HOW CAN A FORMER ROMANIAN COLLECTIVE FARM BE REDEVELOPED USING LOW-IMPACT MATERIALS TO ACHIEVE ENERGY EFFICIENCY?
Abstract

Following the model of collective farming of the Soviet Union, Romania’s agricultural sector was transformed during communism in Agricultural Cooperatives for Production. In the period 1949 – 1962, the country’s agricultural land was collectivized in such state-owned cooperations. Small-scale private farming became nonexistent and, even though the initiative was meant to boost the agricultural production in Romania, the project ended up failing and leaving the country’s sector of agriculture in a very unproductive state.

The fall of this regime in 1989 has left the newly privatised farms abandoned and in need of redevelopment. Different factors led to this problem: a generation gap between the original land owners and the ones to receive it back from the state, general disinterest due to the shift to a capitalist economy from a subsistence-farm society, the change of regime and the availability of new opportunities, disconnection between farmers and land and a general negative perception of the former collective farms due to the way they were collectivized.

These farms are present all throughout the country, in almost every commune, therefore I will take into discussion one example, in the South of Romania, in Cojasca, in order to be able to create a whole new design for this farm which can serve as example for other farms throughout the country.

In order to be able to create a new design for the farm in the village of Cojasca, Romania, a thorough research needs to be conducted first in order to determine which are the best solutions for refurbishing or constructing new buildings on the site using low-impact materials.
Introduction

PART I - Collectivization in Romania
  1.1 Historical context of Romanian collective farms
  1.2 Case study: former CAP Cojasca - current situation

PART II - Romanian context: history & architecture
  2.1 General geographic and climatic aspects - Cojasca
  2.2 Vernacular architecture in Southern Romania

PART III - Low-impact construction
  3.1 Energy efficiency and embodied energy in constructions
  3.2 Low-impact building materials
    Group 1: In-depth study
      3.2.1 Straw
      3.2.2 Earth
      3.2.3 Hempcrete
      3.2.5 Wood
      3.2.5 Stone
    Group 2: Observation (Rubble, Flax, Hemp, Sheep wool, Cork)
  3.3. Comparison
  3.4 Conclusions low-impact materials

PART IV - Scenarios for redevelopment

Conclusions
Bibliography and references
The present paper is my research and starting point for my Master graduation project within the Explore Lab studio at the Faculty of Architecture and the Built Environment. My project theme is concerned with designing a sustainable redevelopment strategy for one of the many abandoned former Romanian collective farms.

Between 1949 and 1962, under the rule of the communist regime, almost all of Romania’s agricultural land was gathered in so called Agricultural Cooperatives for Production, a typology of farms following the Soviet model of kolkhozy. All private agricultural land became state-owned, leaving peasants to work for the state and eventually impoverishing this class of workers. After the fall of communism in Romania in 1989, this typology of farms was obsolete and the headquarter sites of each farm was left abandoned and decayed over time, while the agricultural land owned by the farms was either returned to their previous owners, either sold or kept in possession of the state. The recent steadily growing development of the country provided a great opportunity for progress, interest and investment in agriculture. Therefore, there is a need for creating a sustainable redevelopment strategy for these sites, to reintegrate them into the modern society and use their potential to revitalize the rural life and activity. These farms are present all throughout the country, in almost every commune, therefore I will take into discussion one example, in the South of Romania, in Cojasca, in order to be able to create a whole new design for this farm that can serve as example for other farms throughout the country.

In order to be able to create a new design for the farm in the village of Cojasca, Romania, a thorough research needs to be conducted first in order to determine which are the best solutions for refurbishing or constructing new buildings on the site. As I set out to create a redevelopment strategy for a sustainable farm, it was only natural to reach the point where I questioned myself how can the reconstruction be performed in a sustainable way as well, through the use of low-impact materials, such as local, renewable, biodegradable
materials or through reusing the materials available on site after the demolition of the highly decayed buildings. The ultimate goal is to **achieve high energy efficiency** in the design in both construction and operational phase, through using low-impact materials, with low embodied energy and carbon footprint and through applying Cradle2Cradle and passive building principles in the design phase.

For the purpose of this research, I will mainly study different low-impact materials, their properties and ways in which they can be used together in a design, in order to try to answer my research question: **How can a former Romanian collective farm be redeveloped using low-impact materials to achieve energy efficiency?**

One of the missions of this research is to identify the lessons that can be learned from the past, from vernacular architecture, in what concerns building techniques and materials and how can they be applied in a modern context to contribute to a sustainable future.

