*sustainability*

*Article*

# Sustainable Retrofitting Solutions: Evaluating the Performance of Jute Fiber Nets and Composite Mortar in Natural Fiber Textile Reinforced Mortars

**Arnas Majumder [1,2,*], Flavio Stochino [3], Andrea Frattolillo [3], Monica Valdes [3], Gianluca Gatto [2] and Enzo Martinelli [1]**

[1] Department of Civil Engineering, University of Salerno, Via Giovanni Paolo II n.132, 84084 Fisciano, Italy; e.martinelli@unisa.it
[2] Department of Electrical and Electronic Engineering, University of Cagliari, Via Marengo 2, 09123 Cagliari, Italy; gatto@unica.it
[3] Department of Civil Environmental Engineering and Architecture, University of Cagliari, Via Marengo 2, 09123 Cagliari, Italy; fstochino@unica.it (F.S.); andrea.frattolillo@unica.it (A.F.); m.valdes@unica.it (M.V.)
* Correspondence: arnas.majumder@unica.it

**Abstract:** Sustainable building materials for integrated (structural and thermal) retrofitting are the need of the hour to retrofit/upgrade the seismic vulnerable and ill-insulated existing building stocks. At the same time, the use of natural fibers and their recyclability could help construct safer and more sustainable buildings. This paper presents three aspects of jute fiber products: (1) the evaluation of the mechanical performance of the jute nets (2.5 cm × 2.5 cm and 2.5 cm and 1.25 cm mesh configurations) through tensile strength tests (with the aim for these to be used in upgrading masonry wall with natural fiber textile reinforced mortars (NFTRM) systems); (2) the hundred percentage recyclability of left-over jute fibers (collected during the net fabrication and failed nets post-tensile strength tests) for the composite mortar preparation; (3) and the evaluation of insulation capacity of the recycled jute net fiber composite mortar (RJNFCM) through thermal conductivity (TC) measurements, when a maximum amount of 12.5% of recycled jute fiber could be added in the mortar mixture at laboratory conditions and with available instruments Notably, when more than the said amount was used, the fiber–mortar bonding was found to be not optimal for the composite mortar preparation. These studies have been carried out considering these products' applicability for integrated retrofitting purposes. It has been found that the denser mesh configuration (2.5 cm × 1.25 cm) is 35.80% stiffer than the other net configurations (2.5 cm × 2.5 cm). Also, the mesh configuration (2.5 cm × 1.25 cm) shows about 60% more capability to absorb strain energy. TC tests have demonstrated the moderate insulation capacity of these composite mortar samples, and the TC values obtained from the tests range from 0.110 (W/mK) to 0.121 (W/mK).

**Keywords:** jute fiber; natural fiber textile reinforced mortars (NFTRM); recycled fiber composite; structural retrofitting; thermal capacity

check for updates

**Citation:** Majumder, A.; Stochino, F.; Frattolillo, A.; Valdes, M.; Gatto, G.; Martinelli, E. Sustainable Retrofitting Solutions: Evaluating the Performance of Jute Fiber Nets and Composite Mortar in Natural Fiber Textile Reinforced Mortars. *Sustainability* **2024**, *16*, 1175. https://doi.org/10.3390/su16031175

Academic Editor: Ali Bahadori-Jahromi

Received: 15 December 2023
Revised: 16 January 2024
Accepted: 26 January 2024
Published: 30 January 2024



## 1. Introduction

Creating thermally efficient and structurally safe building stocks stands as a key objective within the contemporary construction and building (C&B) sector. This commitment arises from the industry's pursuit of constructing safer, more sustainable, environmentally friendly, and nearly self-sufficient buildings.

Moreover, a building in its complete service life generates vast amounts of waste, some of which is recyclable, and others are not, and therefore, are responsible for creating environmental problems. In the European Union (EU), construction and demolition (C&D) accounts for about 180 tons of waste per year [1]. The C&D wastes of the C&B sector are mainly dumped in landfills, thus directly damaging the environment and ecosystem and detrimental to human health [2]. The EU, with Directive 2008/98/EC [3], discourages the disposal of 100% of demolition wastes and, to reinforce its Sustainable Development Strategy, in the last decade gradually developed the Integrated Product Policy [4,5] to reduce the environmental impacts of products throughout their life-cycle. Considering environmental and ecological sustainability, different research groups have studied the recyclability of C&D wastes [6–12] for various C&B applications. Similarly in the literature, the use of argo-wastes also can be found in [6,13–18].

In the EU, buildings stocks constructed before the 1990's are not energy efficient [19], and mostly these buildings are constructed without having properly followed the seismic standard [20]. At the same time, these buildings are known to be some of the highest producers of $CO_2$ and other greenhouse gases, and these figures are about 39% globally and 36% in the EU [21]. On the other hand, the C&B sector, directly and indirectly, consumes nearly 36% globally and 40% in the EU, of the total produced energy [22].

Notably, both ancient and modern building stocks are vulnerable to natural and man-made created/caused disasters [23]. According to [24], in the Asian continent, the northern Indian traditional Himalayan buildings, particularly the rammed earth and dry-stone buildings, are predominantly vulnerable and susceptible to seismic activity.

Recently, various laws and regulations, obligatorily or voluntarily, obliged the public and private entities to structurally or/and thermally retrofit/upgrade existing buildings according to the latest standards, like Eurocode 8 [25] and near-zero energy building (nZEB) [26]. Whereas, Ref. [27] has proposed higher energy-performance buildings by 2030 (2027 for the public sector) with new zero-emission buildings (ZEB) requirements.

Therefore, a wide range of newer building materials and composite materials have been studied by many research groups, with the aim to use these materials for structural, thermal, integrated retrofitting or upgrading purposes, and obviously during new building construction.

Due to superior mechanical properties, man-made fibers, like carbon, basalt, steel, glass, etc., have been used predominantly in raw or in textile form, for structural retrofitting or upgrading [20] of building stocks and various structures.

It is well established that natural fibers are cheaply and abundantly available [28], and are also known to have good thermo-mechanical properties [29]. At the same time, they have 78–79.4% lesser carbon footprint [30]; therefore, these fibers can be used for making greener and sustainable building materials.

Whereas due to good insulation capacity, natural fibers like wool, hemp, jute, sisal, etc., are particularly usable for thermal upgrading [20].

In the last few years, the application of raw or recycled natural fibers in composite-mortar forms, as thermos-acoustic building insulation material and integrated retrofitting/upgrading material, can be found in the literature. Some notable works in this direction can be highlighted with the use of jute-clay and loofah-clay [31], jute-composite [32], straw-clay [33], date-palm fiber cementitious composites [34,35], hemp fiber-lime [36], wool-cement [37], recycled oil palm fiber-fly ash [38], rice straw and furcraea foetida fiber [39], jute fiber self-consolidating concrete (SCC) [40], sawdust bio-composite [41], açaí fiber [42], açaí seed ash [43], sheep-wool [44], abaca fiber [45], coir fiber [46], and Eucalyptus globulus bark fiber reinforced concrete [47].

Fiber reinforced polymer (FRP) is predominantly used for civil reinforcement applications [48] due to its strength. Particularly carbon FRP [49], glass FRP [50], and basalt FRP [51,52] are mainly used for civil applications, while scholars and researchers are also working on the natural FRP [53,54] or hybrid FRP [55], extensively.

Whereas the textile reinforced mortar (TRM) is more suitable for masonry retrofitting/upgrading, due to its various advantages over FRP systems [56]. Notably man-made fibers like carbon [57,58], steel [59], glass [60,61], and mineral fiber like basalt [62,63] are predominately used commercially for TRM retrofitting/upgrading.

The use and application of a natural fiber (NF) for TRM systems is also gaining momentum, but still its use at commercial level is very limited and its applicability can be found at the research level only. Some important works, and the use of NFTRM, can be found in [64–67] for jute fiber TRM, hemp fiber TRM, flex fiber TRM systems and banana TRM, respectively.

Among all natural fibers, jute fiber ranks second in terms of the amount/quantity being produced [68]. Notably, jute fiber-made building materials and composite mortars have been developed, and their mechanical and thermal behaviors have been studied and reported in [31,69–74], respectively.

Authors already have proposed in their previous works [75,76], various compositions of jute fiber composite mortars with different proportions of raw fiber (depending on dry mortar mass) mortar and water combinations, while their physical behaviors and thermo-structural performances are reported and were evaluated.

Also, authors have recycled and used jute fiber waste, derived from various sources, to prepare jute fiber composite mortars [77,78] and other fibers (loofa, sheep wool, hemp shives, thistle fibers) for composite building materials [31,77,78] with the aim that these materials could be used for thermal retrofitting or upgrading.

This paper validates the capability of jute fiber nets that are to be used for NFTRM retrofitting or upgrading masonry walls and analyzes the performance of the recycled jute net fiber mortar that might be used for thermal retrofitting. Therefore, to encourage the United Nationals Sustainable Goals (UNSG) and by following the directive of the EU "EU 2008/98/EC", this research was conducted to encourage the recycling of C&B sector residual wastes. By doing so, 100% of the residual scape thread and net fibers, leftover during the net fabrication process and post-flexural tests were recycled to prepare the jute net fiber composite mortar, with the aim of this composite mortar to be used for the thermal retrofitting purpose. Therefore, the novelty of this research work is threefold: (1) the applicability of natural fiber (jute) for integrated upgrading/retrofitting of masonry walls/structures, (2) the assessment and validation of strength (jute fiber net) and insulation properties of the jute fiber composite mortar, and (3) the possible recyclability of the residual natural fiber (jute) from a previous process (net fabrication), therefore encouraging a sustainable production process.

The structure of this paper can be highlighted as it starts with a brief introduction, thereafter the materials and methods used are explained. Section 3 is subdivided into two parts; in Section 3.1 the observations of the jute net tensile strength tests are reported, while in Section 3.2 the thermal conductivity test results are reported and at the end, in Section 4, the conclusive remarks are stated.

