained are 10,000 MPa for the longitudinal modulus and 340 MPa for the hardness. The hardness H is defined as the indentation load P_{max} divided by the projected contact area A, as follows: $H = \frac{P_{\text{max}}}{A}$.

Noting that the compressive strength of aggregates is highly affected by their porosity and on the concentration of lignin and cellulose, in other words on the chemical composition of the aggregates. Plant fibers are mainly composed of cellulose, with non-cellulosic components like hemicellulose, pectin, and lignin [125]. While cellulose provides mechanical strength, lignin enhances resistance to moisture and environmental degradation [126]. Therefore, higher levels of cellulose and lignin contribute in higher elastic modulus (ranging between 0.5 and 6 GPa) and increase resistance to lodging in the stem cells [51].

4.7. Life cycle assessment (LCA)

The life cycle assessment (LCA) of miscanthus has been studied in the literature, with its potential as a bioenergy crop and its environmental impact under different conditions.

A LCA was carried out by Balcioglu et al. (2023) [127] in order to evaluate the cost and environmental impact of bioenergy production of Mxg and other feedstocks from in Turkey. They found that miscanthus-based systems, particularly the combined heat and power (CHP) configurations, contribute in reducing the global warming potential (GWP) by more than 80 % compared to conventional energy systems. The energy crops grown on 6 % of total forest and agricultural lands (equivalent to 3.3 million ha) could supply up to 28 % (or 19 Mtoe) of the annual energy needs and reduce fossil-fuel import expenses by 37 % (or \$4.7 billion per year) by substituting coal-based electricity and natural gas heating with bioenergy.

Weik et al. (2022) [128] demonstrated that ecological benefits and income effects of miscanthus cultivation depend on the regional context and site conditions. The effect of miscanthus cultivation reduces greenhouse gas emissions (-16 % to -724 %) but the potential to reduce nitrate leaching (-4 % to -44 %) is compromised in some sub-regions and scenarios (+4 % to +13 %) by substantial effects on the crop rotation. The framework was applied to Baden-Württemberg, a federal state in southwest Germany with eight agro-ecological regions.

Krzyżaniak et al. (2020) [129] investigated the environmental effects of cultivating giant miscanthus *x giganteus* on low-fertility unutilized lands in Poland and compared the obtained crops between fertilized and with no fertilization cultivation. They concluded that using fertilizer in the cultivation of miscanthus *x giganteus* on this type of lands do not improve yields nor reduce the environmental impact of biomass. This research also underscores the sustainability potential of miscanthus in areas with low agricultural productivity, such as the case of Poland that has approximately two million hectares of such lands, especially for carbon sequestration and renewable energy production.

These are some of the findings that support the applicability of miscanthus as a sustainable energy crop in reducing the use of fossil fuels in order to reduce the environmental impacts.

5. Miscanthus in buildings

Contrary to the previous section, in this section are elaborated the properties of bio-composites made of miscanthus depending on the specific composition of each case studied. The type of composites studied are mainly the thermal insulation materials applied and used in the building sector.

Recently, miscanthus has been used more as a bio aggregate in the production of lightweight concrete, composite panels and lime-based renders, by placing sand and gravel [130]. This offers multiple advantages, including low density, effective thermal insulation, high porosity and sound absorbency. Additionally, miscanthus is attractive economically and environmentally because it is a renewable resource, abundant - also in France - and requires low input for cultivation.

These miscanthus based materials exhibit reduced density and enhanced thermal insulation, with thermal conductivities in the range of 0.09–0.12 W/m·K, and are suitable for non-load-bearing walls or insulation layers [131].

The energy performance, environmental impact, and cost of different insulation materials were studied by Dickson et al. (2021) [132], using a standardized scoring tool. In the first place is the cellulose fiber, with a total score of 78.22: energy score of 20.23, environmental score of 26.85, and economic score of 31.14. In contrast, polyisocyanurate (PIR) board, a conventional petrochemical-based insulation, ranked 20th with a total score of 54.65: 22.18 for energy, 14.43 for environmental and 18.05 for economic.

Compared to conventional materials, miscanthus-based panels are generally lower in cost, due to the abundance and renewability of the feedstock. In the work of Pescari et al. (2022) [133], the prices of different insulation materials without the binder and workmanship cost are presented. The work does not present miscanthus based insulation, but it shows that the prices of straw (3.2 euros/m²), wool (5.24 euros/m²) and cellulose (6.04 euros/m²) are lower than the prices of expanded polystyrene (9.62 euros/m²), extruded polystyrene (13.05 euros/m²) and polyurethane foam (15.75 euros/m²). According to the EU-funded OPTIMISC project [88], the biomass supply cost for miscanthus-based insulation is estimated at approximately 28 euros/m³. Considering the thickness of the panel is 5 cm, the cost will become approximately 5.6 euros/m², this cost includes all the process with the production and transport, contrary to the mentioned values for other insulations where the cost is only of the material.

Thanks to its insulating properties, miscanthus also promotes energy savings in winter by reducing heat loss (figures to be determined based on application), conserves non-renewable resources, and exhibits a lower environmental footprint, supported by crop-level greenhouse gas mitigation of approximately 30.6 t CO₂/ha/year [88].

5.1. Properties of the bio-based composites using miscanthus

Research has focused on improving the properties of bio-based materials, including preparation methods, fibers treatments, long-term durability, production efficiency, mechanical and thermal properties as well as environmental impacts for the obtained composites [30].

The thermal resistance of a concrete block made from an average of 60 % miscanthus shreds is 0.7 m².K/W, approximately three times more insulating than conventional cement blocks with a thermal resistance of 0.2 .K/W [134]. These blocs are developed by the R&D department of the companies Ciments Calcia and Alkern, their dimensions are: 20×50 and 20 cm thickness [135]. Mechanically, the flexural strength of miscanthus lightweight concrete after 28 says is 3.7 MPa for 10 % of pre-soaked miscanthus aggregates of size 2-4 mm in the Portland cement matrix [136], [137], whereas cellular concrete has a flexural strength of around 4 MPa and the classical cement blocks 20 to 50 MPa [138]. The formulation of the lightweight concrete is set as a ratio of 0.25 for ground granulated blast furnace slag GGBS/cement and 0.45 for water/binder. The compressive strength of cement and concrete composites containing miscanthus is 30.5 MPa. Miscanthus fibers increase the fracture energy of concrete containing 0.19 wt% of fibers for up to 5 % with the wedge splitting test (WST) method. The addition of fibers improves the fracture toughness of concrete. And the presence of miscanthus fibers in concrete slightly decreases the concrete's tensile strength, for 8 % miscanthus reinforced specimens in the same study [139], [30].

Therefore, the high thermal resistance of miscanthus concrete leads to improve insulation which contributes to lower energy demands and consumption in the building especially for heating and cooling, and is at the same time efficient and durable, which makes it compatible with the Low-energy building renovation - Bâtiment Basse Consommation Renovation - BBC Renovation French label. This label, established in France, sets a benchmark for newly constructed low-energy residential buildings. Its main requirement is that the primary energy consumption of a building does not exceed 110 kWh/m²/year, including energy used for heating, cooling, domestic hot water, lighting, and auxiliary systems [140]. Additionally, as a bio-based material derived from renewable resources, miscanthus concrete also supports environmental goals by reducing the building's carbon footprint.

5.2. Analysis of the effect of binders

Most bio-based construction materials use Portland cement and lime as mineral binders. Clay, plaster, and other mineral binders have been suggested [107]. Miscanthus is a more recent fiber source than other studied fibers such as hemp; therefore, there isn't much research on its interaction with mineral binders. The type of miscanthus and of the binder used affect the quality of the obtained composite. Ntimugura *et al.* (2022) [107] studied miscanthus particle interactions with mineral binders, including hydrated lime, natural hydraulic lime, formulated lime, and mineral additives such as ground granulated blast furnace slag, fly ash, and Portland cement, from a chemical and mineralogical perspective. Formulated lime binders affect miscanthus particles more than other binders. In formulated lime mixes, absorbance bands at 1407, 1023, and 1160 cm^{-1} were significantly reduced. These bands correspond to the lignin and hemicellulose regions within the wavenumber range of 2000 cm^{-1} and 500 cm^{-1} .

Incorporation of large volume of biomass, particularly miscanthus, into construction and cement / concrete composites, raises a number of issues [119]. Among these issues are the mechanical properties that get deteriorated over time, they are affected mainly by the durability, hygroscopicity, high water absorption and the incompatibility between the fiber and the matrix, cement-miscanthus in this case [30], [141]. This is mainly due to the low water retention capacity and porous inner structure of vegetal added concrete, which are the main factors in the limited lifespan of plants. The alkaline environment in miscanthus mortar leads to the dissolution of certain cellulosic components, causing the degradation of the miscanthus fiber. Miscanthus components, such as the presence of soluble sugars and hemicellulose have a negative impact on the preparation and performances of bio-based composite.

