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SUSTAINABLE CONSTRUCTION STUDY IN MAURITIUS

LOT 4 : BIO-SOURCED MATERIALS PRE-FEASIBILITY STUDY

TECHNICAL ASSISTANCE FOR THE IMPLEMENTATION OF SUNREF III PROGRAMME - MAURITIUS

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Executive Summary

1. The challenges to be addressed

Bio-sourced materials are one attractive option in the construction sector, particularly for Greenfield projects, where innovation is acceptable, and as the best way to limit imports and to cope with the need to have ''low-carbon content'' solutions. Creating local activities with Small and Medium Enterprises (SME) involved in bio-sourced material is also to consider for ''niche'' markets and more widespread dissemination if bulk markets can be identified.

The key elements to consider for getting the success expected are: a) having the local resources in quality and quantity to address market potential, b) meeting requirements of standardisation to guarantee the quality and performance of these construction materials, c) maximizing the processes across the'' whole value chain'' to have the best products if the market is opened to exports, to increase the production scale (in the Indian Ocean for example).

The process could be long from resources identification, full implementation at industrial scale, standardization, and market deployment (locally to have references and then at international level).

2. The key role of insulation as a niche market to promote bio-sourced materials

Insulation plays an important role in limiting the thermal input in buildings to achieve thermal comfort. More so in tropical islands such as Mauritius, where there is heavy reliance on air conditioning during most part of the year. The imported materials used for insulation in the residential sector, and more significantly, in the tertiary sectors (office buildings, education, hotels and resorts) are not always adapted to local climatic conditions, due to a high hygrometry that alters the priorities and performance.

Therefore, the development of local bio-sourced materials would be an advantage for the construction industry, both from an economic and environmental perspective. With the objective to consider the eligibility of bio-sourced materials under the SUNREF green credit line and also to de-risk such investment (from a bank perspective), AFD has commissioned a pre-feasibility study on bio-sourced materials.

3. Scope of materials with their performances

- Biosourced materials are naturally formed construction materials (those generated from plant or animal sources) that provide structural and non-structural functions within the building fabric.

- The methodology used for the pre-feasibility study of bio-sourced materiasl is a desktop research to identify bio-sourced materials available worldwide. A list of 34 materials was drafted.The list was then narrowed down to 14 most promising bio-sourced materials that can be grown or available locally and adapted for the local context. The list is as follows: Bagasse; Bamboo, Banana fibre, Cellulose insulation, Coconut, Cryptomeria, Guava tree, Orb, Pineapple fibre, Potato starch, Ravenala, Straw, Vetiver, and Wood fibre.

- The report provides an analysis of the thermal conductivity properties of the selected materials. Thermal conductivity is a measure of how easily heat can flow through a material. It is a property of the material itself and depends on its composition, structure, and temperature. Materials that are good conductors of heat can transfer heat more easily, while materials that are poor conductors (insulators) resist the flow of heat. As a rule of thumb, the lower the thermal conductivity the better, because the material conducts less heat energy.

  Table 2 of the report identifies the details pertaining to the bio-sourced materials local availability and thermal conductivity with the highest being potato starch (1.6-1.9 W/mK) and the lowest being cellulose insulation and pineapple fibre (0.035 W/mK). Guava tree and bagasse also have low thermal conductivity of 0.045.

4. Key stakeloders locally; insights about availabilty (focus groups)

A second part of the study consisted in consulting key stakeholders to have insights about viability of different bio-sourced materials for Mauritius. The focus group gathered 6 people from 4 key organisations who provided information that was used to do a SWOT analysis for Mauritius. The SWOT

analysis pointed out the different strengths, weaknesses, opportunities and threats pertaining to the growing of and use of bio-sourced materials in Mauritius. The detailed SWOT analysis are found in Table 3.

The focus group conducted with key stakeholders allowed for the Identification of four bio-sourced materials with great potential for Mauritius namely banana, pineapple, coconut and ravenala tree.

In the Indian Ocean, in Reunion Island specifically, a pilot project was conducted to make prototypes from bio-sourced insulation materials and resources available on the island. The project aimed at showcasing the viability of such materials in the construction industry. Four plants were selected for the project namely bagasse (from sugarcane), Vetiver leaves, Guava wood and Cryptomeria wood. This experience should be considered as promising for market deployment.

In Mauritius, there is limited Cryptomeria wood. Bagasse is not currently an option as it has a competitive use for electricity production. However, vetiver leaves and guava wood should be considered. Guava plants can be found in abundance on the island. These plants are considered as invasive and detrimental to endemic species. Therefore, the use of guava wood as bio-sourced material in construction would make absolute sense from a biodiversity preservation perspective as well.

Therefore, the six most promising bio-sourced materials are banana, pineapple, coconut, ravenala tree, vetiver and guava wood.

5. Next steps to evaluate the potential of these resources to enter the market of bio-sourced materials.

- A list of private stakeholders has been established for 14 local materials having good potential to feed the bio-sources market with their products, and their links for future contacts. The idea is to focus on the end, on two or three bio-sourced materials. For moving to monitor standardization and demo projects.

- For promoting the use of bio-sourced materials in the construction sector, demo projects will be a major step, through the implementation of call for projects. Incentives would be a key instrument to develop the market. Private stakeholders are already identified to move forward.