## 2. Materials and Methods

For this experimental campaign, the main raw material for net preparation (i.e., jute threads) was collected from the state of West Bengal, India. This three-yarn jute thread type was fabricated in a local jute mill.

While the mortar used for the composite-mortar preparation is a lime-based mortar and has a dry density equal to 750 kg/m$^3$. It is a thermo-dehumidifying plaster and it certified as R and T/CSII (EN 998-1 [79]).

### *2.1. Jute Fiber Net Preparation*

Figure 1 presents the class 1 mm (1.19 mm with Co.V. of 7.27) [78] jute fiber thread, which has been selected for the jute net fabrications and has tensile strength ($f_t$) and strain energy (U) measured equal to 122.45 MPa (with Co.V. of 26.16%) and 1.03 kN.mm (with Co.V. of 34.59%), respectively [78].

Two types of jute nets were manually prepared with two distinct inner mesh configurations: (1) 2.5 cm × 2.5 cm and (2) 2.5 cm × 1.25 cm, respectively, in the Strength Laboratory at the University of Salerno, Italy (Figure 2). Notably these configurations have been considered for better mortar penetration during the net application on the wall surface.

The length of each tested sample with net mesh types 2.5 cm × 2.5 cm and 2.5 cm × 1.25 cm, were 0.5 m long. About 18 cm of net (Figure 3) was exposed to the applied loads. The net samples are placed inside two clamps, as shown in Figure 4, and the top and the bottom fixtures were tied with a torque wrench with an adjustable pre-set torque value of 50 N/m (Figure 4), this was performed to bind the edges of the net uniformly with quasi-equal force.

**Figure 1.** Jute thread of class 1 mm.

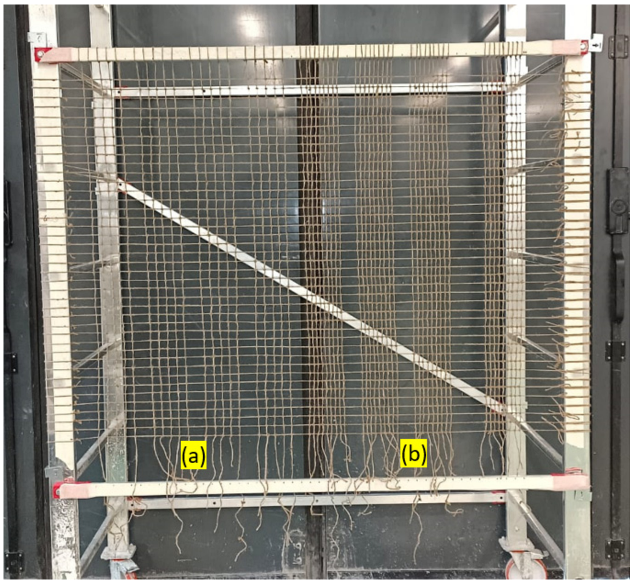



**Figure 2.** Jute net fabrication (**a**) 2.5 cm × 2.5 cm and (**b**) 2.5 cm × 1.25 cm mesh configurations.

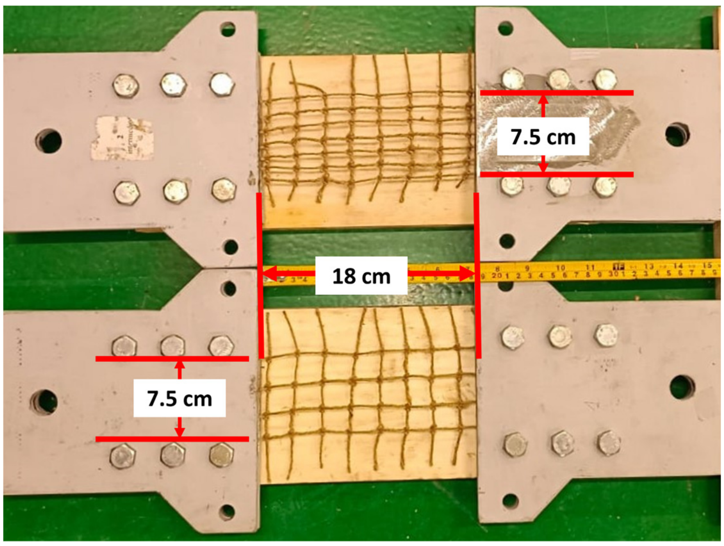
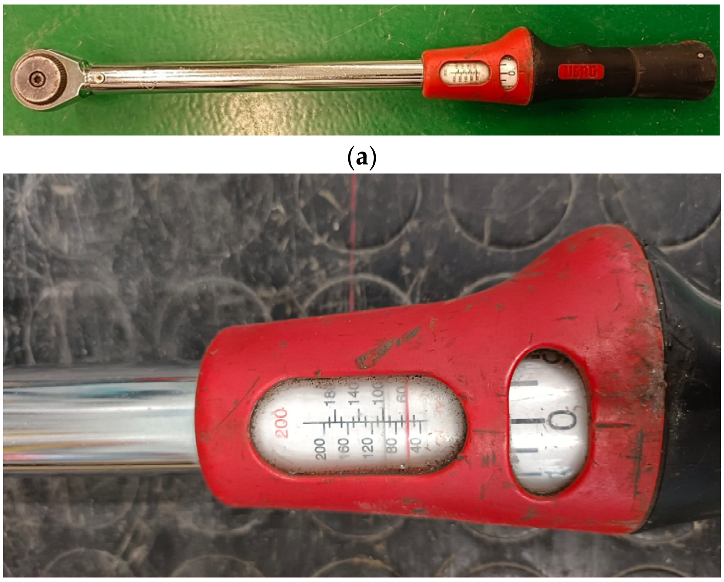



**Figure 3.** Samples were tightly clamped.



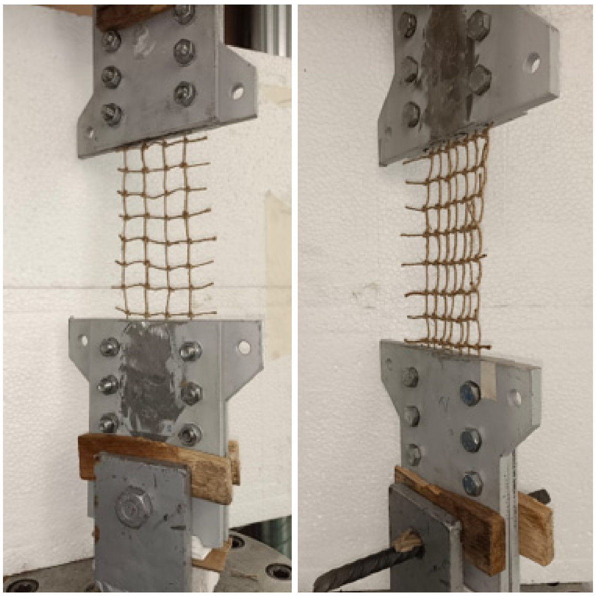
(**a**)

(**b**)

**Figure 4.** (**a**) Complete view and (**b**) the set parameter of the adjustable torque-wrench.

### *2.2. Jute Fiber Nets Tensile Strength Tests*

The fix-clamp fixtures holding the net sample(s) were fixed to the testing machine (Figure 5) and thereafter the mechanical behavior of these net samples was evaluated through the tensile strength tests. For this test, a Schenck universal machine (Figure 6), was used, and it has a maximum load capacity and maximum workable length of 630 kN and 20 cm, respectively. The tensile tests were conducted at a rate of 2 mm/min.



(**a**) (**b**)

**Figure 5.** Net samples with mesh configurations. (**a**) 2.5 cm × 2.5 cm and (**b**) 2.5 cm × 1.25 cm were placed in the machine for the tensile strength test.


**Figure 6.** Schenck universal machine used for tensile strength tests.

## 2.3. Recycled Jute Fiber Net Composite Mortar (RJFNCM) Preparation

Notably during the net fabrication and after the jute-net tensile strength tests, a significant amount of jute net and thread fibers were left over, and these scrap fibers were recycled along with the tensile test failed net fibers (Figure 7), to prepare the recycled jute net fiber composite mortar (RJNFCM).

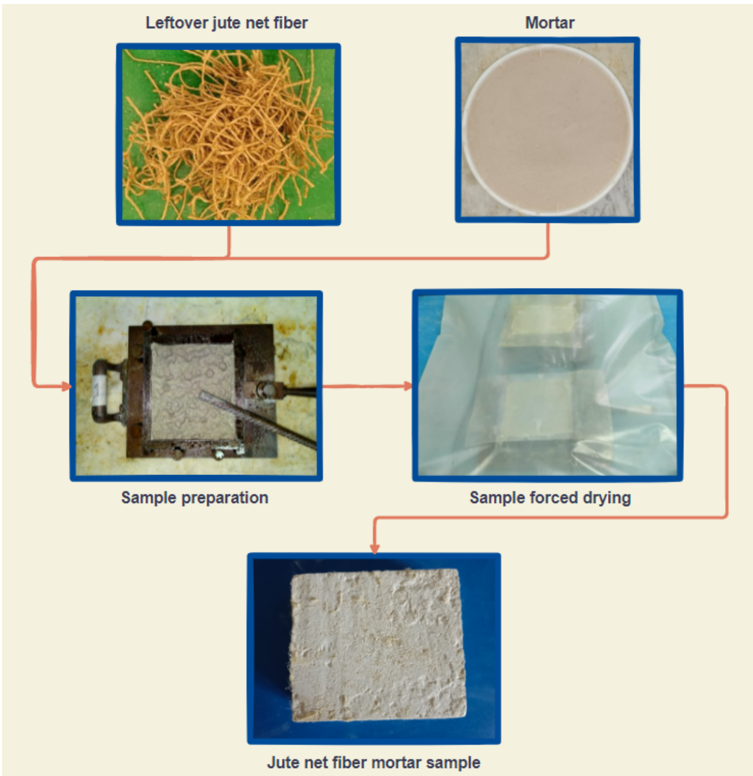



**Figure 7.** Leftovers from the jute net fabrication and post-tensile test used for composite mortar preparation.

The composite mortar's grout was prepared following EN1015-2 [80], while no workability test has been performed as these samples have only been used for the thermal conductivity test. The quantity of water added during the grout preparation was based on the author's previous calculation, and experience of working with raw-jute fiber, threads, and composite mortars, while the information about this research work and respective observations can be found in [20,78].