The long-term durability aspect of miscanthus-based concrete is still not much elaborate in the literature [142], [143]. Wu *et al.* (2022) [110] studied the long-term degradation of a miscanthus-based mortar. They found that heat treatment at 250°C for 3 hours followed by grinding of miscanthus fibers boosted the flexural strength of the mortar by 26.9 % and its compressive strength by 82.7 %, compared to the reference fiber because this treatment reduces the porosity and increases the fiber-matrix compatibility. The alkaline mortar dissolves some fiber cellulose, causing degradation. They concluded that removing sugar from bio-based miscanthus mortar fibers strengthens it. Tran *et al.* (2011) [144] investigated the compressive and flexural strengths after 28 days of 5 wt% non-treated miscanthus stem fragments in a cementitious matrix with those pretreated with acid and aqueous ammonia before saccharification. After 28 days, compressive strength dropped from 25 MPa for untreated parts to less than 10 MPa for the two treatment types. Flexural strength remained at 3 MPa. Also, Dias *et al.* [145] showed the effect of pre-treatment of miscanthus fibers with a silicate sealant or a cement-based fluent. The compressive strength of specimens with a pretreatment based on a silicate sealant reached a compressive strength of 19.3 MPa, which is higher than the compressive strength of a conventional lightweight concrete, its Young's Modulus above 9.9 GPa and its shrinkage deformation of 2244 $\mu\text{m}/\text{m}$.

Vo *et al.* (2016) [146] demonstrated that reducing water uptake and improving cement-biomass compatibility can make miscanthus more durable in alkaline cementitious matrices. Heat-treated miscanthus fibers improve mortar's structural stability and degradation resistance. The use of environmentally damaging chemicals or excessive cost makes some solutions unfeasible. Vo *et al.* (2016) [146] also demonstrated that soluble sugars and low-molecular-weight hemicelluloses degrade concrete preparation and performance. According to the authors, miscanthus helps reducing greenhouse gas emissions by storing the CO_2 . They mentioned that one hectare of miscanthus used in building applications has the ability to store 40 tons of CO_2 . Based on the composition of the concrete, the miscanthus used and the binder, the bio-concrete obtained can keep a thermal conductivity of 0.7 $\text{W}/(\text{m}\cdot\text{K})$ and a compressive strength of 0.95 to 5.84 MPa after 7 days at a temperature of 20 to 60°C and relative humidity of 20 %.

Finally, it can be said that miscanthus face compatibility challenges with mineral binders. To solve them and improve the thermal and mechanical properties of the miscanthus-based composite, multiple treatment methods and optimized binder formulations can be applied.

5.3. Case studies

In this section, several real applications of miscanthus in the construction industry are examined in order to develop an eco-friendly building insulation material. The main focus of these studies is the thermal insulation potential of composites containing miscanthus along with its mechanical properties and porous structure.

Most studies agree that incorporating miscanthus into cementitious matrices reduces density and improves thermal insulation, but this leads to reduce mechanical strength of miscanthus-based materials, especially when miscanthus has not undergone any pre-treatment such as alkali treatment, heat treatment and other physical treatment methods [147], [64], [148], [72].

Ribera *et al.* (2023) [100] valorized several biomass fibers, including miscanthus, in a cementitious matrix for anti-cracking and structural screed. Due to the biomass's high porosity, miscanthus fiber reduces compressive strength by adding air to the composite, same finding as Wu *et al.* (2024) [119] as just mentioned. However, they found that using larger aggregates of size 2–4 mm increases the bending resistance of miscanthus-containing mortars, which mitigates some strength losses. They also noted that 0–2 mm miscanthus aggregates delay cement particle hydration. The flexural strength at 28 days of the mortar containing 15 % miscanthus by volume is around 6.3 MPa for a fiber dosage of 4 kg/m³, which makes a standardized value of 56 % of the flexural strength compared to the anti-cracking screed.

Dias *et al.* (2021) [109] characterized the density (0.122 g/cm³ average), compressive strength (varies between 1.2 N/mm² to 1.8 N/mm), and water absorption of mycelium-miscanthus composite created for building thermal insulation. The thermal conductivity of the obtained material is between 0.09 and 0.1 W/(m.K). And according to EN13501–2:2003, based on the fire-resistant tests conducted, the authors found that the composite belong to the category EI15. They also tested different mix proportions of mycelium and miscanthus in order to identify the most suitable mixture to produce a porous composite, which has the mix proportions of 0.3:1:0.1 of *Ganoderma resinaceum* fungus, Mxg fibers, and potato starch. It was concluded that the new composite prepared has relatively better properties compared to traditional insulation materials and satisfies most of the requirements for indoor building applications.

This suggests that some parameters such as the particle size, fiber treatment, and binder composition can improve both the insulation properties and the mechanical strength of the bio-composite.

Table 9 below presents a summary of some other studies carried out on miscanthus at the laboratory scale, along with the main results obtained.

Table 9: Summary table of some studies on miscanthus at the laboratory scale.

| Author, year | Material | Main results |
|----------------------------------|---|--|
| Chen <i>et al.</i> , 2024. [141] | Miscanthus fibers of 2–4 mm; olivine silica aerogel; binder: supplementary cementitious materials (SCM) at large volume CEM III/A | Examination of the mechanical and insulating properties of lightweight concrete with miscanthus fibers modified with hydrophobic silica aerogel. The water absorption of modified fibers is reduced by up to 33 %. Thermal conductivity is reduced to 0.081 W/(m.K). The |

| | | |
|-------------------------------------|--|--|
| | | compressive strength, flexural strength and insulating performance of the concrete are significantly improved. The acoustic absorption and water resistance are increased, with fibers absorbing 36 % water after 50 hours compared to 293 % for regular miscanthus fibers after 24 hours. |
| Wu et al., 2022. [110] | Miscanthus raw and powder (vol%: 1; 1,5 et 2). Binder: cement CEM I 52,5 R. | Heat treatment of the fibers improves the mechanical properties, dimensional stability and durability of the mortar. |
| Dias et al., 2021. [109] | Dried Mxg fibers and grains of mycelium from the Ganoderma resinaceum fungus as miscanthus husks. | Thermal conductivity is between 0.0882 and 0.104 W/(m.K) with an average density of 0.122 g/cm ³ . Composite panels are classified as EI15 in accordance with EN13501-2:2003. |
| Ntimugura et al. 2021. [149] | Miscanthus blocks - lime; miscanthus blocks with clay bricks; timber frame filled with miscanthus blocks... | Miscanthus blocks can capture 0.135 tons of CO ₂ eq/m ³ assuming a 100-year lifespan. A reduction in the binder/aggregate ratio from 2 to 1.5 reduces the greenhouse gas emissions by 32.9 %. |
| El Hage et al. (2021) [150] | Miscanthus fibers and recycled textile fibers; binder: chitosan; fillers: aluminum trihydroxide | They obtained a thermal conductivity between 0.069 and 0.09 W/(m.K) and a density between 0.27 and 0.299 g/cm ³ . |
| Šekler et al. (2021) [137] | air-dried, dusted-off miscanthus fibers from Serbia of 5 to 10 mm from Serbia. Binder: hydraulic lime made of Ca(OH) ₂ and metakaolin. Plasticizer: Calcium sulfate dehydrate gypsum (CaSO ₄ ·2H ₂ O) | Studied the effect of the binder type, the binder component ratio, the material's fragmentation level on the physical and mechanical properties of the lightweight concrete. The results indicated that the sample with a higher binder content, finer miscanthus granulation (constituting 25 wt% of the total), and molding under higher pressure achieved the highest compressive strength and density values, lowest water absorption. |
| Chen et al., 2020. [151] | Ultra-light concrete (CEM III 52,5 N cement) incorporating two types of miscanthus aggregate (0-2 mm and 2-4 mm) and expanded waste glass EWG (0,25 ~ 8mm). | The particle density of ultra-light concrete with 30 % 2-4 mm miscanthus fibers is 0.554 g/cm ³ with a thermal conductivity of 0.09 W/(m.K) and a sound absorption coefficient of 0.9 at low frequencies. |
| Chupin et al., 2020. [57] | Two clones of Mxg, two clones of M. sinensis and two clones of M. sacchariflorus. | The results highlight that the genotypic effect, the position along the stem, the size of the aggregates and their mechanical properties are strongly interconnected with their respective biochemical and structural characteristics. |