1. Bio-sourced materials in the construction industry: Background

Through its green finance label SUNREF (Sustainable Use of Natural Resources and Energy Finance), Agence Française de Développement (AFD) supports the energy and environmental transition in nearly 30 developing countries by helping private sector actors seize opportunities linked to green growth and implement their projects, while encouraging local partner banks to finance them.
SUNREF commissioned a study on green and sustainable building to better inform project developers and banks on the criteria adopted in the fields of mitigation and adaptation to climate change, and to facilitate and promote bankable projects. This will allow easier evaluation of the applications, and the eligibility of the expenses using appropriate frameworks and methodologies. They will be able to apply the methods for evaluating eligible expenses to their projects, in conjunction with the SUNREF partner banks. For the study, one of the key deliverables is to do a pre-feasibility study by providing a situational analysis of bio-sourced insulation solutions, adapted to the tropical climate with their intrinsic performances compared to available solutions and the possibility of manufacturing locally.
Insulation plays an important role in limiting the thermal input in the building. The imported materials used are not always adapted to local climatic conditions, due to a high hygrometry that alters the properties and performance. Therefore, the development of local bio-sourced channels would be a plus for this construction market, from locally available raw materials.

Evaluation of bio-sourced materials is based on available data on:

1) the usable and locally available raw materials,
2) the properties obtained,
3) the fields of application. A standardisation/certification component could be drafted from the studies already carried out. The manufacture of these bio -sourced materials locally under acceptable conditions will have to be evaluated.

2. Introduction to bio-sourced materials

Bio-sourced materials are classified as naturally-derived construction materials (ie those originating from plant or animal sources) providing both structural and non-structural functions within the building fabric(BRE Group, 2020). The building material selection strongly affects the overall environmental impact of a building, especially the selection of the materials for the structural frame and the building envelope (i.e. basement, exterior walls and roof) on which the former has a major influence(Olga et al., 2019).

Bio-sourced materials are already being used in many applications in the building and construction sector as insulants (vegetable fibre wools, recycled textile, cellulose wadding, hemp shives, shives, straw bales, etc.), panels (vegetable particles or fibres, compressed straw, etc.) but also to create plastic composite materials (matrices, reinforcement fibres, fillers), in addition to textile, paper, packaging, energy, chemistry (adhesives, adjuvants, paints, etc.)(Grenoble INP - UGA Institut d'ingénierie et de management, 2014).

Considering the increasing social emphasis on environmental issues, waste disposal and the depletion of raw materials, bio-based materials constitute a promising alternative to those obtained from fossil carbon. Fast-growing biogenic materials, e.g. straw or hemp shives, are highly promising alternatives for insulation, since their thermal conductivity is generally low(Grenoble INP - UGA Institut d'ingénierie et de management, 2014; Olga et al., 2019).

Bio-based materials, like all materials, are likely to experience a range of environments and challenges that can affect the performance of the material, such as the effects of weathering and moisture. In addition, as bio-based materials are organic in nature, this means that they are likely to be susceptible to attack by natural organisms ranging from bacteria and fungi to insects and higher animals(Dennis & Christian, 2017).

3. Methodology

3.1. Desktop research

Qualitative and quantitative research were both employed for this report. Qualitative research is the collection and analysis of non-numerical data such as texts, with which the researcher deeply understands concepts, perspectives, and participants' experiences. On the contrary, quantitative research is the collection and analysis of numerical data such as the frequency of participants doing things, or the extent to which an activity occurs, or the relationship between variables. The results can be presented in percentages in pie charts, line graphs, or numerical tables (IGI, 2022).

3.2. Focus group (Stakeholder's meeting)

For this study, the following stakeholders were invited to participate in a focus group on the 29th June 2022 (meeting minutes in appendix C) :

- Région Réunion
- Cosmetic Valley
- Mauritius Research and Innovation Council
- Cap Business Océan Indien
- Association of Mauritian Manufacturers
- Mauritius Standards Bureau
- Ministry of Agro-industry and food security
- National Parks and Conservation Service
- Forestry Service
- La Pépinière de Labourdonnais
- ENL Agri Limited
- Medine Ltd
- Endemika
- Flora Nursery – Pépinière
- Citadelle Native Re-vegetation project
- Gamma Materials Ltd
- Lafarge (Mauritius) Cement Ltd
- UBP Group
- Chantier de Plaisance
- Grewals Mauritius Ltd
- Interior Solutions Ltd
- Profilage Océan Indien Ltée
- Riteseal (Mtius) Ltd
- Saint Gobain

The objectives of the focus group were to share information gathered on bio-sourced materials for the construction industry, with the different stakeholders invited, and to have their input pertaining to same. The agenda for the meeting was as follows:

- Introduction to AFD and SUNREF
- Assessment of the potential of the bio-sourced materials market in Mauritius
- Identification of interested stakeholders in the value chain
- Identification of barriers and enablers

4. Bio-sourced materials available worldwide

The bio-sourced materials available worldwide have been reduced to a list comprising of 14 materials. They have been chosen based on the local availability of the raw material or their potential to be grown locally.