During the mixture preparation, the pre-present aggregates were separated from the mortar, and thereafter 12.5% recycled jute net fibers (Table 1) were added based on the measured mortar mass (without any aggregates). During mixing, about 49.8% of water (Table 1) with respect to the total mixture (mortar + fiber) mass was added slowly to prepare the grout. The mixing process was performed for approximately 7 min. Thereafter, two molds of the dimensions 160 mm × 140 mm × 40 mm were used to prepare two samples to be used for thermal conductivity tests. The samples were left inside molds and in plastic bags for the first 2 days, then they were taken out from the molds and re-placed inside another plastic bag for another 3 days. After, they were left in a quasi-constant environmental condition (22 °C and 65% RH) in a room until the 28th aging day. This first drying process is the part to which the utmost attention must be paid, avoiding the formation of surface depressions or specimen distortions, which would compromise their subsequent thermal characterization tests. After this period, the samples were oven dried (at 50 °C) to remove the remaining moisture, which would influence measurements and thermal conductivity values.

**Table 1.** Amount of fiber and water used.

| Total Recycled Jute Net Fiber Used | Total Water Used for the Mixture |
|---|---|
| 12.5% of the dry mortar mass | 49.8% of the total mixture (mortar + fiber) mass |

### *2.4. Jute Net Fiber Composite Mortar Thermal Conductivity Test*

The thermal conductivity values of these samples have been determined at the Applied Thermodynamic and Energetic Laboratory at the University of Cagliari using a TAURUS TCA 300 (Figure 8) device. It is a heat flow meter instrument, that conducts measurements according to ISO 8301 (1991) [81] and EN 1946-3 (1999) [82].

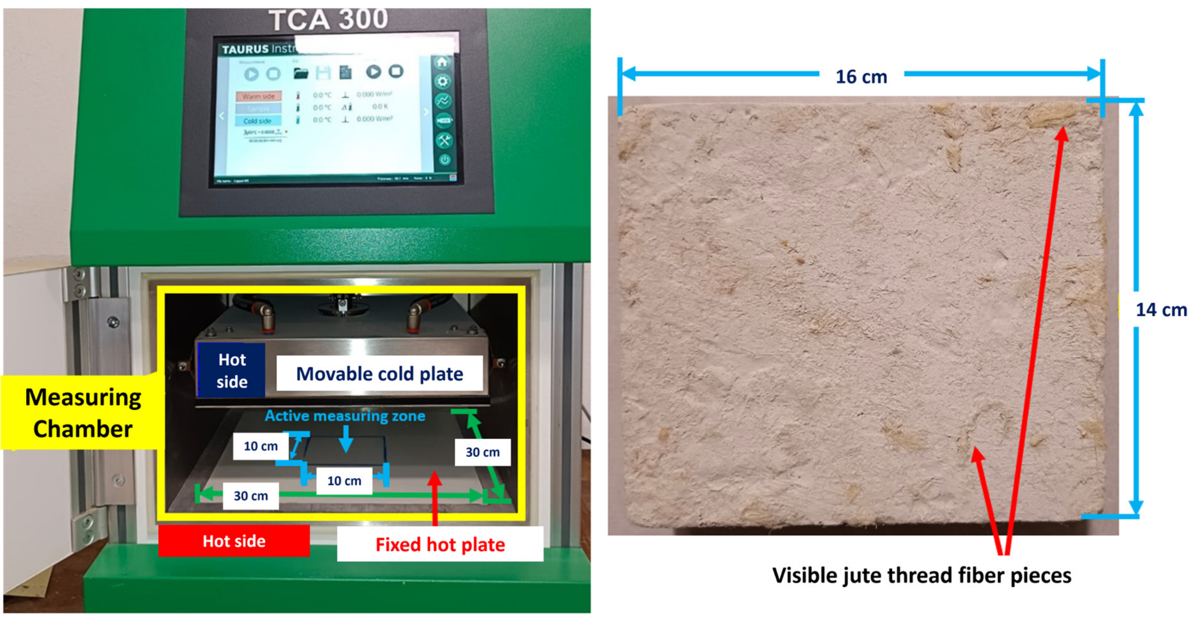



**Figure 8.** Thermal conductivity measuring instrument: TAURUS TCA 300.

The measuring chamber of the TAURUS TCA 300 has two measuring plates, an upper cold plate and a lower hot plate. Notably, the function of these plates can be reversed and can be set accordingly, as required. The original plates have a 300 mm × 300 mm total surface area, while the main measuring zone is located exactly at the center of these plates and the active zones have a 100 mm × 100 mm surface area (Figure 8). Measuring like sample specifications and instrument parameters (Table 2) were set using an instrument-integrated computer.

**Table 2.** TAURUS TCA 300 set parameters.

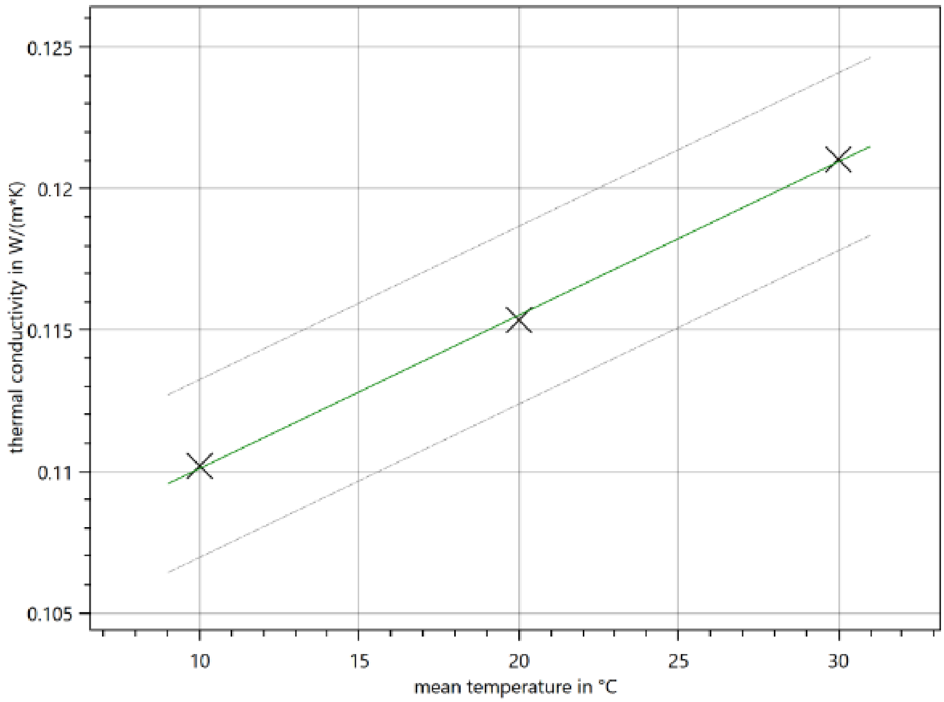
| Measuring Intervals | min |
|---|---|
| Intermediate sampling time | 1 |
| Total measuring time | 300 |

According to EN 12939 [83], the tests were carried out at sample mean temperatures equal to 10 °C, 20 °C, and 30 °C (Figure 9), always maintaining a difference of 20 °C between the two plates. Consequently, the TC values were calculated based on Equation (1), using the measured heat fluxes values:

$$\lambda = \dot{Q}\frac{S}{A(t_H - t_C)}\ [W/mK] \quad (1)$$

where Q = heat flux in $W/m^2$; s = sample thickness (m); $t_H$ = temperature of the hot plate (°C); $t_C$ = temperature of the cold plate (°C); and A = the active zone surface area ($m^2$).

| measurement number | heat flow in $W/m^2$ | temperature of cold side in °C | temperature of warm side in °C | temperature difference in K | mean temperature in °C | thermal conductivity in W/(m*K) |
|---|---|---|---|---|---|---|
| 1 | 44.704 | 0.22 | 19.78 | 19.55 | 10.00 | 0.11020 |
| 2 | 46.746 | 10.23 | 29.77 | 19.53 | 20.00 | 0.11536 |
| 3 | 48.992 | 20.24 | 39.76 | 19.51 | 30.00 | 0.12104 |




**Lambda ( 10°C ) = ( 0.1101 ± 0.0033 ) W/(m*K) / Lambda = 0.10470 + 0.00054 * MT W/(m*K)**

**Figure 9.** Thermal conductivity values of measured sample.

Figure 9 presents a typical result sheet with all measured (heat flow in W/m$^2$, temperatures of cold and warm side in °C) and calculated (temperature difference in K and thermal conductivity in W/mK) quantities, with respect to the set sample mean temperatures (10 °C, 20 °C, and 30 °C).

In Figure 9, the uncertainty bands relating to conductivity values at the three different temperatures are already graphically expressed. While considering the calibration uncertainty of the TAURUS, the repeatability of the measurements obtained and the linear regression error, it is possible to estimate an average standard deviation (SD) equal to 0.004 W/mK.

## 3. Results

In this section, the mechanical strength of the jute nets (fabricated by using 1 mm diameter jute threads) and the thermal conductivity value of the recycled jute net fiber composite mortar are reported.

During this experimental campaign, the mechanical strength of the two types of jute nets, with 2.5 cm × 2.5 cm and 2.5 cm × 1.25 cm mesh configurations, were evaluated through tensile strength tests.

Subsequently, the fiber scraps during the net fabrication and the post-tensile test failed net fibers were collected and recycled to prepare the jute net fiber composite mortar and later the thermal conductivity value of these samples was estimated.