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| Eschenhagen et al. (2019) [147] | Miscanthus and sunflower stalks. Three natural binders were used: starch, casein wood glue, and gelatin bone glue. | Created low-cost insulation particleboard cohesive panels and examined their thermal and mechanical properties. Binder contents ranged from 10 % (for cohesiveness) to 40 %. They obtained promising results: low density and very good thermal conductivity. Despite encouraging density results, several manufactured panels failed to achieve building quality standards for surface appearance (excessively porous) and cohesiveness (material loss after drying, breaking during mechanical test specimen cutting). The aggregate morphology and binder solution viscosity prevent homogenous mixing. |
| Schnabel et al., 2019. [116] | Maize straw (<i>Zea mays</i> L.) and miscanthus (<i>miscanthus sinensis</i> , <i>giganteus</i>) | Lower moisture contents were measured for the treated samples. The use of vapor pressure treated materials has positive effects on bulk density and thermal conductivity when using fractionated materials. Binder content increases mechanical properties: miscanthus fibers with 40 % casein gave the best results. |
| Chen et al., 2017. [111] | <i>M. x giganteus</i> (aggregates of 2 and 4 mm); Cement Portland CEM I 52.5R | Compressive strength decreases significantly with the addition of miscanthus, from 56 to 15 MPa for 2 to 4 mm fibers (replacing 20 % of the volume) in 28 days. All the fibers have a retarding effect on cement hydration, but the 0 to 2 mm fibers displayed the strongest effect on cement hydration. |
| Gbekou et al. 2023 [2] | MDDCH0114 MISCANTHUS 200e500mm/BFF: finely powdered form of micronized miscanthus fibers, with diameters ranging from 200 to 500 m (maximum dosage of 7 wt%) added into a cement mortar. | The experimental tests show that the addition of fibers contribute in significant improvements in the thermal resistance (up to 87 %) of the mortars. But the incorporation of fibers also leads to a reduction in the mechanical properties of the mortars under both flexural and compression tests. This is due to the linear increase in the total porosity, that also results in a decrease of the material's density. |

Even though miscanthus showed potential as insulating material and lightweight concrete, with advantages in terms of thermal performance and carbon footprint reduction, still some challenges persist, including reductions in mechanical strength, inconsistent composite performance, and the absence of standardized processing methods. Addressing these issues will require further research focused on optimizing material formulations, investigating hybrid binder systems, and evaluating long-term durability under practical application conditions.

Examples in France:

- Alkern - an expert company in lime-miscanthus thermal insulation blocks - has launched its “Andelys” site project in 2023, investing €8 million to produce concrete blocks composed of 30 % miscanthus, aimed at low-carbon construction. From 2026-2029, Alkern plans to triple miscanthus block production at its

Normandy factory [152]. A collaboration with Ciments Calcia aims to create blocks with 60 .% miscanthus shreds, offering improved thermal resistance ($0.7 \text{ m}^2 \cdot \text{K}/\text{W}$ vs. 0.2 for traditional blocks) (figure 15). [134]



Figure 15: An ecological building block based on miscanthus. Photo credit: Calcia / Alkern.

- In Saint-Piat (2021), 200 m^3 of miscanthus was used to insulate a 200 m^2 house, reducing heating costs to €150 annually, almost ten times cheaper than flax or hemp [134].
- Kellig Emren has developed insulating panels made from miscanthus, raw earth, and lime. These panels, measuring $66.5 \times 50.0 \times 7.5 \text{ cm}$, are airtight, non-flammable, and have excellent thermal conductivity, with a density of $0.34 \text{ g}/\text{cm}^3$ [134].
- In Bourg-des-Comptes (Bretagne), a 98 m^2 house was insulated with miscanthus at a cost of €1,400 for 53.5 m^2 , achieving thermal resistances of $3.94 \text{ m}^2 \cdot \text{K}/\text{W}$ for walls and $4.26 \text{ m}^2 \cdot \text{K}/\text{W}$ for the ceiling.
- Other projects include:
 - Sprayed miscanthus concrete insulation in office-location of a winery, Ingersheim, Alsace, 2020.
 - A wooden half-timbering with miscanthus concrete infill. Winery in Ammerschwihr, Alsace, 2015.
 - A timber framing with miscanthus concrete infill and miscanthus bundle inner lining. Chai Boesch, Westhalten, Alsace, 2011.

6. Limitations

Even though biobased materials such as miscanthus provide environmentally friendly substitutes for conventional composites, their use is restricted by a number of limitations. One of the main concerns, as previously stated in the study, is the mechanical performance; miscanthus fibers usually show less strength and stiffness than synthetic reinforcements such as carbon fiber or fiberglass [47], [48]. In addition, because they have the hydrophilic aspect, they are sensitive to moisture, which can weaken structural integrity in moist and humid conditions [97]. Environmental and agricultural factors such as soil type, harvesting time, and post-processing also have an impact on the quality of these natural fibers, leading to inconsistent material properties [53], [63].

The use of composites based on miscanthus is further restricted by their low resistance to fire. The environmental advantages of adopting bio-based inputs may be impacted by the need for fire retardants due to the flammability of these fibers [113]. Additionally, they are not appropriate for high-heat applications since their thermal breakdown starts at very low temperatures (between 200 and 250°C) [103].

Compatibility with synthetic polymers and cementitious matrix is another critical challenge. Miscanthus fibers often exhibit poor interfacial bonding, which weakens the overall composite unless chemical treatments like coupling agents or surface modifications (e.g., silane or alkali treatments) are applied—processes that increase cost and complexity [110]. Processing and scalability are also problematic due to the low bulk density of Miscanthus, which makes transport and storage unpractical, and the dust generated during processing can pose both health and fire hazards [111]. Furthermore, these fibers are not always compatible with conventional thermoplastic processing technologies, such as injection molding, without additional modification.

From an agricultural point, miscanthus requires a long establishment period—typically 2 to 3 years—to reach optimal yields, delaying return on investment [63].

Economically, Miscanthus-based materials often face higher upfront costs related to development and processing compared to fossil-based materials. The lack of standardized specifications further hinders their market integration, while underdeveloped supply chains and logistics infrastructure for biomass exacerbate the challenge.

7. Conclusion

Miscanthus is a lignocellulosic perennial plant whose fibrous components exhibit significantly greater mechanical strength than those of conventional materials such as straw. Owing to its favorable chemical composition, miscanthus presents strong potential as a base material for use in the construction sector. Compared to traditional renewable resources, it offers two key advantages: excellent thermal insulation performance and high mechanical strength. Its fibers possess a density ranging from 0.04 to 0.128 g/cm³ and a thermal conductivity between 40 and 60 × 10⁻³ W/m·K. These properties place miscanthus within the mid-range of natural insulation materials, both in terms of lightweight characteristics and thermal performance. Its density is comparable to that of other widely used natural fibers such as coconut, sugarcane bagasse, and hemp, while its thermal conductivity remains within the lower to mid-range spectrum, underscoring its suitability for building insulation applications.

The incorporation of renewable materials like miscanthus into building systems presents considerable opportunities for both the agricultural and industrial sectors. Interest in this area is growing rapidly, driven by the promising results of bio-based construction materials and the remarkable thermo-physical properties of miscanthus. Current research efforts include the exploration of non-cementitious, plant-based binders as a means to integrate miscanthus into sustainable construction systems, thereby avoiding the environmental drawbacks of conventional cement-based composites. Additionally, investigations are underway to assess its feasibility for large-scale applications and to conduct full-scale building trials—an essential step toward commercial viability.

Despite this progress, several critical knowledge gaps persist. Most notably, there is a lack of comprehensive studies on the use of organic, non-cementitious binders that could further enhance the environmental profile of miscanthus-based materials. Moreover, Life Cycle Assessment (LCA) studies remain limited, impeding a thorough understanding of the environmental impacts and long-term sustainability of miscanthus in construction. Although preliminary findings are promising, robust LCA analyses are necessary to substantiate its role as a sustainable building material.

Furthermore, the large-scale, bulk application of miscanthus in construction contexts remains underexplored, with few studies addressing its performance at commercial or industrial scales. This lack of empirical data poses a significant barrier to the widespread adoption of miscanthus-based materials. Additionally, the field suffers from a lack of integration and synthesis, with fragmented research limiting the development of standardized methodologies and best practices. Advancing miscanthus as a viable alternative to conventional building materials will require targeted research, interdisciplinary collaboration, and the establishment of comprehensive guidelines to facilitate its broader implementation in sustainable construction.