Table 1 Bio-sourced materials available worldwide

Material	Use and Description
Bagasse	Can be used as an insulation material which is resistant to moisture and termites which has been tested in an environment having a temperature of 28°C and humidity of 95%(CIRBAT et al., 2019). The material should be first mixed with boric acid and the resulting concentration should be 4.4%(CIRBAT et al., 2019)
Bamboo	Bamboo is part of the subfamily of grass. During its growth, silicon and lignin deposits in the cell walls strengthen the bamboo, which takes three to five years. There are approximately 1500 bamboo species. The woody bamboo species used for building are resistant to insects and funghi. Bamboo is also capable of capturing CO_2 from the atmosphere. In terms of strength and stiffness bamboo performs well. For floors, furniture and walls, bamboo plywood can be used. Plywood are layered sheets of bamboo made by processing large bamboo stems (Centre of Expertise Biobased Economy, nd).
Banana fibre	Banana, as a natural fiber, has inherent advantages like silky luster, high tensile strength, low extensibility, considerable heat and fire resistance and long staple lengths. Banana fiber can be used in many different areas, and has been receiving increasing attention from industry. Their interests focus not only on the traditional uses of banana fiber, but also on the production of other value-added products such as, pulp and paper, geo-textiles, composites and home textiles.(S.Sakthivel, 2019)
Cellulose insulation	An environmentally friendly product, recycled paper insulation is a good option for both new construction and renovation projects. Commonly known as cellulose, and sometimes referred to as newsprint insulation, it is a green choice for insulating your home. Cellulose is made mainly from shredded newsprint. It is treated with a borate additive that acts as a fire retardant and is pest and mold resistant. With an R-value (measure of „insulating effectiveness“) of about 3.6 per inch, it is competitive with other types of insulation. Although not recommended for installation in damp basement conditions, it is considered a good environmental option for attic and wall insulation (Zinck, 2022).
Coconut fibre	Coconut fibre is extracted from the outer shell of a coconut. The common name, scientific name and plant family of coconut fibre is Coir, Cocos nucifera and Arecaceae (Palm), respectively. Coconut cultivation is concentrated in the tropical belts of Asia and East Africa.There are two types of coconut fibres, brown fibre extracted from matured coconuts and white fibres extracted from immature coconuts. Coconut fibres are stiff and tough and have low thermal conductivity. Coconut fibres are commercial available in three forms, namely bristle (long fibres), mattress (relatively short) and decorticated (mixed fibres). These different types of fibres have different uses depending upon the requirement. In engineering, brown fibres are mostly used .(Majid Ali, 2011)
Cryptomeria	Can be used as an insulation material which is resistant to moisture and termites which has been tested in an environment having a temperature of 28°C and humidity of 95%(CIRBAT et al., 2019). The material should be first mixed with boric acid and the resulting concentration should be 4.4%(CIRBAT et al., 2019)
Guava tree (except the fruit)	Can be used as an insulation material which is resistant to moisture and termites which has been tested in an environment having a temperature of 28°C and humidity of 95%(CIRBAT et al., 2019). The material should be first mixed with boric acid and the resulting concentration should be 4.4%(CIRBAT et al., 2019)

Orb	[organic refuse biocompound] is manufactured from difficult to reuse or recycle by-products; utilising resources that would otherwise go to landfill(Biohm, 2022). It is sourced from waste by-products from the food production or agricultural sectors and is processed into a homogenous filler which is bound together with a unique and completely organic binder to form an affordable and sustainable replacement for wood-based sheet materials(Biohm, 2022). As a highly versatile material Orb can be formed into standard sheets for the construction sector that can be worked in the same way as more common composite boards such as MDF, OSB etc. For dry lining, wainscoting or for interior structures, without the need for additional training or safety equipment(Biohm, 2022).
Pineapple fibre	Pineapple leaf fibre composite plays important role in bio composite and material science. Pineapple leaf fibre has been demonstrated as a decent substitute of manufactured filaments, on account of its prudent and inexhaustible nature.Explicit quality of normal strands underpins in improving the physical and mechanical quality of polymer grid without utilizing any extra preparing. PALF is one of the have additionally great potential as support in thermoplastic composite . Utilizing these fibres in reinforced concrete reduced energy consumption, biodegradability and low disposal cost .(R. Abirami, 2022)
Potato Starch	As Medium Density Fibreboard (MDF)'s primary bonding adhesive uses formaldehyde, it cannot be recycled and the huge amount of MDF used in shop displays and furniture ends up in either landfill or the incinerator. To tackle the problem, new forms of medium density fibreboard have been studied by the University of Leicester that substitute the formaldehyde with a resin derived from potato starch(Thorns, 2018).
Ravenala trees	Ravenala is a plant of the family Strelitziaceae (Encyclopaedia Britannica, 2022). Ravenala is used primarily for construction, but other uses have also been noticed including food, medicine and tools. Using Ravenala for house building reduces the pressure on some forest trees, which contributes to the conservation of natural forests and slow growing hardwoods. However, mature trees are needed to source construction materials, and these have become increasingly scarce.(Aina Razanatsima, 2014)
Straw Bales	Straw has been used as a building material for centuries for thatch roofing and also mixed with earth for cob walls, and wattle and daub walls. Straw is the springy tubular stalk of grasses such as wheat and rice that are high in tensile strength. It is not hay, which is used for feeding livestock and includes the grain head. Straw is composed of cellulose, hemicellulose, lignins, and silica. It breaks down in soil, so waste straw can be used as mulch. Different grasses have slightly different qualities: rice straw, for example, has a significant amount of silica which adds density and resists decomposition. Straw bales have excellent insulation properties – among the most cost-effective thermal insulation available. A typical straw bale wall has an R value greater than 7. Straw has a similar insulation value to fibreglass batts for the equivalent thickness and is much cheaper (Downton, 2020).
Vetiver	Can be used as an insulation material which is resistant to moisture and termites which has been tested in an environment having a temperature of 28°C and humidity of 95%(CIRBAT et al., 2019). The material should be first mixed with boric acid and the resulting concentration should be 4.4%(CIRBAT et al., 2019)
Wood Fibre	Wood fibre insulation is a form of insulating material made from waste wood – sawdust, chips, off-cuts – from the sawmill industry. The raw material is untreated softwood that is broken down to its fibrous state before being formed into boards or quilts of natural insulation (Pullen, 2021).