This paper has been structured in three main parts. The first part includes two sections in which I will examine the process of collectivization during the communism years and its effect on the population and the country’s agricultural sector, as well as presenting a case study for the former Romanian collective farms - the farm in the village of Cojasca and its current situation, in order to better understand what the applicability of this research will be on. In the second part I will study the evolution and main characteristics of vernacular architecture in the Southern areas of Romania. In order to later on be able to test the proposed solutions for materials, I will briefly describe here some general aspects about the climate and geography of Southern Romania and Cojasca. In the third and most important part of this research, a series of low-impact materials will be identified, presented and compared, in order to eventually provide an insightful conclusion to the question of this paper as to which are the most suitable materials and in what way can they be applied in the redevelopment project of the farm in Cojasca.
1.1 Historical context of Romanian collective farms

When discussing about the former Romanian collective farms and ways to redevelop them, it is of high importance to understand their history, how did they form and what was their impact on the society, in order to be able to design a redevelopment strategy that will take into account and deal with all the factors that have led to the present condition of these facilities.

Through the term of collectivization we understand the process through which by making changes in the property rights, changes in social relations between villagers occur, in their self-image and their view on society. All these changes empowered and amplified the authority of the Communist party in charge (Iordachi & Dobrincu, 2009, p. 11).

The collectivization of agriculture in Romania has to be studied first the wider context of the Soviet Eastern Bloc and in relation to the events and changes in politics. Towards the end of WWII, Romania’s King Michael I broke away the country from the Axis in favour of the Allied side, opening the way to Soviet troops, which treated Romania as a conquered territory (Curtois, 2002, p. 376 -377). They remained in the country after the Soviet Union was granted a predominant interest in the Yalta Conference.

In March 1945, a Communist-dominated coalition government was established. This was only the beginning of the Communist era that would follow until 1989. In what has been later proved to be falsified elections, the communist controlled Bloc of Democratic Parties won the national parliamentary elections of November 1946. In short, this was followed in 1947 by the forced abdication of King Michael I, the abolition of the Monarchy, the proclamation of the People’s Republic of Romania, the ban of the National Peasant Party - a great voice of the rural areas - and the imprisonments of their leaders. In 1948, the Romanian Workers’ Party (RWP) was created, which was self-intituluated as the “unique party of the working class”. In order to fully confirm the definitive and full establishment of a communist regime in Romania, the first communist Constitution was adopted in April 1948 (Iordachi & Dobrincu, 2009, p. 485-486).
These were the main political events that took place in Romania after the WWII and laid the groundwork for a socialist transformation of the country and later on, of its agriculture.

As Marx & Engels concluded in their political pamphlet, the immediate goal of communists is the “formation of the proletariat into a class, overthrow of the bourgeois supremacy, conquest of political power by the proletariat” (Marx & Engels, 1848, p.22). This was the exact goal the communist regime had in Romania as well. The collectivization of agriculture played therefore a central role in achieving this goal, being characterized as the largest political campaign ever conducted by communist leaders (Iordachi & Dobrincu, 2009, p. 1). This process involved and affected all of Romania’s rural population, which at the beginning of the collectivization process accounted for about 75% of the total population. The main outcome was the fact that the regime managed to get involved into the rural life, by controlling the production and means of existence of the people living there. Through promoting the fight against rich peasants (chiaburi in Romanian), the Romanian Workers’ Party (RWP) promised a new way of living, for everyone as middle-working class, instead of a clear distinction between very rich and very poor peasants.

Collectivization in Eastern Europe

When studying the collectivization patterns among the Eastern European states, several factors played a role in how the process went and why did variations between states appear. The strength of the Communist party and its influence, the understanding and balance of forces between the peasantry and the communist leaders, the degree in which the Soviet Union was involved in the process and the country’s level of urbanization and industrialization all play a role in how the process of collectivization took place and what were its long term effects on the rural areas (Iordachi & Dobrincu, 2009, p. 185). According to these factors, several systems of collectivization can be distinguished, according to
Wider comparative perspective of Soviet-dominated Eastern Europe

National variation factors
- strength of Communist Party
- level of urbanization/industrialization
- balance of forces between regime and peasantry at various times
- extent of Soviet involvement and its impact

The systems marked differences in the type of agrarian structure, in the degree of material satisfaction they generated and in their longer-term social and political implications.
Country-specific patterns - 3 groups

1. Poland and Yugoslavia, where the abandonment of collectivization produced various degrees of mixed (state and private) systems;

2. Albania, Bulgaria and Romania, which all achieved more or less full collectivization on the Soviet model;

3. Czechoslovakia, East Germany and Hungary, which ended with modified forms of collectives, as well as greater possibilities for investing in agriculture owing to their greater industrial development compared with the others.