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References

- [1] MINISTÈRE ÉCOLOGIQUE DE LA TRANSITION ÉCOLOGIQUE ET DE LA COHÉSION DES TERRITOIRES, Bilan énergétique de la France en 2022 - Données définitives, (2024).
- [2] Consommation d'énergie des bâtiments tertiaires : chiffres 2025, (n.d.). <https://opera-energie.com/consommation-energie-batiments-tertiaires/> (accessed August 7, 2025).
- [3] L. Cirrincione, M. La Gennusa, G. Peri, G. Rizzo, G. Scaccianoce, G. Sorrentino, S. Aprile, Green roofs as effective tools for improving the indoor comfort levels of buildings-an application to a case study in sicily, *Appl. Sci.* 10 (2020) 1–19. <https://doi.org/10.3390/app10030893>.
- [4] F.K. Gbekou, A. Boudenne, A. Eddhahak, K. Benzarti, Mechanical and thermal properties of cement mortar composites incorporating micronized miscanthus fibers, *J. Mater. Res. Technol.* 26 (2023) 7649–7664. <https://doi.org/10.1016/j.jmrt.2023.09.093>.
- [5] J. Leroy, Etude écophysiological temporelle de la gestion des réserves carbonées et azotées par trois génotypes de miscanthus, HAL (2023). <https://doi.org/tel-04223136>.
- [6] B.D. Barbuta Marinela, Bucur Roxana Dana Cimpeanu, Sorin Mihai, Paraschiv Gigel, Wastes in Building Materials Industry, *Agroecology* 11 (2015) 13. <http://dx.doi.org/10.5772/59933>.
- [7] F. Frasca, B. Bartolucci, J.L. Parracha, O. Ogut, M.P. Mendes, A.M. Siani, J.N. Tzortzi, C. Bertolin, I. Flores-Colen, The TEnSE approach to assess the nudge of stakeholders in the choice of thermal insulation materials, *Procedia Struct. Integr.* 55 (2024) 127–134. <https://doi.org/10.1016/j.prostr.2024.02.017>.
- [8] B. Durakovic, G. Yildiz, M.E. Yahia, Comparative performance evaluation of conventional and renewable thermal insulation materials used in building envelopes, *Teh. Vjesn.* 27 (2020) 283–289. <https://doi.org/10.17559/TV-20171228212943>.
- [9] S. Hetimy, N. Megahed, O.A. Eleinen, D. Elgheznavy, Exploring the potential of sheep wool as an eco-friendly insulation material: A comprehensive review and analytical ranking, *Sustain. Mater. Technol.* 39 (2024) e00812. <https://doi.org/10.1016/j.susmat.2023.e00812>.
- [10] C.B. Céline Badouard, Fabien Bogard, Guillaume Polidori, Valorisation des sous-produits de pressurage du raisin : caractérisation thermomécanique d'un nouveau matériau biosourcé à base d'aignes, (2023).
- [11] F. Asdrubali, F. D'Alessandro, S. Schiavoni, A review of unconventional sustainable building insulation materials, *Sustain. Mater. Technol.* 4 (2015) 1–17. <https://doi.org/10.1016/j.susmat.2015.05.002>.
- [12] P. He, H. Ruan, C. Wang, H. Lu, Mechanical properties and thermal conductivity of thermal insulation board containing recycled thermosetting polyurethane and thermoplastic, *Polymers (Basel)*. 13 (2021). <https://doi.org/10.3390/polym13244411>.
- [13] B.P. Jelle, Traditional, state-of-the-art and future thermal building insulation materials and solutions - Properties, requirements and possibilities, *Energy Build.* 43 (2011) 2549–2563. <https://doi.org/10.1016/j.enbuild.2011.05.015>.
- [14] Y. Wang, S. Zhang, D. Wang, Y. Liu, Experimental study on the influence of temperature and humidity on the thermal conductivity of building insulation materials, *Energy Built Environ.* 4 (2023) 386–398. <https://doi.org/10.1016/j.enbenv.2022.02.008>.
- [15] F. Collet, S. Pretot, Thermal conductivity of hemp concretes: Variation with formulation, density

- and water content, *Constr. Build. Mater.* 65 (2014) 612–619. <https://doi.org/10.1016/j.conbuildmat.2014.05.039>.
- [16] M. Larcher, E. Leonardi, A. Troi, A. Stefani, G. Nerobutto, D. Herrera-Avellanosa, Assessing the impact of moisture buffering properties of materials on indoor environmental quality: A study on a recycled material plaster, *Build. Environ.* 267 (2025) 112170. <https://doi.org/10.1016/j.buildenv.2024.112170>.
- [17] M. Maaroufi, R. Belarbi, K. Abahri, F. Benmahiddine, Full characterization of hygrothermal, mechanical and morphological properties of a recycled expanded polystyrene-based mortar, *Constr. Build. Mater.* 301 (2021) 124310. <https://doi.org/10.1016/j.conbuildmat.2021.124310>.
- [18] A. Bakkour, S. Ouldboukhitine, P. Biwole, S. Amziane, A review of multi-scale hygrothermal characteristics of plant-based building materials, *Constr. Build. Mater.* 412 (2024) 134850. <https://doi.org/10.1016/j.conbuildmat.2023.134850>.
- [19] H. Jang, Y. Jang, B. Jeong, N.K. Cho, Comparative life cycle assessment of marine insulation materials, *J. Mar. Sci. Eng.* 9 (2021). <https://doi.org/10.3390/jmse9101099>.
- [20] V. Cascione, M. Roberts, S. Allen, C. Charbel, D. Maskell, B. Dams, A. Shea, P. Walker, S. Emmitt, Evaluating environmental impacts of bio-based insulation materials through scenario-based and dynamic life cycle assessment, *Int. J. Life Cycle Assess.* 30 (2025) 601–620. <https://doi.org/10.1007/s11367-024-02425-4>.
- [21] A. Violano, M. Cannaviello, The Carbon Footprint of Thermal Insulation: The Added Value of Circular Models Using Recycled Textile Waste, *Energies* 16 (2023). <https://doi.org/10.3390/en16196768>.
- [22] C. Rabbat, S. Awad, A. Villot, D. Rollet, Y. Andrès, Sustainability of biomass-based insulation materials in buildings: Current status in France, end-of-life projections and energy recovery potentials, *Renew. Sustain. Energy Rev.* 156 (2022). <https://doi.org/10.1016/j.rser.2021.111962>.
- [23] V. Le Ravalec, Panorama Des Coproduits Et Residus Biomasse a Usage Des Filieres Chimie Et Materiaux Biosources En France Synthèse, ADEME (2015).
- [24] L.A. Sofiane Amziane, Bio-aggregate-based Building Materials, *Civ. Eng. Geomech. Ser.* 4 (2017) 9–15.
- [25] R. Verma, M. Shukla, D. Kumar, A treatise on mechanical properties of natural and synthetic fibre reinforced hybrid polymer composites, *Mater. Today Proc.* (2024). <https://doi.org/10.1016/j.matpr.2024.04.058>.
- [26] W. Phamonpon, J.P. Hinestroza, P. Puthongkham, N. Rodthongkum, Surface-engineered natural fibers: Emerging alternative substrates for chemical sensor applications: A review, *Int. J. Biol. Macromol.* 269 (2024) 132185. <https://doi.org/10.1016/j.ijbiomac.2024.132185>.
- [27] W. Wang, Y. Zhang, Z. Mo, N. Chouw, K. Jayaraman, Z. dong Xu, A critical review on the properties of natural fibre reinforced concrete composites subjected to impact loading, *J. Build. Eng.* 77 (2023) 107497. <https://doi.org/10.1016/j.jobe.2023.107497>.
- [28] T. Gurunathan, S. Mohanty, S.K. Nayak, A review of the recent developments in biocomposites based on natural fibres and their application perspectives, *Compos. Part A Appl. Sci. Manuf.* 77 (2015) 1–25. <https://doi.org/10.1016/j.compositesa.2015.06.007>.
- [29] M. Ramesh, Kenaf (*Hibiscus cannabinus* L.) fibre based bio-materials: A review on processing and properties, *Prog. Mater. Sci.* 78–79 (2016) 1–92.

- <https://doi.org/10.1016/j.pmatsci.2015.11.001>.
- [30] L.T.T. Vo, P. Navard, Treatments of plant biomass for cementitious building materials – A review, *Constr. Build. Mater.* 121 (2016) 161–176. <https://doi.org/10.1016/j.conbuildmat.2016.05.125>.
- [31] A. Eschenhagen, M. Raj, N. Rodrigo, A. Zamora, L. Labonne, P. Evon, H. Weleman, Investigation of Miscanthus and Sunflower Stalk Fiber-Reinforced Composites for Insulation Applications, *Adv. Civ. Eng.* 2019 (2019). <https://doi.org/10.1155/2019/9328087>.
- [32] A. Fabbri, F. McGregor, Impact of the determination of the sorption-desorption curves on the prediction of the hemp concrete hygrothermal behaviour, *Constr. Build. Mater.* 157 (2017) 108–116. <https://doi.org/10.1016/j.conbuildmat.2017.09.077>.
- [33] X. Zhou, G. Desmarais, S. Carl, D. Mannes, D. Derome, J. Carmeliet, Investigation of coupled vapor and heat transport in hygroscopic material during adsorption and desorption, *Build. Environ.* 214 (2022) 108845. <https://doi.org/10.1016/j.buildenv.2022.108845>.
- [34] S. Cai, L. Xia, H. Xu, X. Li, Z. Liu, L. Cremaschi, Effect of internal structure on dynamically coupled heat and moisture transfer in closed-cell thermal insulation, *Int. J. Heat Mass Transf.* 185 (2022). <https://doi.org/10.1016/j.ijheatmasstransfer.2021.122391>.
- [35] Y. Kang Liu, B. Hongda Niu, Wang, Moisture absorption and desorption characteristics and prediction model analysis of building thermal insulation materials, *Appl. Therm. Eng.* 248 (2024). <https://doi.org/123196>.
- [36] F.K. Gbekou, Comportement thermo-hydrrique de mortiers cimentaires contenant des matériaux à changement de phase (MCP) biosourcés et/ou des fibres végétales de miscanthus : Etudes aux échelles du matériau et de la paroi, 2023.
- [37] L. Wang, H. Lenormand, H. Zmamou, N. Leblanc, Effect of variability of hemp shiv on the setting of lime hemp concrete, *Ind. Crops Prod.* 171 (2021). <https://doi.org/10.1016/j.indcrop.2021.113915>.
- [38] A. Benallel, A. Tilioua, M. Dlimi, Assessment of the thermal performance of a new insulation material based on date palm and cardboard: Experimental and numerical study, *Constr. Build. Mater.* 419 (2024) 135476. <https://doi.org/10.1016/j.conbuildmat.2024.135476>.
- [39] A. Benallel, A. Tilioua, M. Dlimi, Assessment of the thermal performance of a new insulation material based on date palm and cardboard: Experimental and numerical study, *Constr. Build. Mater.* 419 (2024) 135476. <https://doi.org/10.1016/j.conbuildmat.2024.135476>.
- [40] D.Y. Yoo, N. Banthia, Impact resistance of fiber-reinforced concrete – A review, *Cem. Concr. Compos.* 104 (2019) 103389. <https://doi.org/10.1016/j.cemconcomp.2019.103389>.
- [41] L. Soufeiani, S.N. Raman, M.Z. Bin Jumaat, U.J. Alengaram, G. Ghadyani, P. Mendis, Influences of the volume fraction and shape of steel fibers on fiber-reinforced concrete subjected to dynamic loading – A review, *Eng. Struct.* 124 (2016) 405–417. <https://doi.org/10.1016/j.engstruct.2016.06.029>.
- [42] K. Manohar, Experimental Investigation of Building Thermal Insulation from Agricultural By-products, *Br. J. Appl. Sci. Technol.* 2 (2012) 227–239. <https://doi.org/10.9734/bjast/2012/1528>.
- [43] J.L. Finck, Mechanism of heat flow in fibrous materials, *Bur. Stand. J. Res.* 5 (1930) 973–984.
- [44] R. El Hage, Prétraitement du miscanthus x giganteus : vers une valorisation optimale de la biomasse lignocellulosique, HAL (2020).