### *3.1. Jute Net Tensile Strength Tests*

A total of seven samples of each type of jute thread net (2.5 cm × 2.5 cm and 2.5 cm × 1.25 cm mesh configurations) were used for the displacement-controlled tensile strength tests. The tensile strength and the axial displacement were recorded during the tests. Notably, from each net type, two non-satisfactory results were discarded and were not considered due to faulty measurements.

The results presented in this section clearly highlight that the denser mesh configuration (2.5 cm × 1.25 cm) was found to be significantly more rigid, with an average stiffness increase of 35.80%, compared to the 2.5 cm × 2.5 cm mesh samples (see Figures 10–12). Furthermore, the load-bearing capacity of the denser mesh was observed to be over 50% greater, accompanied by a 14.35% increase in maximum elongation. This mesh also demonstrated superior strain energy transfer, exceeding its counterpart by more than 60%, as evidenced in Table 3.

Further, Table 3 presents a detailed comparison of the mechanical properties, including maximum load, displacement, strain energy, and stiffness, along with the coefficient of variation for each parameter, offering insights into the reliability and variability of the measurements. The different performances of the two mesh configurations can be easily explained, considering that the denser mesh presents more threads for unit area than the other configuration.

Figures 10 and 11 illustrate the force–displacement behavior for each type of mesh configuration. The primary mechanical observations from these tests are further documented in Tables 4 and 5. These tables present specific data points, such as the first collapse load, maximum load, and the corresponding displacement at maximum load for individual samples, providing a granular view of the performance characteristics.

**Table 3.** Mechanical properties of jute fiber nets.

| Sample Nomination | Max. Load | | Max. Displacement | | Strain Energy | | Stiffness | |
|---|---|---|---|---|---|---|---|---|
| | Mean N | Co.V % | Mean mm | Co.V % | Mean kN.mm | Co.V % | Mean N/mm | Co.V % |
| N_1.25 | 337.21 | 9.94 | 82.86 | 18.56 | 14.05 | 21.04 | 10.28 | 11.98 |
| N_2.5 | 217.23 | 24.82 | 72.46 | 17.82 | 8.76 | 39.14 | 7.57 | 20.22 |

where, Co.V. is the coefficient of variation.

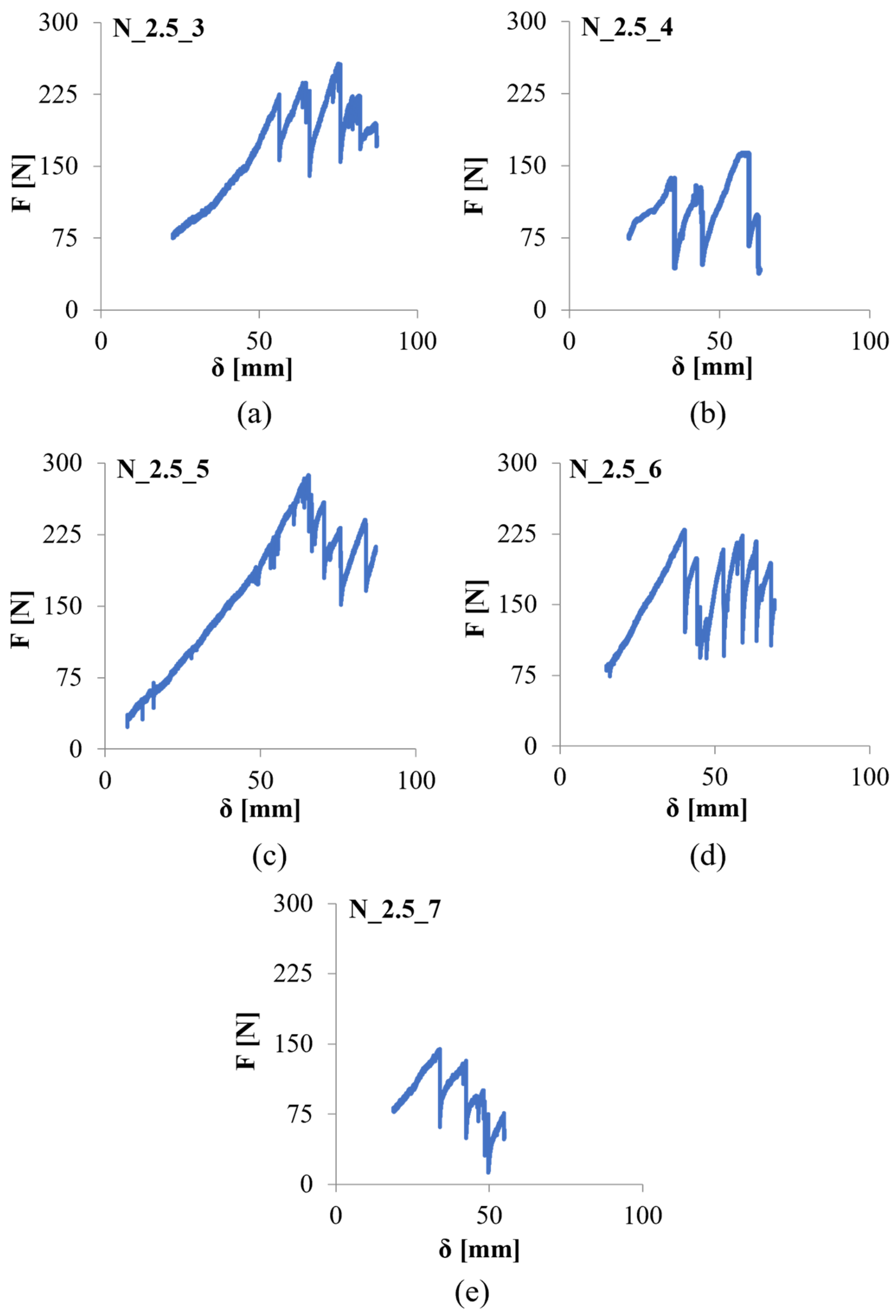



**Figure 10.** Force–displacement graphs of the jute net (**a**) Sample N_2.5_3, (**b**) Sample N_2.5_4, (**c**) Sample N_2.5_5, (**d**) Sample N_2.5_6 and (**e**) Sample N_2.5_7, with fiber mesh 2.5 cm × 2.5 cm configuration.

**Table 4.** Mechanical properties of the jute fiber net type N_2.5.

| Sample | First Collapse Load | Maximum Load | Corresponding Displacement at Maximum Load |
|---|---|---|---|
| | N | N | mm |
| N_2.5_3 (Figure 10a) | 220.5 | 257.38 | 75.69 |
| N_2.5_4 (Figure 10b) | 136.00 | 167.48 | 37.4 |
| N_2.5_5 (Figure 10c) | 287.67 | 287.67 | 65.25 |
| N_2.5_6 (Figure 10d) | 229.42 | 229.42 | 40.14 |
| N_2.5_7 (Figure 10e) | 144.21 | 144.21 | 33.80 |

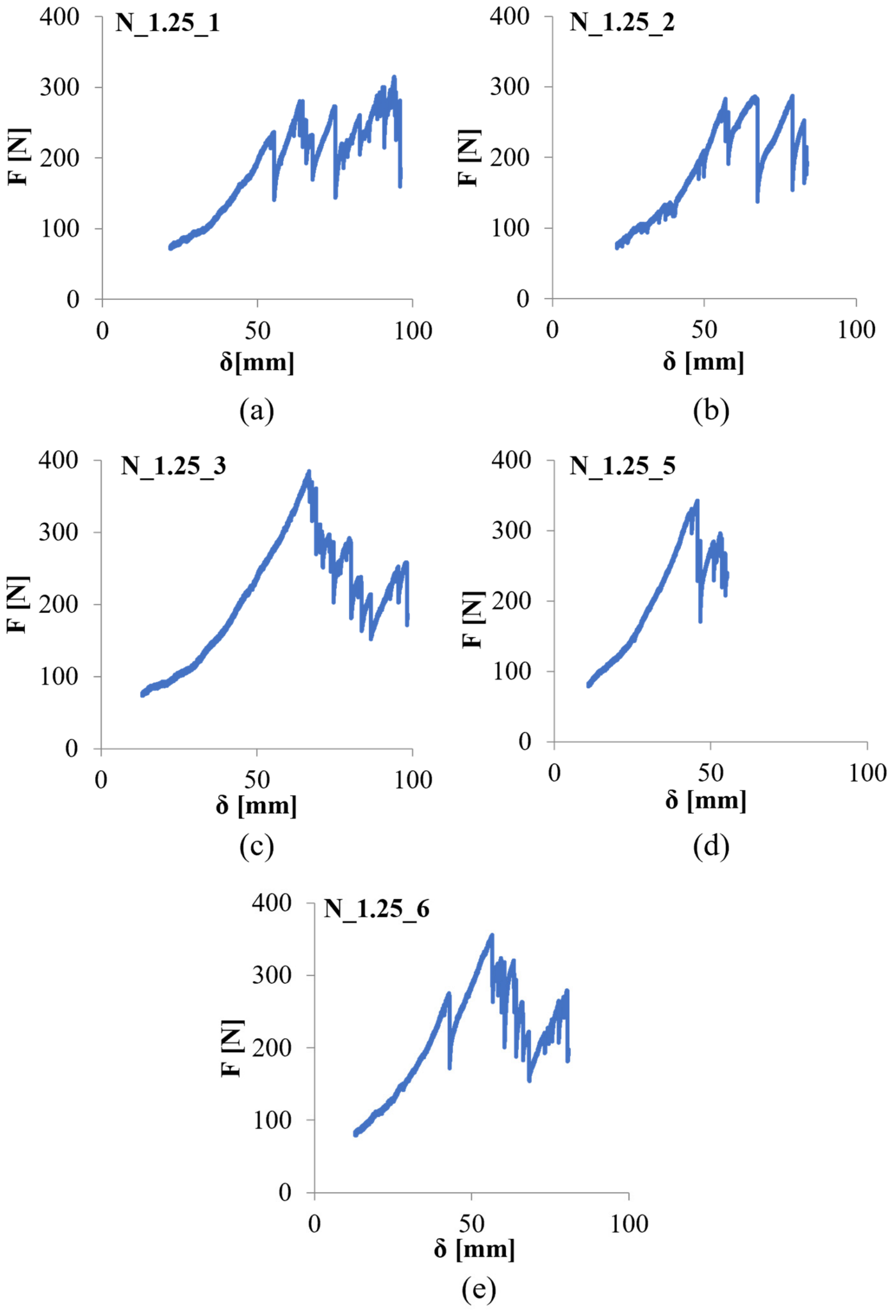



**Figure 11.** Force–displacement graphs of the jute net (**a**) Sample N_1.25_1, (**b**) Sample N_1.25_2, (**c**) Sample N_1.25_3, (**d**) Sample N_1.25_5 and (**e**) Sample N_1.25_6, with fiber mesh 1.25 cm × 2.5 cm configuration.