Figure 2: Patterns of collectivization in Eastern Europe (Source: author)
Nigel Swain (see Figure 1). These systems had different long-term social and politic consequences, as for example in Romania and Albania, where they led to the discouragement of private agriculture, low salaries and eventually impoverishment of the peasantry (Iordachi & Dobrinca, 2009, p. 191).

The process of collectivization in Eastern European countries started in 1948-1949 and was completed at the latest in 1962, with a two year break after Stalin's death in 1953. Overall, the process proved more difficult in Eastern Europe than in the Soviet Union, where it was completed in a little over five years (1928-1933) (see Figure 2). Coercion against the rural bourgeoisie was utilized in all Eastern European states, yet in comparison to the Soviet model, their class was not fully “exterminated”. This approach caused the slower paced collectivization in these countries compared to the Soviet Union, but also a lower level of violence (Iordachi & Dobrinca, 2009, p. 187). According to each country’s specific approach, there are three main categories (see Figure 2). From these, Hungary’s model of collectivization proved out to be the most successful, where different forms of contractual production arrangements have been allowed.

<table>
<thead>
<tr>
<th>Country</th>
<th>% land farmed privately</th>
<th>% land collective farms</th>
<th>% land state farms</th>
</tr>
</thead>
<tbody>
<tr>
<td>Albania</td>
<td>5</td>
<td>74</td>
<td>21</td>
</tr>
<tr>
<td>Bulgaria</td>
<td>13</td>
<td>70</td>
<td>17</td>
</tr>
<tr>
<td>Czechoslovakia</td>
<td>6</td>
<td>64</td>
<td>30</td>
</tr>
<tr>
<td>East Germany</td>
<td>10</td>
<td>82</td>
<td>8</td>
</tr>
<tr>
<td>Hungary</td>
<td>14</td>
<td>71</td>
<td>15</td>
</tr>
<tr>
<td>Poland</td>
<td>78</td>
<td>4</td>
<td>18</td>
</tr>
<tr>
<td>Romania</td>
<td>15</td>
<td>55</td>
<td>30</td>
</tr>
<tr>
<td>USSR</td>
<td>2</td>
<td>30</td>
<td>68</td>
</tr>
</tbody>
</table>

The first column is worded so as to include both land that is privately owned and the personal plots of collective farmers, which inappropriately inflates the so-called “private” sector.


Figure 3: Proportion of agricultural land (1980)
Collectivization in Romania
The process of socialist collectivization of agriculture in Romania started in 1949 and it was completed in 1962. The reason for starting this transformation was due to the Communist leaders’ vision on agriculture, according to which small scale farming is unprofitable and unable to modernize. The aim of the project was to increase agricultural production through nationalising the agricultural sector. The collectivization process took place in 3 stages:
- **1949-1952: The first wave** - Central policies and their implementation, massive land expropriation of rich farmers (*chiaburi*)
- **1953-1956: The stagnation period** after Stalin’s death
- **1957-1962: The final wave** - Final stage leading to 94% of agricultural land being nationalized

At the beginning of the process, Romania’s level of industrialisation was very low, meaning that about 75% of the population was living in rural areas, employed in agriculture or practicing subsistence agriculture, while only 12% was employed in industry (Iordachi & Dobrincu, 2009, p. 189).

Collectivization 20% - 1958
Collectivization 50.3% - 1960
Collectivization 93.9% - 1962
1945

March 6: The establishment of a Communist-dominated coalition government

March 23: “The Law on Agrarian Reform” (expropriation of owners of over 50ha of land and redistribution to poor peasant in lots of 5ha -> destruction of large estates)

April 19: All private tractors and agricultural equipment are confiscated by the state

July 16: The State institutes a monopoly over the circulation and commercialization of agricultural products. In the next months, it also establishes mandatory requisition quotas on all agricultural products.

1946

November 19: National parliamentary elections. Bloc of Democratic Parties, controlled by the communists, claims a sweeping victory.