- [45] D.U. Shah, J. Konnerth, M.H. Ramage, C. Gusenbauer, Mapping thermal conductivity across bamboo cell walls with scanning thermal microscopy, *Sci. Rep.* 9 (2019) 1–8. <https://doi.org/10.1038/s41598-019-53079-4>.
- [46] K. Jamil, F. Shabbir, A. Raza, Performance evaluation of jute fiber-reinforced recycled aggregate concrete: Strength and durability aspects, *Struct. Concr.* 24 (2023) 6520–6538. <https://doi.org/10.1002/suco.202200948>.
- [47] F.K. Gbekou, A. Boudenne, A. Eddahak, K. Benzarti, Mechanical and thermal properties of cement mortar composites incorporating micronized miscanthus fibers, *J. Mater. Res. Technol.* 26 (2023) 7649–7664. <https://doi.org/10.1016/j.jmrt.2023.09.093>.
- [48] J. Girones, L. Vo, S. Arnoult, M. Brancourt-Hulmel, P. Navard, Miscanthus stem fragment – Reinforced polypropylene composites: Development of an optimized preparation procedure at small scale and its validation for differentiating genotypes, *Polym. Test.* 55 (2016) 166–172. <https://doi.org/10.1016/j.polymertesting.2016.08.023>.
- [49] R. Verma, M. Shukla, D. Kumar, A treatise on mechanical properties of natural and synthetic fibre reinforced hybrid polymer composites, *Mater. Today Proc.* (2024). <https://doi.org/10.1016/j.matpr.2024.04.058>.
- [50] A.E. Frank Komi GBEKOU, Florence Collet, Naima BELAYACHI, Rachid Bennacer, Mohammed Lachi, Karim Benzarti, Abderrahim BOUDENNE, THESE DE DOCTORAT École Doctorale SIE (N° 531) : Sciences, Ingénierie et Environnement Comportement thermo-hydrrique de mortiers cimentaires contenant des matériaux à changement de phase (MCP) biosourcés et/ou des fibres végétales de miscanthus : Etudes au, 2023.
- [51] K. Kaack, K.U. Schwarz, P.E. Brander, Variation in morphology, anatomy and chemistry of stems of Miscanthus genotypes differing in mechanical properties, *Ind. Crops Prod.* 17 (2003) 131–142. [https://doi.org/10.1016/S0926-6690\(02\)00093-6](https://doi.org/10.1016/S0926-6690(02)00093-6).
- [52] Y. Xu, X. Duan, Y. Wu, T. Fu, W. Hou, S. Xue, Z. Yi, The efficiency and stability of soil organic carbon sequestration by perennial energy crops cultivation on marginal land depended on root traits, *Soil Tillage Res.* 235 (2024). <https://doi.org/10.1016/j.still.2023.105909>.
- [53] C. Brami, Enjeux de la filière thermique du Miscanthus : évaluation de l’effet d’une culture de Miscanthus x giganteus et de la valorisation agronomique de ses cendres, sur la qualité du sol, HAL (2020). <https://theses.hal.science/tel-03793800>.
- [54] Z. Chen, Y. He, Y. Iqbal, Y. Shi, H. Huang, Z. Yi, Investigation of genetic relationships within three Miscanthus species using SNP markers identified with SLAF-seq, *BMC Genomics* 23 (2022) 1–12. <https://doi.org/10.1186/s12864-021-08277-8>.
- [55] E.A. Heaton, F.G. Dohleman, A.F. Miguez, J.A. Juvik, V. Lozovaya, J. Widholm, O.A. Zobotina, G.F. Mcisaac, M.B. David, T.B. Voigt, N.N. Boersma, S.P. Long, Miscanthus: A Promising Biomass Crop, *Adv. Bot. Res.* 56 (2010). [https://doi.org/10.1016/S0065-2296\(10\)56003-8](https://doi.org/10.1016/S0065-2296(10)56003-8).
- [56] A.M. Cortés, A. V. Bridgwater, Kinetic study of the pyrolysis of miscanthus and its acid hydrolysis residue by thermogravimetric analysis, *Fuel Process. Technol.* 138 (2015) 184–193. <https://doi.org/10.1016/j.fuproc.2015.05.013>.
- [57] L. Chupin, L. Socalingame, D. de Ridder, E. Gineau, G. Mouille, S. Arnoult, M. Brancourt-Hulmel, C. Lapierre, L. Vincent, A. Mija, S. Corn, N. Le Moigne, P. Navard, Thermal and dynamic mechanical characterization of miscanthus stem fragments: Effects of genotypes, positions along the stem and their relation with biochemical and structural characteristics, *Ind.*

- Crops Prod. 156 (2020). <https://doi.org/10.1016/j.indcrop.2020.112863>.
- [58] H.L. Thomas, H.F.P. Nolasco, H. Carrère, M. Lartaud, T.V. Cao, C. Baptiste, J.L. Verdeil, Alkaline Pretreatments for Sorghum and Miscanthus Anaerobic Digestion: Impacts at Cell Wall and Tissue Scales, *Bioenergy Res.* 15 (2022) 792–809. <https://doi.org/10.1007/s12155-021-10342-9>.
- [59] Q. SUN, Q. LIN, Z.-L. YI, Z.-R. YANG, F.-S. ZHOU, A taxonomic revision of *Miscanthus* s.l. (Poaceae) from China, *Bot. J. Linn. Soc.* 164 (2010) 178–220. <https://doi.org/10.1111/j.1095-8339.2010.01082.x>.
- [60] M.J.I. Briones, A. Massey, D.M.O. Elias, J.P. McCalmont, K. Farrar, I. Donnison, N.P. McNamara, Species selection determines carbon allocation and turnover in *Miscanthus* crops: Implications for biomass production and C sequestration, *Sci. Total Environ.* 887 (2023) 164003. <https://doi.org/10.1016/j.scitotenv.2023.164003>.
- [61] LINDE-LAURSEN, Cytogenetic analysis of *Miscanthus* ‘ Giganteus ’, an interspecific hybrid, *Hereditas* 119 (1993) 297–300.
- [62] C. Jury, J. Girones, L.T.T. Vo, E. Di Giuseppe, G. Mouille, E. Gineau, S. Arnoult, M. Brancourt-Hulmel, C. Lapiere, L. Cézard, P. Navard, One-step preparation procedure, mechanical properties and environmental performances of miscanthus-based concrete blocks, *Mater. Today Commun.* 31 (2022). <https://doi.org/10.1016/j.mtcomm.2022.103575>.
- [63] I. Lewandowski, J.C. Clifton-Brown, J.M.O. Scurlock, W. Huisman, *Miscanthus*: European experience with a novel energy crop, *Biomass and Bioenergy* 19 (2000) 209–227. [https://doi.org/10.1016/S0961-9534\(00\)00032-5](https://doi.org/10.1016/S0961-9534(00)00032-5).
- [64] C. Jury, J. Girones, L.T.T. Vo, E. Di Giuseppe, G. Mouille, E. Gineau, S. Arnoult, M. Brancourt-Hulmel, C. Lapiere, L. Cézard, P. Navard, One-step preparation procedure, mechanical properties and environmental performances of miscanthus-based concrete blocks, *Mater. Today Commun.* 31 (2022). <https://doi.org/10.1016/j.mtcomm.2022.103575>.
- [65] J.J. De Vega, A. Teshome, M. Klaas, J. Grant, J. Finnan, S. Barth, Physiological and transcriptional response to drought stress among bioenergy grass *Miscanthus* species, *Biotechnol. Biofuels* 14 (2021) 1–14. <https://doi.org/10.1186/s13068-021-01915-z>.
- [66] T. Le Ngoc Huyen, M. Queneudec T’Kint, C. Remond, B. Chabbert, R.M. Dheilly, Saccharification of *Miscanthus x giganteus*, incorporation of lignocellulosic by-product in cementitious matrix, *Comptes Rendus - Biol.* 334 (2011) 837.e1-837.e11. <https://doi.org/10.1016/j.crv.2011.07.008>.
- [67] M.J.I. Briones, A. Massey, D.M.O. Elias, J.P. McCalmont, K. Farrar, I. Donnison, N.P. McNamara, Species selection determines carbon allocation and turnover in *Miscanthus* crops: Implications for biomass production and C sequestration, *Sci. Total Environ.* 887 (2023). <https://doi.org/10.1016/j.scitotenv.2023.164003>.
- [68] I. Lewandowski, J.C. Clifton-Brown, J.M.O. Scurlock, W. Huisman, *Miscanthus*: European experience with a novel energy crop, *Biomass and Bioenergy* 19 (2000) 209–227.
- [69] R. Pude, C.H. Treseler, R. Trettin, G. Noga, Suitability of *Miscanthus* genotypes for lightweight concrete, *Bodenkultur* 56 (2005) 61–69.
- [70] N. Namoi, C. Jang, G.D. Behnke, J.W. Lee, W. Yang, D.K. Lee, Nitrogen fertilization effects on aged *Miscanthus x giganteus* stands: Exploring biomass yield, yield components, and biomass