**Table 5.** Mechanical properties of the jute fiber net type N_1.25.

| Sample | First Collapse Load | Maximum Load | Corresponding Displacement at Maximum Load |
|---|---|---|---|
| | N | N | mm |
| N_1.25_1 (Figure 11a) | 236.50 | 314.40 | 94.21 |
| N_1.25_2 (Figure 11b) | 281.99 | 287.33 | 79.00 |
| N_1.25_3 (Figure 11c) | 384.69 | 384.69 | 66.65 |
| N_1.25_5 (Figure 11d) | 342.76 | 342.76 | 45.72 |
| N_1.25_6 (Figure 11e) | 271.84 | 356.09 | 56.20 |

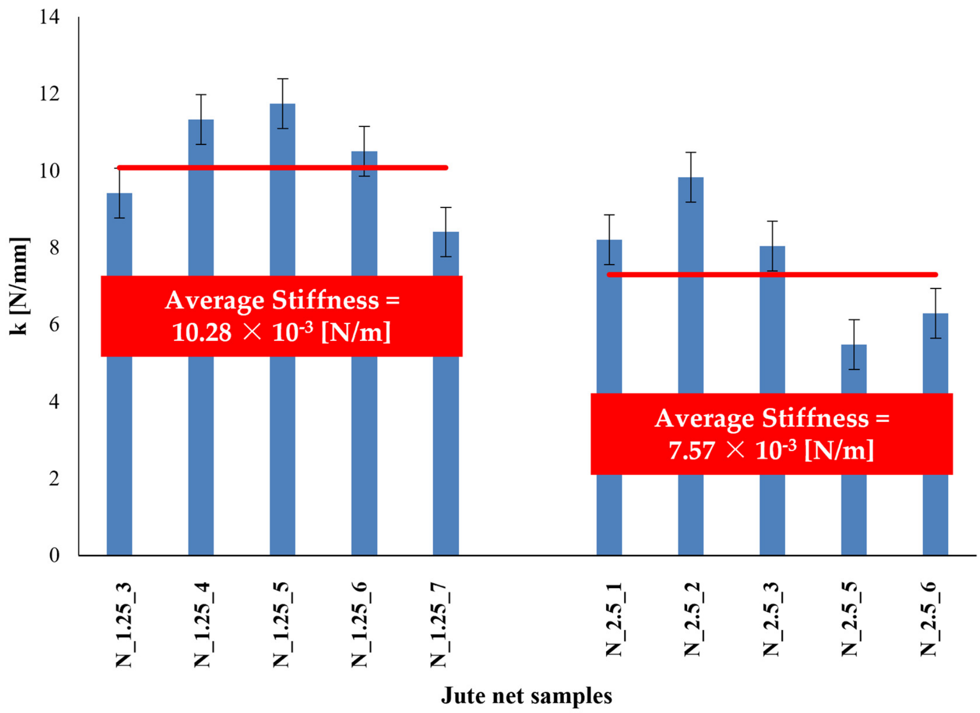



**Figure 12.** Jute nets (sample types: N_1.25 and N_2.5) stiffnesses.

Interestingly, none of the net samples experienced complete rupture during testing. Instead, multiple collapses were observed, attributed to failures at knot points or within the thread fiber between knots. This behavior resulted in various spikes in the force–displacement graphs, (Figures 10 and 11), indicating the localized nature of the failures. On the positive side, the denser mesh configuration shows promise for enhanced load-bearing capacity and stiffness, which are desirable traits for applications in construction. However, the occurrence of the multiple collapses suggests that while the material is strong, the nets' reliability is related to the manufacturing processes or material behavior at micro-scales, such as at knots.

Figure 12 presents a comparison of the stiffnesses between the jute net mesh configurations 2.5 cm × 1.25 cm and 2.5 cm × 2.5 cm. It is clearly noticeable that the first configuration is stiffer than the latter configuration. The maximum and minimum stiffness for the 2.5 cm × 1.25 cm mesh configuration was found to be 11.75 N/mm and 8.41 N/mm, respectively. While 9.83 N/mm and 5.48 N/mm are the maximum and minimum stiffness for the 2.5 cm × 2.5 cm mesh configuration.

### *3.2. Recycled Jute Net Fiber Composite Mortar (RJNFCM) Thermal Conductivity Tests*

The TC values of the jute fiber (12.5% of fiber, with respect to the dry mortar mass) composite mortar samples were evaluated. The samples were prepared based on the authors previous experience, which can be found in [20,75].

Table 6 presents the TC values measured at 10 °C, 20 °C and 30 °C, respectively, and it has been found that the composite sample RJNF(12.5%)CM with 12.5% (with respect to the dry mortar mass) recycled jute fiber is 48.36%, 47.61%, and 46.22%, respectively lower (in average) than the sample [75] with the 6.5% of recycled jute fiber (added with respect to the dry mortar mass) composite mortar (Figure 12).

**Table 6.** Thermal conductivity of the RJNFCM.

| λ (W/mK) | | | | |
|---|---|---|---|---|
| Sample Nomenclature | Tests Performed at | | | |
| | 10 (°C) | 20 (°C) | 30 (°C) | Reference Thermal Conductivity Values of Samples with Different Combinations [Jute Fiber Percentages (with Respect to the Dry Mortar Mass) & Jute Fiber Lengths]. |
| RJNF(12.5%)CM (12% of recycled jute net fiber with respect to the dry mortar mass) | 0.110 (with Co.V. of 8.5%) | 0.115 (with Co.V. of 6.52%) | 0.121 (with Co.V. of 4.12%) | • 0.5%: 0.434 (min for 10 mm) to 0.654 (max for 30 mm) [20]. • 1.0%: 0.432 (min for 10 mm) to 0.512 (max for 30 mm) [20]. • 1.5%: 0.420 (min for 10 mm) to 0.566 (max for 30 mm) [20]. • 2.0%: 0.438 (min for 10 mm) to 0.546 (max for 30 mm) [20]. • 6.5%: 0.213 to 0.225 [75]. |

where, Co.V. is the coefficient of variation.

The TC values of RJNF(12.5%)CM sample were compared to the sample combinations with different fiber percentages (0.5%, 1.0%, 1.5%, and 2.0%) and fiber lengths (30 mm, 10 mm, and 5 mm), as highlighted in [75]. The TC values of the RJNF(12.5%)CM are lower in the range between 74% and 80% approximately, with respect to the samples mentioned [75].

Figure 13 presents a comparison between the obtained TC values of the RJNFCM (under observation) and similar types of samples (with different fiber lengths and fiber percentages (with respect to the dry mortar mass) combinations) reported in [20,75], while the sample preparation and drying conditions are same. Notably the comparison has been also carried out with the samples made with 6.5% recycled fibers [75]. In this regard, it is the authors' opinion that the previous processing of jute fibers does not influence the thermal conductivity of the samples to a significant extent.

Notably, the samples considered here are oven dried before conducting the TC measurements. However, as highlighted by the authors in [78], during the composite mortar mixing, fiber balls are formed when the jute fibers came in contact with water. Therefore, jute fibers not only have the ability to absorb water individually but also can trap some extra water collectively in the fiber balls cavity. As the fiber used in this case were three yarn jute threads, therefore in the yarn cavity, too, there could be the possibility of trapping a small amount of water.

Here, it is worth highlighting that with the available instruments and at the given laboratory condition, it was only possible to prepare the composite mortar with a maximum of 12.5% of recycled jute fiber. Notably, more than the said amount of the fiber–mortar bonding was not optimum for the composite mortar preparation.

When the RJNF(12.5%)CM samples dried and the trap water was removed, there must be some empty cavities formed inside of the said samples. So, a higher fiber density in the sample means more numbers of empty cavities, consequently improving the insulation capacity of the sample. Therefore, it can be said that RJNF(12.5%)CM is a better insulator than the other compared samples in Figure 13.