The list above presents materials relevant to the Mauritian context. More information about other bio-sourced materials available worldwide can be found in Appendix A.

5. Most promising bio-sourced materials to the local context: Products Information

Table 2: Insulation Materials Information

S	Name	Bio-sourced	Material	Can be grown/ sourced locally?	Manufacturer	Thermal conductivity W/mk	Link
1	Bagasse	Yes	Sugarcane	Yes	-	0.04420	-
2	Bamboo	Yes	Bamboo	Yes	-	0.55-0.59	-
3	Banana fibre	Yes	Banana tree	Yes	-	0.04415	https://www.ajer.org/papers/v5(08)/ZH050802490255.pdf
4	Cellulose insulation	Yes	recycled newspaper	Yes	RK Insulation	0.035 - 0.040	https://rkinsulation.in/index.html
5	Coconut fibre	Yes	Coconut	Yes	-	0.058	https://www.astm.org/stp12281s.html#:~:text=The%20thermal%20conductivity%20test%20results,of%2085%20kg%2Fm3.
6	Cryptomeria	Yes	Cryptomeria	Yes	-	0.04595	-
7	Guava tree	Yes	Guava tree	Yes	-	0.03886	-
8	Orb	Yes	Food waste	Yes	-	-	-

9	Pineapple fibre	Yes	Pineapple	Yes	-	0.035	https://academicjournals.org/article/article1380792235_Tangjuank.pdf
10	Potato starch	Yes	Potato	Yes	-	1.6 – 1.9	-
11	Ravenala	Yes	Ravenala tree	Yes	-	-	-
12	Straw	Yes	straw bales	Yes	-	0.080	https://www.dw.com/en/house-made-of-straw-bales/av-47612050
13	Vetiver	Yes	Vetiver	Yes	-	0.04869	-
14	Wood fibre	Yes	Sawmill residue	Yes	Jayswal Agencies	0.038	https://jayswal.in/web/wood-wool-board-2/

6. SWOT analysis (Mauritius)

A SWOT analysis was performed to identify the strengths, weaknesses, opportunities and threats concerning the production and use of bio-sourced materials in Mauritius. Input for the SWOT was obtained mainly from the focus group conducted.

Table 3 SWOT Analysis

Strengths	Weaknesses
• Mauritius is a tropical island with a good climate for tropical species • Mauritius has fertile land • Actors in the whole supply chain available in Mauritius	• Small size of market – No business model • Scaling of innovation • Lack of collaboration between actors in the supply chain • Lack of commitment from important actors
Opportunities	**Threats**
• National campaign for removal of invasive species (example, guava trees, Ravenala, filao) • Small planters are stopping agricultural exploitation (theft, expensive manpower, family business with no take over) • National agro-forestry campaigns • Existing research and development • Presence of international building product manufacturers with headquarters in Mauritius • Government interest (Ministry of National Infrastructure) in alternative materials • Increase in the cost for importing building material	• Use of biomass for electricity instead of transformation • Lengthy process to allow planting of non-existent species • Extinction of natural pollinators for some species • Lack of collaboration between actors in the supply chain

7. Conclusion

The report provides the results of desktop research regarding bio-sourced materials and their viable growth and use in Mauritius. A list of bio-sourced materials was hence crafted.

The focus group conducted with key stakeholders allowed for the identification of new bio-sourced materials with great potential for Mauritius namely banana, pineapple, coconut and ravenala tree.

As a natural fiber, banana has intrinsic benefits such as silky luster, high tensile strength, low extensibility, significant heat and fire resistance, and long staple lengths. Both pineapple and ravenala takes a long time to decay, and must therefore not be left in fields. Coconut fibres are classified into two types: brown fibre taken from mature coconuts and white fibre extracted from immature coconuts. Coconut fibers are tough and stiff, with minimal thermal conductivity.

The SWOT analysis shows that the climatic zone of the island is appropriate for tropical species such as pineapple and provides for fertile lands. Ravenala (*Ravenala madagascariensis)* is major threat for endemic plants of the island. Using Ravenala tree as construction material give rise to removal opportunities of this invasive species. However a lack of collaboration between actors in the supply chain was found.
The focus group also helped Identify stakeholders showing interest in utilisng bio-sourced materials for the manufacturing of construction materials, namely Saint-Gobain. The company showed interest in making boards and insulation materials from naturally sourced fibers.

Through the focus group, it was also seen that there are already various initiatives and projects already being conducted and funded on bio-sourced materials. There is an ongoing project on agro waste, in collaboration with the University of Mauritius. MRIC funded projects on banana and pineapple fibre.Coordination among the relevant stakeholders is important to ensure the scaling up of the projects on bio-sourced materials.

In the Indian Ocean, in Reunion Island specifically, a pilot project was conducted to make prototypes from bio-sourced insulation materials from resources in the island. The project aimed at showcasing the viability of such materials in the construction industry. Four plants were selected for the project namely bagasse (from sugarcane), Vétiver leaves, guava wood and Cryptomeria wood.