- prediction using in-season morphological traits, *GCB Bioenergy* 16 (2024) 1–19. <https://doi.org/10.1111/gcbb.13139>.
- [71] J.L. Kane, R.G. Schartiger, N.K. Daniels, Z.B. Freedman, L.M. McDonald, J.G. Skousen, E.M. Morrissey, Bioenergy crop *Miscanthus x giganteus* acts as an ecosystem engineer to increase bacterial diversity and soil organic matter on marginal land, *Soil Biol. Biochem.* 186 (2023) 109178. <https://doi.org/10.1016/j.soilbio.2023.109178>.
- [72] F. Ntimugura, R. Vinai, A. Harper, P. Walker, Mechanical, thermal, hygroscopic and acoustic properties of bio-aggregates – lime and alkali - activated insulating composite materials: A review of current status and prospects for miscanthus as an innovative resource in the South West of England, *Sustain. Mater. Technol.* 26 (2020) e00211. <https://doi.org/10.1016/j.susmat.2020.e00211>.
- [73] C. Brami, Enjeux de la filière thermique du *Miscanthus* : évaluation de l'effet d'une culture de *Miscanthus x giganteus* et de la valorisation agronomique de ses cendres, sur la qualité du sol, HAL (2020). <https://hal.science/tel-03793800v1>.
- [74] Promisc Bical Belux, (n.d.). www.promisc.be.
- [75] E.A. Heaton, F.G. Dohleman, A.F. Miguez, J.A. Juvik, V. Lozovaya, J. Widholm, O.A. Zabolina, G.F. McIsaac, M.B. David, T.B. Voigt, N.N. Boersma, S.P. Long, *Miscanthus*. A Promising Biomass Crop, *Adv. Bot. Res.* 56 (2010) 75–137. <https://doi.org/10.1016/B978-0-12-381518-7.00003-0>.
- [76] S.A. Edrisi, P.C. Abhilash, Exploring marginal and degraded lands for biomass and bioenergy production: An Indian scenario, *Renew. Sustain. Energy Rev.* 54 (2016) 1537–1551. <https://doi.org/10.1016/j.rser.2015.10.050>.
- [77] M.A. Yost, B.K. Randall, N.R. Kitchen, E.A. Heaton, R.L. Myers, Yield potential and nitrogen requirements of *miscanthus x giganteus* on eroded soil, *Agron. J.* 109 (2017) 684–695. <https://doi.org/10.2134/agronj2016.10.0582>.
- [78] C. Zumpf, M.S. Lee, S. Thapa, J. Guo, R. Mitchell, J.J. Volenec, D.K. Lee, Impact of warm-season grass management on feedstock production on marginal farmland in Central Illinois, *GCB Bioenergy* 11 (2019) 1202–1214. <https://doi.org/10.1111/gcbb.12627>.
- [79] Y. Xu, X. Duan, Y. Wu, T. Fu, W. Hou, S. Xue, Z. Yi, The efficiency and stability of soil organic carbon sequestration by perennial energy crops cultivation on marginal land depended on root traits, *Soil Tillage Res.* 235 (2024) 0–7. <https://doi.org/10.1016/j.still.2023.105909>.
- [80] S. Cadoux, F. Ferchaud, C. Demay, H. Boizard, J.M. Machet, E. Fourdinier, M. Preudhomme, B. Chabbert, G. Gosse, B. Mary, Implications of productivity and nutrient requirements on greenhouse gas balance of annual and perennial bioenergy crops, *GCB Bioenergy* 6 (2014) 425–438. <https://doi.org/10.1111/gcbb.12065>.
- [81] M. Zapater, M. Catterou, B. Mary, M. Ollier, L. Fingar, E. Mignot, F. Ferchaud, L. Strullu, F. Dubois, M. Brancourt-Hulmel, A Single and Robust Critical Nitrogen Dilution Curve for *Miscanthus x giganteus* and *Miscanthus sinensis*, *Bioenergy Res.* 10 (2016) 115–128. <https://doi.org/10.1007/s12155-016-9781-8>.
- [82] C.P. Witzel, R. Finger, Economic evaluation of *Miscanthus* production - A review, *Renew. Sustain. Energy Rev.* 53 (2016) 681–696. <https://doi.org/10.1016/j.rser.2015.08.063>.
- [83] S. Xue, O. Kalinina, I. Lewandowski, Present and future options for *Miscanthus* propagation and

- establishment, *Renew. Sustain. Energy Rev.* 49 (2015) 1233–1246.
<https://doi.org/10.1016/j.rser.2015.04.168>.
- [84] Novabiom, Novabiom, (n.d.).
- [85] Y.A. Gismatulina, V. V. Budaeva, Chemical composition of five *Miscanthus sinensis* harvests and nitric-acid cellulose therefrom, *Ind. Crops Prod.* 109 (2017) 227–232.
<https://doi.org/10.1016/j.indcrop.2017.08.026>.
- [86] N. Ben Fradj, S. Rozakis, M. Borzęcka, M. Matyka, *Miscanthus* in the European bio-economy: A network analysis, *Ind. Crops Prod.* 148 (2020). <https://doi.org/10.1016/j.indcrop.2020.112281>.
- [87] I. Lewandowski, J.C. Clifton-Brown, J.M.O. Scurlock, W. Huisman, *Miscanthus*: European experience with a novel energy crop, 2000.
- [88] I. Lewandowski, J. Clifton-Brown, L.M. Trindade, G.C. Van Der Linden, K.U. Schwarz, K. Müller-Sämman, A. Anisimov, C.L. Chen, O. Dolstra, I.S. Donnison, K. Farrar, S. Fonteyne, G. Harding, A. Hastings, L.M. Huxley, Y. Iqbal, N. Khokhlov, A. Kiesel, P. Lootens, H. Meyer, M. Mos, H. Muylle, C. Nunn, M. Özgüven, I. Roldán-Ruiz, H. Schüle, I. Tarakanov, T. Der Weijde, M. Wagner, Q. Xi, O. Kalinina, Progress on optimizing miscanthus biomass production for the european bioeconomy: Results of the EU FP7 project OPTIMISC, *Front. Plant Sci.* 7 (2016) 1–23.
<https://doi.org/10.3389/fpls.2016.01620>.
- [89] E. Chupakhin, O. Babich, S. Sukhikh, S. Ivanova, E. Budenkova, O. Kalashnikova, O. Kriger, Methods of increasing miscanthus biomass yield for biofuel production, *Energies* 14 (2021).
<https://doi.org/10.3390/en14248368>.
- [90] F. *Miscanthus*, France miscanthus, (n.d.). <https://france-miscanthus.org/>.
- [91] J.R. STEWART, Y. TOMA, F.G. FERNÁNDEZ, A. NISHIWAKI, T. YAMADA, G. BOLLERO, The ecology and agronomy of *Miscanthus sinensis*, a species important to bioenergy crop development, in its native range in Japan: a review, *GCB Bioenergy* 1 (2009) 126–153.
<https://doi.org/10.1111/j.1757-1707.2009.01010.x>.
- [92] Y.X. Chen, F. Wu, Q. Yu, H.J.H. Brouwers, Bio-based ultra-lightweight concrete applying miscanthus fibers: Acoustic absorption and thermal insulation, *Cem. Concr. Compos.* 114 (2020).
<https://doi.org/10.1016/j.cemconcomp.2020.103829>.
- [93] M. El Akkari, N. Ben Fradj, B. Gabrielle, S. Njakou Djomo, Spatially-explicit environmental assessment of bioethanol from miscanthus and switchgrass in France, *Clean. Circ. Bioeconomy* 6 (2023) 100059. <https://doi.org/10.1016/j.clcb.2023.100059>.
- [94] D. Liu, W. Diao, X. Sun, J. Zong, X. Qi, C. Liang, Application of *Miscanthus* substrates in the cultivation of *Ganoderma lingzhi*, *Arch. Microbiol.* 205 (2023) 1–9.
<https://doi.org/10.1007/s00203-023-03720-8>.
- [95] I.A.P. Pinzon, R.A. Razal, R.C. Mendoza, R.B. Carpio, R.C.P. Eusebio, Parametric study on microwave-assisted extraction of runo (*Miscanthus sinensis* Andersson) dye and its application to paper and cotton fabric, *Biotechnol. Reports* 28 (2020) e00556.
<https://doi.org/10.1016/j.btre.2020.e00556>.
- [96] Z. Hu, T. Zhou, H. Tian, L. Feng, C. Yao, Y. Yin, D. Chen, Effects of pyrolysis parameters on the distribution of pyrolysis products of *Miscanthus*, *Prog. React. Kinet. Mech.* 46 (2021).
<https://doi.org/10.1177/14686783211010970>.
- [97] F.S. Chapin, E.D. Schulze, H.A. Mooney, The ecology and economics of storage in plants, *Annu.*