December 30: Forced abdication of King Mihai I. Abolition of the Monarchy and the proclamation of the People’s Republic of Romania.

1947

July 29: The government bans the National Peasant Party and the leaders of the National Peasant Party are sentenced to long-term imprisonment.

1948

February 21–23: Creation of the Romanian Workers’ Party (RWP) as a “unique party of the working class.”

April 13: The Grand National Assembly adopts the first communist Constitution of the People’s Republic of Romania.

1949

March 2–3: Decree no. 83 concerning the expropriation of the last remnants of former landed estates. About 3,000 large landowners are deported to labor camps together with their families.

March 3–5: The collectivization campaign is formally launched by the RWP’s Resolution of the Plenary of the CC.

June–August: The first collective farms are established
1950

December 12–13: The **first Five-Year Plan** is launched (1951–1955), stipulating that 62% of the country’s arable is to be collectivized by 1955, and an additional 8% is to be organized in State Farms.

1951

March 2: Decision of the RWP and the Council of Ministers for the economic and organizational consolidation of the existing GACs. Each member of a collective farm is obliged to work at least 80 days a year.

At the time, there were **1,029 GACs** containing 65,974 peasant families.

September 18: Decisions of the CC of the RWP concerning the establishment of collective farms and associations. Excesses, abuses and coercion in the collectivization campaign are openly acknowledged.

1952


1953

March 5: Death of Joseph Visarionovich Stalin

Spring: Romanian leaders temporary **halt the collectivization campaign**.

1954

End of 1954: There are **2,070 GACs** containing 178,561 peasant families and 884,194 ha. In addition, there are **2,833 associations** containing 139,125 peasant families and 315,119 ha.

1955


End of 1955: The number of **GACs** increased with 82 units, to a total of **2,152**. The number of **TOZs** almost doubles, from 2,833 in 1954 to **4,471**.

1956

June 11: Meeting of the CC evaluating the outcome of the experiment on collectivizing the Galati region. Decision to **resume collectivization** in the whole country.

July–August: **Peasant revolts** against the forced requisition of grains and against collectivization.
End of 1956: There are 2,564 GACs and 8,130 TOZs.

1957

January–August: **Intensification** of bureaucratic-administrative measures to force the peasants to give up their land, resulting in the **escalation of rural tensions**.

October 18: The official press announces the completion of collectivization in Constanta region, at a time when collectivized land encompassed only **51% of the country’s total** land and 52% of the total number of households.

1958

November 26–28: Plenary of the CC of RWP. Announcement that 1,760,000 families are enrolled in **15,723 collective farms**.

1960

March 1: Official statistics claim that **GACs possess 76.6% of the country’s arable land**.

June 20–25: Launching of the **third Five-Year Plan** (1960–1965). Announcement that **81% of the rural population** is enrolled in collective farms or associations.

1961

June 30–July 1: Report on the full collectivization of the **Bucharest** district.

September 1: The socialist sector in agriculture encompasses **82.8% of the total arable land**; collective farms own 66.6% of the total arable land.

1962

April 3: The **collectivization campaign is officially declared complete** during the Grand National Assembly. The socialist sector in agriculture encompasses 96% of the arable land of the country and 3,201,000 peasant families. Mountainous regions are exempt from collectivization.

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*Figure 4: Grand National Assembly 1962 (www.comunismulinromania.ro)*
Conclusions
In great sense, Romania’s collectivization programme was one of the most radical in the Eastern European Bloc, where the agricultural land was almost completely collectivized, except for the areas in the mountains. The program was very close to the Soviet one, from which Romania had very little independence compared to other states. Through structuring the program in such a way that alternatives would not exist and through use of extensive coercion, the system of collectivization became one of the most centralized systems of socialist agriculture, with peasants being actually forced to work in collective farms to gain their existence. Even so, the country’s collective farms turned out to be one of the least successful examples in the area, since its results were the massive impoverishment of the rural population and as consequence, their migration to urban, industrialised areas. In some parts of the country though, the new model of agriculture led to an period of economic development of farming (Iordachi & Dobrincu, 2009, p. 191).