In Mauritius, there is limited Cryptomeria wood. Bagasse is not currently an option as it has a competitive use for electricity production. However, vetiver leaves and guava wood should also be considered.

Therefore, the six most promising bio-sourced materials are banana, pineapple, coconut, ravenala tree, vetiver and guava wood.

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Appendix A

Bio-sourced materials available worldwide

Material	Use and description
Bioplastics (Soybean)	As plastic accumulates in our oceans and rivers, it has become imperative that we both reduce our consumption and find cleaner, biodegradable alternatives. Bioplastics break down much faster than synthetic plastic–at the same rate as paper does–and produces biomass. One of the main ingredients used is a soy-based adhesive that helps to reduce carbon dioxide emissions and the use of the carcinogenic pollutant formaldehyde, while also requiring significantly lower temperatures during production. Although so far soy bioplastics have been limited to disposable food containers and bin bags, with more research, there is certainly potential for biodegradable plastics to be seen in the future of construction(Thorns, 2018)
Blowing wool	Blowing Wool is an unbonded, virgin fibrous glass blowing insulation designed for broad applications for new-built and retrofitting housing. It is produced as a loose-fill product to be blown with a dedicated blowing machine and installation accessories (Knaufinsulation, 2022).
Cork	Cork comes from the outer bark of the cork oak tree, Quercus Suber, which grows mainly in the Mediterranean region. The bark is an agglomeration of cells filled with a gaseous mixture similar to air and lined with alternating layers of cellulose and subering (Hirshberg, 2022). The harvesting of cork is a completely renewable process that causes no harm to the tree and naturally regrows after ten years. It also boasts many desirable properties as a fire retardant, acoustic insulator and is extremely waterproof. Its adaptive qualities have seen it being used both for internal and external purposes(Thorns, 2018).
Cotton Wool	Can be used as an insulation material which is resistant to moisture and termites which has been tested in an environment having a temperature of 28°C and humidity of 95%(CIRBAT et al., 2019). The material should be first mixed with boric acid and the resulting concentration should be 4.4%(CIRBAT et al., 2019)
Finite	Recently developed by students Carolyn Tam, Hamza Oza, Matteo Maccario and Saki Maruyama at the Imperial College London, Finite is a composite material comparable to concrete that uses abundant desert sand rather than the fine white sand usually used in construction (and which is now running out). It makes for a biodegradable material that at the same time is saving the world from the next sustainability crisis. Unlike concrete that can't biodegrade, Finite's organic binders allow it not only to be left to decompose but it can

	also be collected and reused for multiple life-cycles, reducing material consumption(Thorns, 2018).
Hemp	Hemp is first grown and cultivated in a wide variety of climatic conditions. It's a plant with a fast yield, reaching maturity in 90-120 days. Hemp insulation comes in the form of batts made from the inner fibrous layer of the hemp plant. The insulation can be intertwined with flax, polyester, or kenaf fibers that help act as a binder. Hemp insulation is a dense type of batting that's not as flexible as sheep and mineral wool (Saxton, 2021).
Hempcrete	Hempcrete is a composite made of natural materials, lime and hemp. The lime component consists of air lime that is formulated to speed up the setting process. The hurds are made using hemp stalks. Hemp is a plant that can be grown without using plant protection chemicals, requires little water and contributes to agricultural soil regeneration. The combination of lime and hemp creates a natural concrete which is lightweight, or ultra-lightweight even. Its thermal mass and vapour permeability properties result in high-performance buildings capable of meeting current and future thermal regulations. Hempcrete is one of those bio-based materials that can be used to build, renovate and restore all types of building, from houses and apartment blocks to service and public sector buildings and all types of built heritage, from traditional buildings to listed historic buildings. Hempcrete is made by mixing lime and hemp in proportions adapted to the work to be done. This makes it very versatile, and it can be used to build insulating walls, linings, roofs, screeds, attic spaces and renders (Tradical, 2022).
Humins	It is a biomacromolecular by-product of a HydroxyMethylFurfural/FuranDiCarboxylic Acid biorefinery. Humins are obtained by acidic treatment of polysaccharides and show very interesting potential as a reactive, semi-ductile thermoset matrix to impregnate cellulosic fibres(Alice et al., 2017).
Lightweight Expanded Clay Aggregate or Expanded Clay Aggregate	LECA is produced from special plastic clay with no or very little content of lime. The clay is dried, heated and burned in rotary kilns at very high temperatures of approximately 1100–1300C. It is an inert lightness substance and does not contain harmful materials with natural pH value (nearly 7), it does not damage in water, moisture impermeable, non-combustible, nonbiodegradable, non-decomposition against severe conditions, excellent thermal insulation, fire resistance, soundproofing by its high acoustic resistance. The abundant numbers of small, air-filled cavities in LECA give its lightweight, thermal as well as sound isolation characterises (Rashad, 2018).
Linoleum	Linoleum is made entirely from natural materials—linseed oil, natural resin, ground cork dust, wood flour, and powdered limestone—resulting in a floor