- Rev. Ecol. Syst. 21 (1990) 423–447. <https://doi.org/10.1146/annurev.es.21.110190.002231>.
- [98] E.M. Hodgson, D.J. Nowakowski, I. Shield, A. Riche, A. V. Bridgwater, J.C. Clifton-Brown, I.S. Donnison, Variation in *Miscanthus* chemical composition and implications for conversion by pyrolysis and thermo-chemical bio-refining for fuels and chemicals, *Bioresour. Technol.* 102 (2011) 3411–3418. <https://doi.org/10.1016/j.biortech.2010.10.017>.
- [99] H. Yan, W. Li, X. Liu, M. Zhu, M. Wang, Morphological Structure and Basic Characteristics of *Miscanthus floridulus* Fibers, *ACS Omega* 7 (2022) 19412–19419. <https://doi.org/10.1021/acsomega.2c01025>.
- [100] Sergio Pons Ribera, Valorisation des fibres végétales dans des matériaux cimentaires : application dans les formulations de chapes fluides, HAL (2023).
- [101] E. Rodriguez Alonso, C. Dupont, L. Heux, D. Da Silva Perez, J.M. Commandre, C. Gourdon, Study of solid chemical evolution in torrefaction of different biomasses through solid-state ¹³C cross-polarization/magic angle spinning NMR (nuclear magnetic resonance) and TGA (thermogravimetric analysis), *Energy* 97 (2016) 381–390. <https://doi.org/10.1016/j.energy.2015.12.120>.
- [102] F. Ntimugura, R. Vinai, A. Harper, P. Walker, Mechanical, thermal, hygroscopic and acoustic properties of bio-aggregates – lime and alkali - activated insulating composite materials: A review of current status and prospects for miscanthus as an innovative resource in the South West of England, *Sustain. Mater. Technol.* 26 (2020). <https://doi.org/10.1016/j.susmat.2020.e00211>.
- [103] L. Chupin, L. Soccalingame, D. de Ridder, E. Gineau, G. Mouille, S. Arnoult, M. Brancourt-Hulmel, C. Lapiere, L. Vincent, A. Mija, S. Corn, N. Le Moigne, P. Navard, Thermal and dynamic mechanical characterization of miscanthus stem fragments: Effects of genotypes, positions along the stem and their relation with biochemical and structural characteristics, *Ind. Crops Prod.* 156 (2020) 112863. <https://doi.org/10.1016/j.indcrop.2020.112863>.
- [104] J.Y. Kim, S. Oh, H. Hwang, Y.H. Moon, J.W. Choi, Assessment of miscanthus biomass (*Miscanthus sacchariflorus*) for conversion and utilization of bio-oil by fluidized bed type fast pyrolysis, *Energy* 76 (2014) 284–291. <https://doi.org/10.1016/j.energy.2014.08.010>.
- [105] A.M. Cortés, A. V. Bridgwater, Kinetic study of the pyrolysis of miscanthus and its acid hydrolysis residue by thermogravimetric analysis, *Fuel Process. Technol.* 138 (2015) 184–193. <https://doi.org/10.1016/j.fuproc.2015.05.013>.
- [106] A. Arizzi, G. Cultrone, M. Brümmer, H. Viles, A chemical, morphological and mineralogical study on the interaction between hemp hurds and aerial and natural hydraulic lime particles: Implications for mortar manufacturing, *Constr. Build. Mater.* 75 (2015) 375–384. <https://doi.org/10.1016/j.conbuildmat.2014.11.026>.
- [107] F. Ntimugura, R. Vinai, A. Harper, P. Walker, Chemical, mineralogical, and microstructural interactions between lime-pozzolan binders and miscanthus particles in lightweight concretes, *Clean. Mater.* 3 (2022). <https://doi.org/10.1016/j.clema.2022.100053>.
- [108] S.E. Hamdi, C. Delisée, J. Malvestio, N. Da Silva, A. Le Duc, J. Beaugrand, X-ray computed microtomography and 2D image analysis for morphological characterization of short lignocellulosic fibers raw materials: A benchmark survey, *Compos. Part A Appl. Sci. Manuf.* 76 (2015) 1–9. <https://doi.org/10.1016/j.compositesa.2015.04.019>.
- [109] P.P. Dias, L.B. Jayasinghe, D. Waldmann, Investigation of Mycelium-Miscanthus composites as building insulation material, *Results Mater.* 10 (2021).

- <https://doi.org/10.1016/j.rinma.2021.100189>.
- [110] F. Wu, Q. Yu, H.J.H. Brouwers, Long-term performance of bio-based miscanthus mortar, *Constr. Build. Mater.* 324 (2022). <https://doi.org/10.1016/j.conbuildmat.2022.126703>.
- [111] Y. Chen, Q.L. Yu, H.J.H. Brouwers, Acoustic performance and microstructural analysis of bio-based lightweight concrete containing miscanthus, *Constr. Build. Mater.* 157 (2017) 839–851. <https://doi.org/10.1016/j.conbuildmat.2017.09.161>.
- [112] K.A.P. Wijesinghe, C. Gunasekara, D.W. Law, H.D. Hidallana-Gamage, N. Wanasekara, L. Wang, Thermal and acoustic performance in textile fibre-reinforced concrete: An analytical review, *Constr. Build. Mater.* 412 (2024) 134879. <https://doi.org/10.1016/j.conbuildmat.2024.134879>.
- [113] Y. Khalaf, R. Sonnier, N. Brosse, R. El Hage, An Extensive Study of an Eco-Friendly Fireproofing Process of Lignocellulosic Miscanthus × giganteus Particles and Their Application in Flame-Retardant Panels, *Polymers (Basel)*. 17 (2025) 1–18. <https://doi.org/10.3390/polym17020241>.
- [114] S. Witzleben, Minimizing the Global Warming Potential with Geopolymer-Based Insulation Material with Miscanthus Fiber, *Polymers (Basel)*. 14 (2022). <https://doi.org/10.3390/polym14153191>.
- [115] A. Hussain, J. Calabria-holley, M. Lawrence, Y. Jiang, Hygrothermal and mechanical characterisation of novel hemp shiv based thermal insulation composites, *Constr. Build. Mater.* 212 (2019) 561–568. <https://doi.org/10.1016/j.conbuildmat.2019.04.029>.
- [116] T. Schnabel, H. Huber, A. Petutschnigg, A. Jäger, Analysis of plant materials pre-treated by steam explosion technology for their usability as insulating materials, *Agron. Res.* 17 (2019) 1191–1198. <https://doi.org/10.15159/AR.19.061>.
- [117] C.E.A. Saclay, NF EN 12667 Détermination de la résistance thermique par la méthode de la plaque chaude gardée et la méthode fluxmétrique, (2001).
- [118] H. Ajabli, A. Zoubir, R. Elotmani, M. Louzazni, K. Kandoussi, A. Daya, Review on Eco-friendly insulation material used for indoor comfort in building, *Renew. Sustain. Energy Rev.* 185 (2023) 113609. <https://doi.org/10.1016/j.rser.2023.113609>.
- [119] F. Wu, X. Chen, H.J.H. Brouwers, Application of miscanthus to enhance plant growth adaptability of bio-based vegetal concrete, *Constr. Build. Mater.* 425 (2024) 136096. <https://doi.org/10.1016/j.conbuildmat.2024.136096>.
- [120] P. Evaluation, Evaluation of the thermal performance of an innovative pre-fabricated natural plant-fibre building system ., 34 (2013) 369–380.
- [121] P.E. Mason, L.I. Darvell, J.M. Jones, A. Williams, Comparative Study of the Thermal Conductivity of Solid Biomass Fuels, (2016). <https://doi.org/10.1021/acs.energyfuels.5b02261>.
- [122] K. Kaack, K.U. Schwarz, Morphological and mechanical properties of Miscanthus in relation to harvesting, lodging, and growth conditions, *Ind. Crops Prod.* 14 (2001) 145–154. [https://doi.org/10.1016/S0926-6690\(01\)00078-4](https://doi.org/10.1016/S0926-6690(01)00078-4).
- [123] J.L. Thomason, J. Carruthers, J. Kelly, G. Johnson, Fibre cross-section determination and variability in sisal and flax and its effects on fibre performance characterisation, *Compos. Sci. Technol.* 71 (2011) 1008–1015. <https://doi.org/10.1016/j.compscitech.2011.03.007>.