In conclusion, even though there may be both positive and negative aspects to the process the rural society underwent, it is far more important to assess the results of collectivization through stating that the transformations in regards to property rights and economics of the rural areas have strong economic, social and demographic effects, with consequences which can still be observed and felt in the modern times.
Romania - 94% collectivized

- discouragement of private agriculture, low remuneration and the pauperization of peasantry;

- the country’s collective farms remained among the least successful in the bloc;

- the result was the gradual pauperization of rural areas, favoring the process of internal migration that accompanied industrialization;

- the failure of the socialist experiment in agriculture is made evident by the reinstatement in the 1980s of the system of requisition quotas on private production that had been abolished in 1956;

- deep economic, social and demographic effects, with long-term contemporary consequences.

Figure 5: Effects of collectivization in Romania (Iordachi & Dobrinetu, 2009, p. 217)
PART I - COLLECTIVIZATION IN ROMANIA

PAST
(before 1948)
- Private-owned agricultural land
- Subsistence farming
- Rural society
(75 % of population - farmers)

COLLECTIVE FARMS
(1949 - 1989)
- State-owned agricultural land organized in collective farms
- Villagers work the land and receive a quota of the production
- Rural society

PRESENT
(after 1989)
- Private-owned agricultural land, returned to original owners or sold
- Capitalist society and professionals, urban development

Figure 6: Evolution of agriculture in Romania (Source: author)
### 1.2 Case study: former CAP Cojasca - current situation

<table>
<thead>
<tr>
<th>Building</th>
<th>Surface</th>
<th>Original function</th>
</tr>
</thead>
<tbody>
<tr>
<td>C1</td>
<td>318 m²</td>
<td>Offices</td>
</tr>
<tr>
<td>C2</td>
<td>220 m²</td>
<td>Fertilizer storage</td>
</tr>
<tr>
<td>C3</td>
<td>162 m²</td>
<td>Iron workshop</td>
</tr>
<tr>
<td>C4</td>
<td>38 m²</td>
<td>Machine storage</td>
</tr>
<tr>
<td>C5</td>
<td>88 m²</td>
<td>Harvest storage (fence)</td>
</tr>
<tr>
<td>C6</td>
<td>364 m²</td>
<td>Harvest storage (wood)</td>
</tr>
<tr>
<td>C7</td>
<td>84 m²</td>
<td>Mill building</td>
</tr>
<tr>
<td>C8</td>
<td>176 m²</td>
<td>Harvest storage (fence)</td>
</tr>
<tr>
<td>C9</td>
<td>627 m²</td>
<td>Cereals storage</td>
</tr>
<tr>
<td>C10</td>
<td>566 m²</td>
<td>Cereals storage</td>
</tr>
<tr>
<td>C11</td>
<td>369 m²</td>
<td>Pig barn</td>
</tr>
<tr>
<td>C12</td>
<td>422 m²</td>
<td>Pig barn</td>
</tr>
<tr>
<td>C13</td>
<td>413 m²</td>
<td>Pig barn</td>
</tr>
<tr>
<td>C14</td>
<td>292 m²</td>
<td>Pig barn</td>
</tr>
<tr>
<td>C15</td>
<td>580 m²</td>
<td>Sheep barn</td>
</tr>
<tr>
<td>C16</td>
<td>49 m²</td>
<td>Shepard house</td>
</tr>
<tr>
<td>C17</td>
<td>698 m²</td>
<td>Cow barn</td>
</tr>
<tr>
<td>C18</td>
<td>667 m²</td>
<td>Cow barn</td>
</tr>
<tr>
<td>C19</td>
<td>687 m²</td>
<td>Cow barn</td>
</tr>
<tr>
<td>C20</td>
<td>634 m²</td>
<td>Cow barn</td>
</tr>
<tr>
<td>C21</td>
<td>39 m²</td>
<td>Machine garage</td>
</tr>
<tr>
<td>C22</td>
<td>70 m²</td>
<td>Machine garage</td>
</tr>
<tr>
<td>C23</td>
<td>70 m²</td>
<td>Machine garage</td>
</tr>
<tr>
<td>C24</td>
<td>91 m²</td>
<td>Machine garage</td>
</tr>
<tr>
<td>C25</td>
<td>677 m²</td>
<td>Nursery</td>
</tr>
<tr>
<td>C26</td>
<td>791 m²</td>
<td>Cow barn</td>
</tr>
<tr>
<td>C27</td>
<td>616 m²</td>
<td>Hey storage</td>
</tr>
<tr>
<td>C28</td>
<td>607 m²</td>
<td>Hey storage</td>
</tr>
<tr>
<td>C29</td>
<td>69 m²</td>
<td>Chipper building</td>
</tr>
<tr>
<td>C30</td>
<td>386 m²</td>
<td>Combined feed plant</td>
</tr>
<tr>
<td>F</td>
<td>60 m²</td>
<td>Firefighters facility</td>
</tr>
</tbody>
</table>

The Agricultural Cooperative for Production (CAP) in Cojasca was built in the period 1958-1960, during the communist regime rule as part of the socialist transformation of agriculture through the collectivization of all agricultural land. The site of the farm used to be the “headquarters” of the CAP Cojasca, with multiple barns for cows, sheep, pigs and goats, with sheds for storage of the harvest, crops, supplies, fertilizers and machinery and houses and offices for the people in charge of the farm.