	choice that is both biodegradable and can be incinerated to provide a relatively clean source of energy(Thorns, 2018).
Mycelium	Mycelium is the vegetative part of the fungus, made up of hundreds of interwoven fibers produced by the spores which makes it an incredibly strong material when dried. If combined with farm waste in moulds, the fungus culture forms organic bricks that can be used in construction that afterward decompose and return to the carbon cycle, Research conducted by the Munster Chamber of Crafts on the long-term in situ performance of bio- based materials such as mycelium has demonstrated that they are at least as durable as conventional materials and maintain their insulative properties over the course of their life. (Biohm, 2022; Thorns, 2018; Tobias, 2020).
Polybond Superfine Loose Mineral & Granulated Wool	Polybond Superfine Loose Mineral Wool is a collection of fine fibers drawn from molten selected basalt rocks. The Mineral Wool is an ideal material for most insulation applications because of its favourable handling and application characteristics. It is fireproof, dirt proof and moisture resistant. Chemically, it neither reacts nor accelerates corrosion. It is durable, odourless, easy to handle and store and conforms to IS:3677. The Loose Mineral Wool and Granulated Wool possess low thermal conductivity on account of enormous minute air cells created by the fine fibre and can be used in a wide range of temperatures of -50°C to 750°C. It is oil free and has prudent low thermal conductivity properties (Polybond, 2022).
Rockinsul Building Rolls	Rockinsul Building Rolls is used mainly in pre-engineered buildings for roofs and walls to achieve excellent thermal and acoustic insulation. It can be used for both under purlin and over purlin application on the roof. Stone wool fibers in ROCKINSUL Building Rolls are fine and uniformly distributed that ensures excellent & uniform thermal resistance. The stable stone wool fibers bonded with thermosetting resins are light in weight, strong and resilient (Rockwool India, n.d.).
Rockwool	Rockwool refers to a type of thermal insulation made from actual rocks and minerals. A wide range of products can be made from this material because of its superior ability to block heat and sound. Rockwool insulation is commonly used in building construction, industrial plants, and in automotive applications. The term “rockwool” is sometimes used interchangeably with “mineral wool,” although the latter term is, in fact, a larger category of thermal insulators that includes rockwool, slag wool and fiberglass (Gromicko, 2022).
Sheep Wool	Sheep’s wool insulation starts as sheared wool that grows naturally on sheep—often wool that is deemed too coarse to make into clothing or other

	fabric. Sheep's wool is a thick, dense material, making it an excellent insulator. Sheep's wool insulation offers an R-13 to R-19 value, which is equal to or greater than most of its fiberglass, cellulose, and rockwool counterparts. Its natural base and effectiveness make sheep's wool insulation a desirable option for many homeowners. Sheep's wool insulation offers supreme durability due to its elasticity, and will keep a home toasty or cool for years to come. Each wool fiber acts like a coiled spring: It elongates when extended and retracts when it's released, which is why wool is highly resistant to breakage and tearing. Sheep's wool also has a protective skin that acts as a shield against abrasion. The moisture content in each fiber of sheep's wool make it naturally fire resistant. And because of its high nitrogen content of approximately 16 percent, sheep's wool is considered a self-extinguishing material that won't support flames below temperatures of 1,040 degrees Fahrenheit. (Though, as noted above, most sheep's wool insulation products are treated with additives to further reduce their flammability.) Finally, because wool is a keratin, it also naturally resists mold growth (Erickson, 2021).
Sinicon Sand (Sinicon PP Heat-Proofing Sand)	It is a unique volcanic glass, a large deposit of which is found at only one location on the earth which is South Africa. Sinicon Sand is made out of feed from this mine using patented manufacturing process to convert this volcanic glass into well-sealed tough glass granules which is ideally suited for use with cementitious and other binders. Under the microscope, each tough granules comprises a froth of glass-walled closed cells each enclosing a near vacuum. Sinicon Sand is therefore best described as comprising millions of tiny sealed "thermos flasks", making it a unique and unrivalled insulating and fireproofing material (Sinicon, 2022).
Timber	Timber is biodegradable and a renewable material as long as it is sourced sustainably. However, when used in construction, the timber treatment must be factored in, as much of it can end up as "special waste" that requires extra treatment before heading to landfill—an unnecessary process that can be prevented(Thorns, 2018).
Twiga CR boards	Manufactured under licensee of ISOVER Saint Gobain, France, the crimped wool has improved insulation and load bearing features. The crimping technology improves at least 25% higher compressive strength after curing through high temperature oven. When compared with standard fiber insulation products, Twiga CR boards are strong, durable, and more sustainable even under foot traffic load (Twiga, 2022).
Twiga Eco Insul	Twiga Eco Insul (TEI),is a new generation glass wool insulation introduced by U.P.Twiga Fiberglass Limited. It's a high performing insulation solution for thermal and acoustic applications. Eco Insul is soft to skin, odourless

	and formaldehyde-free. The product is completely fire safe (non-combustible). It is available in flexible blanket/roll form and semi-rigid or rigid board form. Several factory-applied laminations or facing options are available with Twiga Eco Insul products for better vapour control or noise absorption as per application requirements (Twiga, 2022).
Wool	Insulation sourced from regenerative grazed herds(Tobias, 2020)

Appendix B

Bio sourced materials used in the construction industry and some of their specifications

SN	Name	Bio-sourced	Material	Can be grown / sourced locally?	Manufacturer	Thermal conductivity W/mk	Location	Link
1	Lightweight Expanded Clay Aggregate or Expanded Clay Aggregate	Yes (clay)	Firing natural clay at 1200deg C	No	Rivashaa Eco Design solutions P. Ltd.	0.090	Ahmedabad, Gujarat	https://www.expandedclayaggregate.com/
2	PUF and PIR Panel for wall and roof applications	**Rigid Polyurethane Foam** - NO (di-isocyanates and polyols) **Polyisocyanurate Foam** - NO (isocyanurate and polyol) **Rockwool** - Yes (Basalt rock and Recycled Slag)	Rigid Polyurethane Foam, Polyisocyanurate Foam & Rockwool	No	Artifex Infra	0.020	Delhi	http://artifexinfra.com/PDF/ARTIFEX_INFRA_PUF_Panels_Spec.pdf