- [124] A. Bourmaud, S. Pimbert, Investigations on mechanical properties of poly(propylene) and poly(lactic acid) reinforced by miscanthus fibers, *Compos. Part A Appl. Sci. Manuf.* 39 (2008) 1444–1454. <https://doi.org/10.1016/j.compositesa.2008.05.023>.
- [125] F.C. Barb, MODIFICACIÓ DE FIBRES DE JUTE PER L'ELABORACIÓ DE PLÀSTICS REFORÇATS, 2005.
- [126] S.P. Ribera, Valorisation des fibres végétales dans des matériaux cimentaires : application dans les formulations de chapes fluides To cite this version : HAL Id : tel-04018330 Valorisation des fibres végétales dans les matériaux cimentaires : application dans les for, (2023).
- [127] G. Balcioglu, H.K. Jeswani, A. Azapagic, A sustainability assessment of utilising energy crops for heat and electricity generation in Turkey, *Sustain. Prod. Consum.* 41 (2023) 134–155. <https://doi.org/10.1016/j.spc.2023.08.003>.
- [128] J. Weik, J. Lask, E. Petig, S. Seeger, N. Marting Vidaurre, M. Wagner, M. Weiler, E. Bahrs, I. Lewandowski, E. Angenendt, Implications of large-scale miscanthus cultivation in water protection areas: A Life Cycle Assessment with model coupling for improved policy support, *GCB Bioenergy* 14 (2022) 1162–1182. <https://doi.org/10.1111/gcbb.12994>.
- [129] M. Krzyżaniak, M.J. Stolarski, K. Warminski, Life Cycle Assessment of Giant: Production on Marginal Soil with Various Fertilisation Treatments, *Energies* 13 (2020) 1–76. <https://doi.org/10.3390/en13081931>.
- [130] M. Rondin, Sur les traces d'une nouvelle filière dans le secteur du bâtiment : le miscanthus, HAL (2022).
- [131] S. Rosa Latapie, V. Sabathier, A. Abou-Chakra, Bio-based building materials: A prediction of insulating properties for a wide range of agricultural by-products, *J. Build. Eng.* 86 (2024) 108867. <https://doi.org/10.1016/j.job.2024.108867>.
- [132] T. Dickson, S. Pavía, Energy performance , environmental impact and cost of a range of insulation materials, *Renew. Sustain. Energy Rev.* 140 (2021) 110752. <https://doi.org/10.1016/j.rser.2021.110752>.
- [133] S. Pescari, M. Merea, A. Pitroacă, C.B. Vilceanu, A Particular Case of Urban Sustainability: Comparison Study of the Efficiency of Multiple Thermal Insulations for Buildings, *Sustain.* 14 (2022). <https://doi.org/10.3390/su142316283>.
- [134] C.L. Justine NETO, Les différents usages possibles du miscanthus et du switchgrass hors paillages agricoles Utilisation en matériaux de construction, 2022.
- [135] L.E.S. Produits, D.U. Btp, E.T.D.E.L. Industrie, Produits gallery, (2025) 15–18.
- [136] Y. Chen, Q.L. Yu, H.J.H. Brouwers, Acoustic performance and microstructural analysis of bio-based lightweight concrete containing miscanthus, *Constr. Build. Mater.* 157 (2017) 839–851. <https://doi.org/10.1016/j.conbuildmat.2017.09.161>.
- [137] I.Z. Šekler, S.S. Vještica, V.M. Janković, S.S. Stefanović, V.L. Ristić, Miscanthus x giganteus as a building material-lightweight concrete, *Hem. Ind.* 75 (2021) 147–154. <https://doi.org/10.2298/HEMIND201116013S>.
- [138] T. Gereziher Atsbha, S. Zhutovsky, The effect of external curing methods on the development of mechanical and durability-related properties of normal-strength concrete, *Constr. Build. Mater.* 324 (2022) 126706. <https://doi.org/10.1016/j.conbuildmat.2022.126706>.

- [139] I. Merta, E.K. Tschegg, Fracture energy of natural fibre reinforced concrete, *Constr. Build. Mater.* 40 (2013) 991–997. <https://doi.org/10.1016/j.conbuildmat.2012.11.060>.
- [140] Labels Bâtiment Basse Consommation en rénovation | Ministères Aménagement du territoire Transition écologique, (2024). <https://www.ecologie.gouv.fr/politiques-publiques/labels-batiment-basse-consommation-renovation#exigences-pour-le-label-bbc-renovation-residentiel-2024-0> (accessed August 25, 2025).
- [141] Y.X. Chen, Q. Yu, Surface modification of miscanthus fiber with hydrophobic silica aerogel for high performance bio-lightweight concrete, *Constr. Build. Mater.* 411 (2024) 134478. <https://doi.org/10.1016/j.conbuildmat.2023.134478>.
- [142] M.S.P. M. Sivaraja, Kandasamy, N. Velmani, Study on durability of natural fibre concrete composites using mechanical strength and microstructural properties, *Bull. Mater. Sci.* 33 (2010) 719–729.
- [143] K. Gunasekaran, R. Annadurai, P.S. Kumar, Long term study on compressive and bond strength of coconut shell aggregate concrete, *Constr. Build. Mater.* 28 (2012) 208–215. <https://doi.org/10.1016/j.conbuildmat.2011.08.072>.
- [144] T. Le Ngoc Huyen, M. Queneudec T’Kint, C. Remond, B. Chabbert, R.M. Dheilily, Saccharification of *Miscanthus x giganteus*, incorporation of lignocellulosic by-product in cementitious matrix, *Comptes Rendus - Biol.* 334 (2011) 837.e1-837.e11. <https://doi.org/10.1016/j.crv.2011.07.008>.
- [145] P.P. Dias, D. Waldmann, Optimisation of the mechanical properties of *Miscanthus* lightweight concrete, *Constr. Build. Mater.* 258 (2020) 119643. <https://doi.org/10.1016/j.conbuildmat.2020.119643>.
- [146] L.T.T. Vo, P. Navard, Treatments of plant biomass for cementitious building materials – A review, *Constr. Build. Mater.* 121 (2016) 161–176. <https://doi.org/10.1016/j.conbuildmat.2016.05.125>.
- [147] A. Eschenhagen, M. Raj, N. Rodrigo, A. Zamora, L. Labonne, P. Evon, H. Weleman, Investigation of *Miscanthus* and Sunflower Stalk Fiber-Reinforced Composites for Insulation Applications, *Adv. Civ. Eng.* 2019 (2019). <https://doi.org/10.1155/2019/9328087>.
- [148] A. Savic, D. Antonijevic, I. Jelic, D. Zakic, Thermomechanical behavior of bio-fiber composite thermal insulation panels, *Energy Build.* 229 (2020) 110511. <https://doi.org/10.1016/j.enbuild.2020.110511>.
- [149] F. Ntimugura, R. Vinai, A.B. Harper, P. Walker, Environmental performance of miscanthus-lime lightweight concrete using life cycle assessment: Application in external wall assemblies, *Sustain. Mater. Technol.* 28 (2021) e00253. <https://doi.org/10.1016/j.susmat.2021.e00253>.
- [150] R. El Hage, Y. Khalaf, C. Lacoste, M. Nakhl, A. Bergeret, P. Lacroix, A flame retarded chitosan binder for insulating miscanthus / recycled textile fibers reinforced biocomposites To cite this version : HAL Id : hal-02416405, *J. Appl. Polym. Sci.* 136 (2019) 47306. <https://doi.org/10.1002/app.47306>.
- [151] H.J.H.B. Y.X. Chen, F. Wu, Qingliang Yu, Bio-based ultra-lightweight concrete applying miscanthus fibers: Acoustic absorption and thermal insulation, *Cem. Concr. Compos.* 114 (2020).
- [152] A. Bonazzi, Des blocs en béton de miscanthus, un matériau biosourcé, isolant et bas carbone dédié à l'éco-construction, 2023. <https://www.neozone.org/innovation/des-blocs-en-beton-de-miscanthus-un-materiau-biosource-isolant-et-bas-carbone-dedie-a-leco-construction/>.