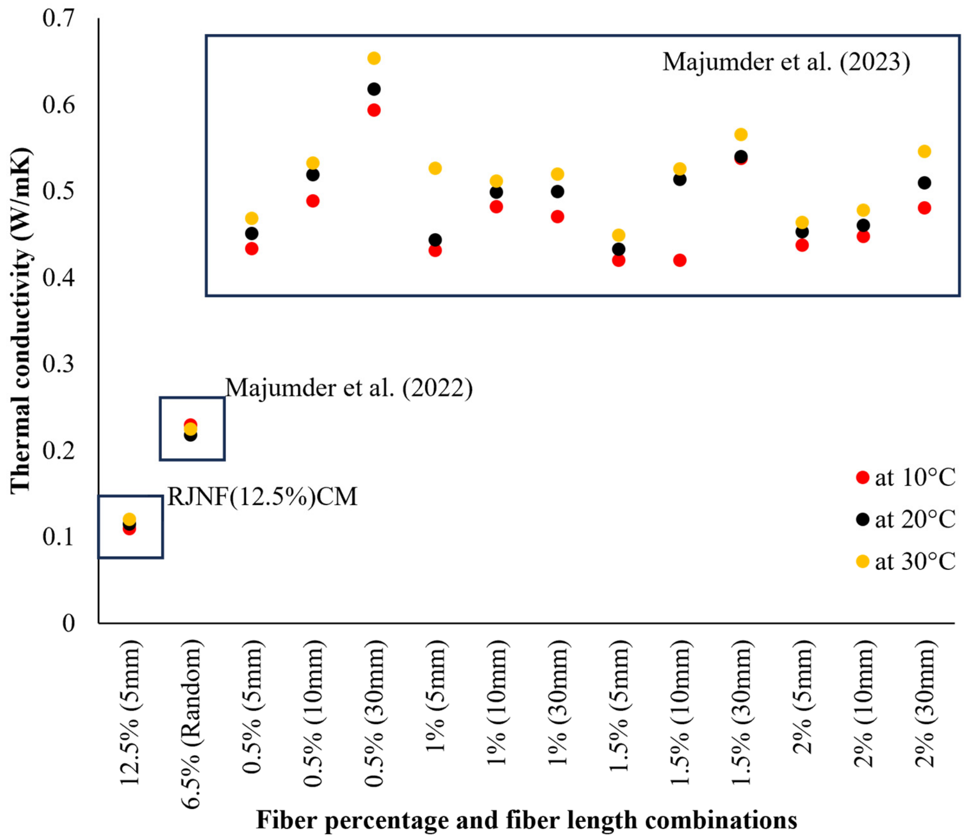



**Figure 13.** Thermal conductivity values of the tested samples vs. different combinations (fiber % and length) of jute fiber composite mortar samples, can be found in [20] Majumder et al. (2023) and [75] Majumder et al. (2022).

## 4. Conclusions

This study investigates the mechanical and thermal properties of jute fiber products and the recyclability of residual waste thread and net fibers, which are leftover during the net fabrication process and post-flexural tests.

Tensile strength tests have been conducted to evaluate the feasibility of the jute fiber nets to be used for net fiber textile retrofitting mortar (NFTRM) of the masonry walls or structures. For this campaign, two types of jute nets with 2.5 cm × 2.5 cm and 2.5 cm × 1.25 cm were tested.

Both types of jute nets were manually fabricated using jute fiber threads in the Strength laboratory of the University of Salerno, Italy. During the net fabrication process, scrap thread fibers and net fibers were collected. Additionally net fibers leftovers after the tensile strength tests were also collected and all these collected fibers were recycled to prepare RJNFCM. About 12% of recycled jute fiber (with respect to the dry mortar mass) was used for RJFCM preparation.

The tensile strength tests have demonstrated that the net sample 2.5 cm × 1.25 cm is 35.80% stiffer than the other net configurations (2.5 cm × 2.5 cm). While the previous one also has the capability to dissipate about 60% more applied load in terms of strain energy.

Whereas the TC tests have shown the TC values of the RJNFCM range from 0.110 (W/mK) to 0.121 (W/mK), and these composite samples have shown better insulation capacity in comparison to the author's previous works [20].

Following this experimental campaign, authors have used these jute fiber products (jute fiber nets and jute fiber composite mortars) for integrated upgrading of the masonry walls, and both structural behavior and thermal performance of these walls are evaluated.

Therefore, this work shows how it is possible to use these natural fiber products for integrated retrofitting or upgrading of the masonry wall or structures, to have sustainable, eco-friendly, greener, healthier, safer, and energy-efficient buildings.

More research is needed to optimize the thickness of TRM in order to obtain a given structural or thermal performance. In addition, the production process of jute nets should be improved to be scaled for industrial production. Further research is also scheduled to analyze the aging time of the jute net (prepared with jute threads (Figure 1), which are about one year older) used for the TRM system.

Finally, it is important to highlight that incorporating life cycle assessment (LCA) strategies is essential to comprehensively understand the environmental implications of jute fiber products and fiber-reinforced mortars in the construction industry, see for example [84]. LCA can produce a detailed analysis of the carbon footprint at every stage of a product's life; from the cultivation of jute, which typically requires lower inputs of fertilizers and pesticides compared to other crops, thereby reducing the initial environmental impact, through the processing and manufacturing phases, where energy consumption and waste generation can be significant. For jute fiber-reinforced mortars, an LCA would consider not only the direct emissions and energy use during production, but also the potential savings in the use phase, due to improved energy efficiency from the material's insulating properties. Furthermore, the end-of-life recyclability of jute enhances its sustainability profile, potentially reducing landfill waste and allowing for the material's reuse or repurposing, thus contributing to a circular economy [85]. By applying LCA to jute products, the construction industry can better align with the EU's sustainability directives, moving towards greener building practices that minimize the carbon footprint and foster long-term ecological balance.

**Author Contributions:** Conceptualization: A.M., F.S. and E.M.; methodology: A.M., F.S. and E.M.; validation: F.S., A.F., G.G. and E.M.; formal analysis: A.M., F.S. and E.M.; investigation: A.M., F.S. and E.M.; resources: F.S. and E.M.; data curation: A.M. and M.V.; writing—original draft preparation: A.M.; writing—review and editing: A.M., F.S., A.F., M.V., G.G. and E.M.; supervision: F.S., A.F., G.G. and E.M. All authors have read and agreed to the published version of the manuscript.

**Funding:** The financial support of projects DPC-RELUIS 2022-2024 WP5 and PRIN PNRR 2022-IntegraTRM - P2022RSSK5 is acknowledged by the authors.

**Institutional Review Board Statement:** Not applicable.

**Informed Consent Statement:** Not applicable.

**Data Availability Statement:** Data are available upon reasonable request.

**Acknowledgments:** Authors would like to thank Engineer Francesco Perri and Engineer Ciro Esposito of the University of Salerno, Italy, for their technical support.

**Conflicts of Interest:** The authors declare no conflicts of interest.

## References

1. Towards Sustainable Plastic Construction and Demolition Waste Management in Europe. Available online: https://Www.Acrplus.Org/Images/Pdf/Document142.Pdf (accessed on 12 December 2023).
2. Mah, C.M.; Fujiwara, T.; Ho, C.S. Environmental Impacts of Construction and Demolition Waste Management Alternatives. *Chem. Eng. Trans.* **2018**, *63*, 343–348. [CrossRef]
3. Directive 2008/98/EC of the European Parliament and of the Council of 19 November 2008 on Waste and Repealing Certain Directives. 2008. Available online: http://Data.Europa.Eu/Eli/Dir/2008/98/2018-07-05 (accessed on 12 December 2023).
4. EU Construction and Demolition Waste Protocol and Guidelines. Available online: https://single-market-economy.ec.europa.eu/news/eu-construction-and-demolition-waste-protocol-2018-09-18_en (accessed on 12 December 2023).
5. Integrated Product Policy: Building on Environmental Life-Cycle Thinking. 2003. Available online: https://Eur-Lex.Europa.Eu/Legal-Content/EN/TXT/PDF/?uri=CELEX:52003DC0302 (accessed on 12 December 2023).
6. Šupić, S.; Bulatović, V.; Malešev, M.; Radonjanin, V.; Lukić, I. Sustainable Masonry Mortars with Fly Ash, Blast Furnace Granulated Slag and Wheat Straw Ash. *Sustainability* **2021**, *13*, 12245. [CrossRef]
7. Li, X.; Qin, D.; Hu, Y.; Ahmad, W.; Ahmad, A.; Aslam, F.; Joyklad, P. A Systematic Review of Waste Materials in Cement-Based Composites for Construction Applications. *J. Build. Eng.* **2022**, *45*, 103447. [CrossRef]