SN	Name	Bio-sourced	Material	Can be grown / sourced locally?	Manufacturer	Thermal conductivity W/mk	Location	Link
3	Blowing Wool	Yes (sand, limestone. Etc)	Crimped glass wool insulation	No	Knauf	0.030	Pune	https://www.knaufinsulation.com/what-we-do/our-solutions/blowing-wool
4	Rockinsul Building Rolls	Yes (stable rock)	Sable rock fibres bonded with a minimum quantity of thermosetting resin binder	No	Rock wool	0.036	Hyderabad	https://www.rockwoolindia.com/pdf/products-download-brochure/rockinsul_building_roll.pdf
5	Twiga Eco Insul	Yes (sand, limestone. Etc)	Glass wool insulation	No	Twiga	0.030	New Delhi	https://www.twigafiber.com/twiga-eco-insul.php
6	Twiga CR boards	Yes (fibres of glass(sand))	Crimped glass wool insulation	No	Twiga	0.038	New Delhi	https://www.twigafiber.com/twiga-crimped-products-roof-slab-insulation.php
7	Sinicon Sand (Sinicon PP Heat-Proofing Sand)	Yes (lava or magma)	Volcanic glass	No	Sinicon	0.130	Kerala	https://www.sinicon.net/

SN	Name	Bio-sourced	Material	Can be grown / sourced locally ?	Manufacturer	Thermal conductivity W/mk	Location	Link
8	Sheets, Pads…Etc	Yes (cork)	High-grade cork granules	No	Divine cork pvt ltd	0.035	Gujarat	https://www.divinecork.com/cork-plain.html
9	Cork Insulation Panels	Yes (cork)	Granulated cork	No	Advance cork	0.040	Delhi	https://www.advancecork.com/cork-insulation-panels.html
10	Polybond Superfine Loose Mineral & Granulated Wool	Yes (rocks)	Molten selected basalt rocks	No	Polybond	0.040	Delhi	http://www.polybond.co.in/polybond/loosewool.php
11	Hemp	Yes	hemp or hemp mixed with either recycled cotton fibres or wood fibres	No		0.039 - 0.040		https://timesofindia.indiatimes.com/city/dehradun/in-a-first-in-country-house-built-using-hemp-fibre-in-ukhands-pauri/articleshow/87897260.cms
12	Hempcrete	Yes	hemp hurds (shives) and lime (possibly including natural hydraulic lime, sand,	No		0.060	Uttarakhand	https://en.gaonconnection.com/a-start-up-in-uttarakhand-uses-hemp-fibre-in-construction-makes-it-to-top-five-at-global-housing-technology-challenge-india/

SN	Name	Bio-sourced	Material	Can be grown / sourced locally?	Manufacturer	Thermal conductivity W/mk	Location	Link
			pozzolans or cement)					
13	Cork	Yes	cork bark	No	DIVINE CORK	0.038	Gujarat	https://www.divinecork.com/
14	Clay	Yes	Clay & Waste	No				https://www.thebetterindia.com/222302/gujarat-architect-sustainable-home-traditional-clay-waste-recycling-india-gop94/
15	Desert Sand	Yes	Desert Sand	No	-	1.19	-	-
16	Humins	Yes	Furfural	Yes	-	-	-	-
17	Cotton	Yes	pure cotton fibre	Yes	HARNAVA		Maharashtra	https://www.unido.org/sites/default/files/2017-09/House_Insulation_v_5.8_EN_0.pdf

Appendix C

Focus group on bio sourced materials – Notes of meeting.

Focus group on bio sourced materials – Notes of meeting				
Date: 29th June 2022				
Attendees- Apologies (A), Present (P)				
P	Tony LEE LUEN LEN	Ecosis Ltd	tony@ecosisltd.com	TL
P	Jeanne Huguette PERRINE	Ecosis Ltd	huguette@ecosisltd.com	JHP
P	Claire BAISSAC	Saint-Gobain	claire.baissac@saint-gaubain.com	CB
P	Amaury D'UNIENVILLE	Saint-Gobain	amaury.dunienville@saint-gobain.com	AD
P	C. CYPARSADE	Forestry Service	ccyparsade@govmu.org	CC
P	Vinesh GOPAL	National Parks and Conservation Service	svsgopal@gmail.com	VG
P	Hafsah RAMJANE	Mauritius Research and Innovation Council (MRIC)	h.ramjane@mric.mu	HR
P	Poonam Veer RAMJEAWON	Mauritius Research and Innovation Council (MRIC)	pvramjeawon@mric.mu	PVR
A	Région Réunion			
A	Cosmetic Valley			
A	Cap Business Océan Indien			
A	Association of Mauritian Manufacturers			
A	Mauritius Standards Bureau			
A	Ministry of Agro-industry and food security			
A	La Pépinière de Labourdonnais			
A	ENL Agri Ltd			
A	Medine Ltd			
A	Endemika			
A	Flora Nursery - Pépinière			
A	Citadelle Native Re-vegetation Project			
A	Gamma Materials Ltd			
A	Lafarge (Mauritius) Cement Ltd			
A	UBP Group			
A	Chantier de Plaisance			
A	Grewals Mauritius Ltd			
A	Interior Solutions Ltd			
A	Profilage Océan Indien Ltée			
A	Riteseal (Mtius) Ltd			
Item		Description		Responsibilities