8. Nasr, M.S.; Shubbar, A.A.; Abed, Z.A.-A.R.; Ibrahim, M.S. Properties of Eco-Friendly Cement Mortar Contained Recycled Materials from Different Sources. *J. Build. Eng.* **2020**, *31*, 101444. [CrossRef]
9. He, X.; Zheng, Z.; Yang, J.; Su, Y.; Wang, T.; Strnadel, B. Feasibility of Incorporating Autoclaved Aerated Concrete Waste for Cement Replacement in Sustainable Building Materials. *J. Clean. Prod.* **2020**, *250*, 119455. [CrossRef]
10. Czarnecki, S.; Rudner, M. Recycling of Materials from Renovation and Demolition of Building Structures in the Spirit of Sustainable Material Engineering. *Buildings* **2023**, *13*, 1842. [CrossRef]
11. Robayo-Salazar, R.A.; Valencia-Saavedra, W.; Mejía De Gutiérrez, R. Construction and Demolition Waste (CDW) Recycling—As Both Binder and Aggregates—In Alkali-Activated Materials: A Novel Re-Use Concept. *Sustainability* **2020**, *12*, 5775. [CrossRef]
12. Abadel, A.A.; Nasr, M.S.; Shubbar, A.; Hashim, T.M.; Tuladhar, R. Potential Use of Rendering Mortar Waste Powder as a Cement Replacement Material: Fresh, Mechanical, Durability and Microstructural Properties. *Sustainability* **2023**, *15*, 11659. [CrossRef]
13. Leone, R.; Calà, A.; Capela, M.N.; Colajanni, S.; Campisi, T.; Saeli, M. Recycling Mussel Shells as Secondary Sources in Green Construction Materials: A Preliminary Assessment. *Sustainability* **2023**, *15*, 3547. [CrossRef]
14. Sathiparan, N.; Anburuvel, A.; Selvam, V.V. Utilization of Agro-Waste Groundnut Shell and Its Derivatives in Sustainable Construction and Building Materials—A Review. *J. Build. Eng.* **2023**, *66*, 105866. [CrossRef]
15. Maraveas, C. Production of Sustainable and Biodegradable Polymers from Agricultural Waste. *Polymers* **2020**, *12*, 1127. [CrossRef] [PubMed]
16. Liuzzi, S.; Sanarica, S.; Stefanizzi, P. Use of Agro-Wastes in Building Materials in the Mediterranean Area: A Review. *Energy Procedia* **2017**, *126*, 242–249. [CrossRef]
17. Bellei, P.; Magalhães, F.; Pereira, M.; Torres, I.; Solstad, R.; Flores-Colen, I. Innovative Thermal Renders Incorporating Oyster Shells for Sustainable Insulation. *Sustainability* **2023**, *15*, 15952. [CrossRef]
18. De Siqueira, A.A.; Cordeiro, G.C. Sustainable Cements Containing Sugarcane Bagasse Ash and Limestone: Effects on Compressive Strength and Acid Attack of Mortar. *Sustainability* **2022**, *14*, 5683. [CrossRef]
19. Mistretta, F.; Stochino, F.; Sassu, M. Structural and Thermal Retrofitting of Masonry Walls: An Integrated Cost-Analysis Approach for the Italian Context. *Build. Environ.* **2019**, *155*, 127–136. [CrossRef]
20. Majumder, A.; Stochino, F.; Frattolillo, A.; Valdes, M.; Mancusi, G.; Martinelli, E. Jute Fiber-Reinforced Mortars: Mechanical Response and Thermal Performance. *J. Build. Eng.* **2023**, *66*, 105888. [CrossRef]
21. Benzar, B.-E.; Park, M.; Lee, H.-S.; Yoon, I.; Cho, J. Determining Retrofit Technologies for Building Energy Performance. *J. Asian Archit. Build. Eng.* **2020**, *19*, 367–383. [CrossRef]
22. Kelly, S. *REPORT on the Implementation of the Energy Performance of Buildings Directive*; Committee on Industry, Research and Energy; European Parliament: Strasbourg, France, 2021.
23. Pitilakis, K. *Systemic Seismic Vulnerability and Risk Analysis for Buildings, Lifeline Networks and Infrastructures Safety Gain*; University of Pavia: Pavia, Italy, 2011.
24. Surana, M.; Ghosh, A.; Baldev, D. Seismic Features and Vulnerability of Traditional Building Practices in the Himalayan State, Himachal Pradesh, India. *J. Build. Eng.* **2022**, *62*, 105376. [CrossRef]
25. *EN 1998-3*; Eurocode 8, Design of Structures for Earthquake Resistance—Part 3: Assessment and Retrofitting of Buildings. Comite Europeen de Normalisation: Brussels, Belgium, 2005.
26. Directive (EU) 2018/844 of the European Parliament and of the Council of 30 May 2018 Amending Directive 2010/31/EU on the Energy Performance of Buildings and Directive 2012/27/EU on Energy Efficiency. Available online: https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32018L0844 (accessed on 25 January 2024).
27. European Commission. Nearly Zero-Energy Buildings. Energy, Climate Change, Environment. Available online: https://energy.ec.europa.eu/topics/energy-efficiency/energy-efficient-buildings/nearly-zero-energy-buildings_en (accessed on 12 December 2023).
28. Verma, D.; Senal, I. Natural Fiber-Reinforced Polymer Composites. In *Biomass, Biopolymer-Based Materials, and Bioenergy*; Elsevier: Amsterdam, The Netherlands, 2019; pp. 103–122. ISBN 978-0-08-102426-3.
29. Patel, R.V.; Yadav, A.; Winczek, J. Physical, Mechanical, and Thermal Properties of Natural Fiber-Reinforced Epoxy Composites for Construction and Automotive Applications. *Appl. Sci.* **2023**, *13*, 5126. [CrossRef]
30. de Beus, N.; Carus, M.; Barth, M. Natural Fibres Show Outstandingly Low $CO_2$ Footprint Compared to Glass and Mineral Fibres–Nova-Institute Updates Its Reference Study for the Automotive and Insulation Industry, PRESS RELEASE. Available online: https://renewable-carbon.eu/news/natural-fibres-show-outstandingly-low-co2-footprint-compared-to-glass-and-mineral-fibres/ (accessed on 12 December 2023).
31. Majumder, A.; Achenza, M.; Mastino, C.C.; Baccoli, R.; Frattolillo, A. Thermo-Acoustic Building Insulation Materials Fabricated with Recycled Fibers–Jute, Wool and Loofah. *Energy Build.* **2023**, *293*, 113211. [CrossRef]
32. Yooprasertchai, E.; Wiwatrojanagul, P.; Pimanmas, A. A Use of Natural Sisal and Jute Fiber Composites for Seismic Retrofitting of Nonductile Rectangular Reinforced Concrete Columns. *J. Build. Eng.* **2022**, *52*, 104521. [CrossRef]
33. Azhary, K.E.; Chihab, Y.; Mansour, M.; Laaroussi, N.; Garoum, M. Energy Efficiency and Thermal Properties of the Composite Material Clay-Straw. *Energy Procedia* **2017**, *141*, 160–164. [CrossRef]
34. Adamu, M.; Alanazi, F.; Ibrahim, Y.E.; Alanazi, H.; Khed, V.C. A Comprehensive Review on Sustainable Natural Fiber in Cementitious Composites: The Date Palm Fiber Case. *Sustainability* **2022**, *14*, 6691. [CrossRef]

35. Benmansour, N.; Agoudjil, B.; Gherabli, A.; Kareche, A.; Boudenne, A. Thermal and Mechanical Performance of Natural Mortar Reinforced with Date Palm Fibers for Use as Insulating Materials in Building. *Energy Build.* **2014**, *81*, 98–104. [CrossRef]
36. Elfordy, S.; Lucas, F.; Tancret, F.; Scudeller, Y.; Goudet, L. Mechanical and Thermal Properties of Lime and Hemp Concrete ("Hempcrete") Manufactured by a Projection Process. *Constr. Build. Mater.* **2008**, *22*, 2116–2123. [CrossRef]
37. Valenza, A.; Fiore, V.; Nicolosi, A.; Rizzo, G.; Scaccianoce, G.; Di Bella, G. Effect of Sheep Wool Fibres on Thermal-Insulation and Mechanical Properties of Cement Matrix. *Acad. J. Civ. Eng.* **2015**, *33*, 40–45. [CrossRef]
38. Raut, A.N.; Gomez, C.P. Thermal and Mechanical Performance of Oil Palm Fiber Reinforced Mortar Utilizing Palm Oil Fly Ash as a Complementary Binder. *Constr. Build. Mater.* **2016**, *126*, 476–483. [CrossRef]
39. Madival, A.S.; Shetty, R.; Doreswamy, D.; Maddasani, S. Characterization and Optimization of Thermal Properties of Rice Straw and Furcraea Foetida Fiber Reinforced Polymer Composite for Thermal Insulation Application. *J. Build. Eng.* **2023**, *78*, 107723. [CrossRef]
40. Hasan, R.; Sobuz, M.H.R.; Akid, A.S.M.; Awall, M.R.; Houda, M.; Saha, A.; Meraz, M.M.; Islam, M.S.; Sutan, N.M. Eco-Friendly Self-Consolidating Concrete Production with Reinforcing Jute Fiber. *J. Build. Eng.* **2023**, *63*, 105519. [CrossRef]
41. Wei, Z.; Gu, K.; Chen, B.; Wang, C. Comparison of Sawdust Bio-Composites Based on Magnesium Oxysulfate Cement and Ordinary Portland Cement. *J. Build. Eng.* **2023**, *63*, 105514. [CrossRef]
42. Da Silva, T.R.; De Matos, P.R.; Tambara Júnior, L.U.D.; Marvila, M.T.; De Azevedo, A.R.G. A Review on the Performance of Açaí Fiber in Cementitious Composites: Characteristics and Application Challenges. *J. Build. Eng.* **2023**, *71*, 106481. [CrossRef]
43. Rocha, J.H.A.; De Siqueira, A.A.; De Oliveira, M.A.B.; Castro, L.D.S.; Caldas, L.R.; Monteiro, N.B.R.; Toledo Filho, R.D. Circular Bioeconomy in the Amazon Rainforest: Evaluation of Açaí Seed Ash as a Regional Solution for Partial Cement Replacement. *Sustainability* **2022**, *14*, 14436. [CrossRef]
44. Parlato, M.C.M.; Cuomo, M.; Porto, S.M.C. Natural Fibers Reinforcement for Earthen Building Components: Mechanical Performances of a Low Quality Sheep Wool ("Valle Del Belice" Sheep). *Constr. Build. Mater.* **2022**, *326*, 126855. [CrossRef]
45. Lee, G.-W.; Choi, Y.-C. Effect of Abaca Natural Fiber on the Setting Behavior and Autogenous Shrinkage of Cement Composite. *J. Build. Eng.* **2022**, *56*, 104719. [CrossRef]
46. Ali, B.; Hawreen, A.; Ben Kahla, N.; Talha Amir, M.; Azab, M.; Raza, A. A Critical Review on the Utilization of Coir (Coconut Fiber) in Cementitious Materials. *Constr. Build. Mater.* **2022**, *351*, 128957. [CrossRef]
47. Mansilla, C.; Pradena, M.; Fuentealba, C.; César, A. Evaluation of Mechanical Properties of Concrete Reinforced with Eucalyptus Globulus Bark Fibres. *Sustainability* **2020**, *12*, 10026. [CrossRef]
48. Navaratnam, S.; Selvaranjan, K.; Jayasooriya, D.; Rajeev, P.; Sanjayan, J. Applications of Natural and Synthetic Fiber Reinforced Polymer in Infrastructure: A Suitability Assessment. *J. Build. Eng.* **2023**, *66*, 105835. [CrossRef]
49. Suparp, S.; Ejaz, A.; Khan, K.; Hussain, Q.; Joyklad, P.; Saingam, P. Load-Bearing Performance of Non-Prismatic RC Beams Wrapped with Carbon FRP Composites. *Sensors* **2023**, *23*, 5409. [CrossRef]
50. Kalali, A.; Kabir, M.Z. Cyclic Behavior of Perforated Masonry Walls Strengthened with Glass Fiber Reinforced Polymers. *Sci. Iran.* **2012**, *19*, 151–165. [CrossRef]
51. Padalu, P.K.V.R.; Singh, Y.; Das, S. Out-of-Plane Flexural Strengthening of URM Wallettes Using Basalt Fibre Reinforced Polymer Composite. *Constr. Build. Mater.* **2019**, *216*, 272–295. [CrossRef]
52. Tempesta, G. Seismic Retrofit of Historical Masonry Walls by Means of Natural Basalt Fiber Strips System (BFRP). Pre-Modern Concepts and Innovative Materials. *MATEC Web Conf.* **2018**, *242*, 01014. [CrossRef]
53. Codispoti, R.; Oliveira, D.V.; Olivito, R.S.; Lourenço, P.B.; Fangueiro, R. Mechanical Performance of Natural Fiber-Reinforced Composites for the Strengthening of Masonry. *Compos. Part B Eng.* **2015**, *77*, 74–83. [CrossRef]
54. Li, X.; Gao, Z.; Zhou, Y.; Sui, L.; Chen, C. Optimizing Natural Fiber Reinforced Polymer Strengthening of RC Beams. *Mater. Struct.* **2021**, *54*, 66. [CrossRef]
55. Huang, S.; Yan, L.; Kasal, B. Flexural Behaviour of Wood Beams Strengthened by Flax-Glass Hybrid FRP Subjected to Hygrothermal and Weathering Exposures. *Constr. Build. Mater.* **2023**, *365*, 130076. [CrossRef]
56. *CNR-DT 215/2018*; Guide for the Design and Construction of Externally Bonded Fibre Reinforced Inorganic Matrix Systems for Strengthening Existing Structures. National Research Council: Rome, Italy, 2018.
57. Tran, H.V.; Truong, G.T.; Choi, K.-K. Effect of Harsh Conditions on the Tensile Behaviour of Lap-Spliced Carbon Fiber Textile-Reinforced Mortar (TRM) with Different Surface Treatment Methods. *Appl. Sci.* **2019**, *9*, 3087. [CrossRef]
58. Babaeidarabad, S.; Caso, F.D.; Nanni, A. Out-of-Plane Behavior of URM Walls Strengthened with Fabric-Reinforced Cementitious Matrix Composite. *J. Compos. Constr.* **2014**, *18*, 04013057. [CrossRef]
59. De Santis, S.; De Canio, G.; De Felice, G.; Meriggi, P.; Roselli, I. Out-of-Plane Seismic Retrofitting of Masonry Walls with Textile Reinforced Mortar Composites. *Bull. Earthq. Eng.* **2019**, *17*, 6265–6300. [CrossRef]
60. Flayeh, A.H.; Toopchi-Nezhad, H.; TahamouliRoudsari, M. The Use of Fiberglass Textile-Reinforced Mortar (TRM) Jacketing System to Enhance the Load Capacity and Confinement of Concrete Columns. In Proceedings of the 2018 2nd International Conference for Engineering, Technology and Sciences of Al-Kitab (ICETS), Karkuk, Iraq, 4–6 December 2018; pp. 66–71.
61. Akhoundi, F.; Vasconcelos, G.; Lourenço, P. In-Plane Behavior of Infills Using Glass Fiber Shear Connectors in Textile Reinforced Mortar (TRM) Technique. *Int. J. Struct. Glass Adv. Mater. Res.* **2018**, *2*, 1–14. [CrossRef]
62. Ibrahim, M.; Galal, M.; Kohail, M.; Rashad, A.; ElShafie, H. Behaviour of Unreinforced Masonry Walls Retrofitted by Using Basalt Textile Reinforced Mortar. *Eng. Struct.* **2022**, *260*, 114201. [CrossRef]

63. Fossetti, M.; Minafò, G. Strengthening of Masonry Columns with BFRCM or with Steel Wires: An Experimental Study. *Fibers* **2016**, *4*, 15. [CrossRef]
64. Ferrara, G.; Caggegi, C.; Martinelli, E.; Gabor, A. Shear Capacity of Masonry Walls Externally Strengthened Using Flax-TRM Composite Systems: Experimental Tests and Comparative Assessment. *Constr. Build. Mater.* **2020**, *261*, 120490. [CrossRef]
65. Majumder, A.; Stochino, F.; Frattolillo, A.; Valdes, M.; Martinelli, E. Integrated Upgrading of Masonry Wall with Jute Fiber TRM System: Structural Behavior and Thermal Performance Evaluation. *Eng. Struct.* **2023**, *submitted*.
66. Menna, C.; Asprone, D.; Durante, M.; Zinno, A.; Balsamo, A.; Prota, A. Structural Behaviour of Masonry Panels Strengthened with an Innovative Hemp Fibre Composite Grid. *Constr. Build. Mater.* **2015**, *100*, 111–121. [CrossRef]
67. Pilien, V.P.; Promentilla, M.A.B.; Leaño, J.L.; Oreta, A.W.C.; Ongpeng, J.M.C. Confinement of Concrete Using Banana Geotextile-Reinforced Geopolymer Mortar. *Sustainability* **2023**, *15*, 6037. [CrossRef]
68. Townsend, T. Natural Fibres and the World Economy July 2019. Available online: https://dnfi.org/natural-fibres-and-the-world-economy-july-2019 (accessed on 12 December 2023).
69. Deepak, K.; Vattikuti, S.V.P.; Venkatesh, B. Experimental Investigation of Jute FiberReinforcedNano Clay Composite. *Procedia Mater. Sci.* **2015**, *10*, 238–242. [CrossRef]
70. Prasanthi, P.; Kondapalli, S.B.; Morampudi, N.K.S.R.; Vallabhaneni, V.V.M.; Saxena, K.K.; Mohammed, K.A.; Linul, E.; Prakash, C.; Buddhi, D. Elastic Properties of Jute Fiber Reinforced Polymer Composites with Different Hierarchical Structures. *Materials* **2022**, *15*, 7032. [CrossRef]
71. Wang, H.; Memon, H.; AM Hassan, E.; Miah, M.S.; Ali, M.A. Effect of Jute Fiber Modification on Mechanical Properties of Jute Fiber Composite. *Materials* **2019**, *12*, 1226. [CrossRef]
72. Ferrandez-García, M.T.; Ferrandez-Garcia, C.E.; Garcia-Ortuño, T.; Ferrandez-Garcia, A.; Ferrandez-Villena, M. Study of Waste Jute Fibre Panels (*Corchorus capsularis* L.) Agglomerated with Portland Cement and Starch. *Polymers* **2020**, *12*, 599. [CrossRef]
73. Jin, Z.; Li, J.; Wang, Q.; Su, W.; Duan, X.; Tang, Z. Characterization of Multifunctional Panels from Jute Fibers for Interior Wall Covering. *Ind. Crops Prod.* **2021**, *167*, 113530. [CrossRef]
74. Formisano, A.; Chiumiento, G.; Dessì, E.J. Laboratory Tests on Hydraulic Lime Mortar Reinforced With Jute Fibres. *Open Civ. Eng. J.* **2020**, *14*, 152–162. [CrossRef]
75. Majumder, A.; Stochino, F.; Frattolillo, A.; Valdes, M.; Fraternali, F.; Martinelli, E. Sustainable Building Material: Recycled Jute Fiber Composite Mortar for Thermal and Structural Retrofitting. In *Computational Science and Its Applications–ICCSA 2022 Workshops*; Gervasi, O., Murgante, B., Misra, S., Rocha, A.M.A.C., Garau, C., Eds.; Lecture Notes in Computer Science; Springer International Publishing: Cham, Switzerland, 2022; Volume 13379, pp. 657–669. ISBN 978-3-031-10544-9.
76. Majumder, A.; Farina, I.; Stochino, F.; Fraternali, F.; Martinelli, E. Natural Fibers Reinforced Mortars: Composition and Mechanical Properties. *Key Eng. Mater.* **2022**, *913*, 149–153. [CrossRef]
77. Majumder, A.; Canale, L.; Mastino, C.C.; Pacitto, A.; Frattolillo, A.; Dell'Isola, M. Thermal Characterization of Recycled Materials for Building Insulation. *Energies* **2021**, *14*, 3564. [CrossRef]
78. Majumder, A.; Stochino, F.; Farina, I.; Valdes, M.; Fraternali, F.; Martinelli, E. Physical and Mechanical Characteristics of Raw Jute Fibers, Threads and Diatons. *Constr. Build. Mater.* **2022**, *326*, 126903. [CrossRef]
79. *EN 998-1*; Specification for Mortar for Masonry—Part 1: Rendering and Plastering Mortar. Comite Europeen de Normalisation: Brussels, Belgium, 2016.
80. *EN 1015-2*; Methods of Test for Mortar for Masonry—Part 2: Bulk Sampling of Mortars and Preparation of Test Mortars. European Committee for Standardization: Brussels, Belgium, 2007.
81. *ISO 8301:1991*; Thermal Insulation. Determination of Steady-State Thermal Resistance and Related Properties—Heat Flow Meter Apparatus. The International Organization for Standardization (ISO): Geneva, Switzerland, 1991.
82. *EN 1946-3*; Thermal Performance of Building Products and Components—Specific Criteria for the Assessment of Laboratories Measuring Heat Transfer Properties—Part 3: Measurements by the Heat Flow Meter Method. European Committee for Standardization: Brussels, Belgium, 1999.
83. *EN 12939*; Thermal Performance of Building Materials and Products—Determination of Thermal Resistance by Means of the Hot Plate with Guard Ring and the Heat Flow Meter Method—Thick Products with High and Medium Thermal Resistance. European Committee for Standardization: Brussels, Belgium, 2002.
84. La Rosa, A.D.; Grammatikos, S.A. Comparative Life Cycle Assessment of Cotton and Other Natural Fibers for Textile Applications. *Fibers* **2019**, *7*, 101. [CrossRef]
85. Gonzalez, V.; Lou, X.; Chi, T. Evaluating Environmental Impact of Natural and Synthetic Fibers: A Life Cycle Assessment Approach. *Sustainability* **2023**, *15*, 7670. [CrossRef]