1.0	**Introduction**	
	TL welcomed everyone and provided a short introduction to the project. He explained that through its green finance label SUNREF (Sustainable Use of Natural Resources and Energy Finance), AFD supports the energy and environmental transition in nearly 30 developing countries by helping private sector actors seize opportunities linked to green growth and implement their projects, while encouraging local partner banks to finance them. One of the deliverables of the "Réalisation d'une étude sur la construction à Maurice" is a pre-feasibility study on the local positioning of bio-sourced insulation solutions for the construction industry adapted to the tropical climate. CC stated that there is an ongoing project on agro waste, in collaboration with the University of Mauritius. CC also mentioned that jute can be manufactured in Mauritius for instance and provide a livelihood for vulnerable communities. Banana, pineapple, and coconut fibre can also be used in construction, textile and other industries. CB pointed out that Saint-Gobain currently does not use biosourced materials at all. The research and development teams mainly focus on minerals. They can take ideas about using bio-sourced materials and take them to the group. CB also mentioned that for Saint-Gobain, it is not the input to the products that they consider as such, but rather the way they construct (sustainable construction). However, Saint-Gobain would buy materials from bio-sourced products.	
2	**Bio-sourced materials considered for the local context**	
2.1	**Coconut**	
2.1.1	CC talked about how coconut has a good potential as bio-sourced material. It is relatively easy to import. However, it was pointed out that one barrier is the lack of commitment.	
2.2	**Arundo donax**	
2.2.1	VG talked about "Arundo donax', commonly referred to as "fatak" and explained that while it is good biomass, there are issues with the plant. As such, it takes up most of the water in the soil. The same applies to bamboo and eucalyptus. VG also explained that there is also a plant named myrtaceae. The plant cannot be grown on a large scale because there are risks of diseases growing.	
2.3	**Guava tree**	
2.3.1	National budget 50ha to be removed annually. EU programme to remove 600ha of guava tree over 5 years.	
2.3.2	CC pointed out that guava tree is a good biomass for energy production. The biomass framework is currently looking into the matter. Cultivation can be done by restricted plantation.	
2.3.3	VG explained that there is a "Man & Biosphere Reserve", a project by UNESCO. Under the label, hotels collect glass bottles, crush them, and mix with "goyave de chine" to create a new product. AGRIA provided land for the project.	
2.4	**Ravenala**	
2.4.1	Ravenala cuttings take a relatively long time to decay. The tree also grows very fast. It is exotic and nothing grows underneath since it has a toxin that falls and kills seeds.	

	VG explained that ravinale can be a viable bio-source material unless the plantation is abandoned after 50 years. Then it will be a problem.	
2.5	**Vetiver**	
2.5.1	VG mentioned that there is an endemic vetiver found on round island in Mauritius. The problem with vetiver is that it is difficult to produce since the seeds don't propagate easily naturally. This is due to the extinction of natural pollinators for the species.	
2.6	**Cryptomeria**	
2.6.1	When it comes to cryptomerial, VG explained that is not a local species, it is rather exotic and introduced. Cryptomeria is also invasive and a nest for bats.	
2.7	**Pineapple**	
2.7.1	VG explained that pineapple fibre takes a lot of time to decay and therefore cannot be left in the fields.	
3.	**General**	
3.1	PVR mentioned that there is previous research done on bamboo for instance, which can be found in the MRIC repository. Projects on banana and pineapple fibre were also funded. There is also a National Research Group that looks at locally available materials. There is a need for such alternate products. However, while MRIC can conduct research, they do not do the scaling up of the projects.	
3.2	VG proposed that for the purpose of the study, there is a collaboration with National Parks and Conservation Service to identify problems associated with plants considered.	
3.3	TL mentioned the "PAPAM" project, which deals with bioeconomy and uses plants to make oil, among others.	
3.4	AD explained that Saint Gobain would be interested in doing boards and insulation materials based on natural fibre.	
3.5	TL asked whether it is currently possible to bring seeds to Mauritius. It was explained that the opportunity is being considered by the biomass framework.	
3.6	PVR proposed that for the purpose of the project, a list of plants for the Mauritian context is drafted, as the current list does not have banana, coconut, and pineapple for example. It was also pointed out that biomass for construction should not compete with biomass for energy production. The biomass should be categorised.	
3.7	It was also pointed out that forest management and conservation is important. For example, not all the guava trees can be removed. Removal of guava trees found inside of the forests should be prioritised.	
3.8	Mauritius has fertile land and a good climate for tropical species. However, because of the small size of the market for growing bio-sourced materials, there is no business model. There is also a lack of collaboration between actors of the supply chain.	
	There is an opportunity to do national campaigns for removal of invasive species (example, guava trees, Ravenala, filao) as well as agro-forestry campaigns.	
3.9	TL pointed out that small planters are stopping agricultural practices because of various reasons such as theft of their products, expensive manpower, family business with no take over and so on.	
4.0	Other opportunities include the presence of international building product manufacturers with headquarters in Mauritius. Moreover, ther is government interest (Ministry of National Infrastructure and Community Development) in alternative materials. There is also the increase in the cost for importing building material.	

4.1	Weaknesses identified include the fact that there is a lengthy process to allow the planting of non-existent species.	
5	**Next meeting - TBA**	