Nowadays, many of the buildings are (largely) decayed and they need to be demolished or refurbished. Some buildings can be repaired and function in the current form. The materials from the demolition have the potential to be reused for a great part for the new constructions on site.
Figure 7: Functions of the buildings of CAP Cojasca (Source: author)
Figure 8: Value assessment of the CAP Cojasca buildings (Source: author)
PART I - COLLECTIVIZATION IN ROMANIA

High Value
PART I - COLLECTIVIZATION IN ROMANIA

Positive Value
Disregard Value
<table>
<thead>
<tr>
<th>Building</th>
<th>Surface</th>
<th>Original function</th>
<th>Current state</th>
<th>Value</th>
<th>Current state Description</th>
<th>Value Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>C1</td>
<td>318 m²</td>
<td>Offices</td>
<td>Damage: high (cracks, destroyed roof and walls, water infiltration)</td>
<td>Demolish, reuse materials</td>
<td>Demolish, reuse materials</td>
<td>Demolish, reuse materials</td>
</tr>
<tr>
<td>C2</td>
<td>220 m²</td>
<td>Fertilizer storage</td>
<td>Damage: high (all walls are destroyed and half of the roof has crashed)</td>
<td>Demolish, reuse materials</td>
<td>Demolish, reuse materials</td>
<td>Demolish, reuse materials</td>
</tr>
<tr>
<td>C3</td>
<td>162 m²</td>
<td>Iron workshop</td>
<td>Damage: medium (cracks in walls and roof)</td>
<td>Reparations/ demolition</td>
<td>Reparations/ demolition</td>
<td>Reparations/ demolition</td>
</tr>
<tr>
<td>C4</td>
<td>38 m²</td>
<td>Machine storage</td>
<td>Damage: low (roof needs reparations)</td>
<td>Reparations</td>
<td>Reparations</td>
<td>Reparations</td>
</tr>
<tr>
<td>C5</td>
<td>88 m²</td>
<td>Harvest storage (fence)</td>
<td>Original building destroyed</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>C6</td>
<td>364 m²</td>
<td>Harvest storage (wood)</td>
<td>Damage: medium (parts of roof and functional elements missing)</td>
<td>Reparations</td>
<td>Reparations</td>
<td>Reparations</td>
</tr>
<tr>
<td>C7</td>
<td>84 m²</td>
<td>Mill building</td>
<td>Damage: low (roof and walls need reparations)</td>
<td>Reparations</td>
<td>Reparations</td>
<td>Reparations</td>
</tr>
<tr>
<td>C8</td>
<td>176 m²</td>
<td>Harvest storage (fence)</td>
<td>Damage: low (roof needs reparations)</td>
<td>Reparations</td>
<td>Reparations</td>
<td>Reparations</td>
</tr>
<tr>
<td>C9</td>
<td>627 m²</td>
<td>Cereals storage</td>
<td>Damage: medium (destroyed wall parts, roof needs reparations)</td>
<td>Reparations/ demolition</td>
<td>Reparations/ demolition</td>
<td>Reparations/ demolition</td>
</tr>
<tr>
<td>C10</td>
<td>566 m²</td>
<td>Cereals storage</td>
<td>Damage: medium (destroyed wall parts, roof needs reparations)</td>
<td>Reparations/ demolition</td>
<td>Reparations/ demolition</td>
<td>Reparations/ demolition</td>
</tr>
<tr>
<td>C11</td>
<td>369 m²</td>
<td>Pig barn</td>
<td>Damage: low (walls and roof need reparations, missing structural parts)</td>
<td>Reparations</td>
<td>Reparations</td>
<td>Reparations</td>
</tr>
<tr>
<td>C12</td>
<td>422 m²</td>
<td>Pig barn</td>
<td>Damage: medium (walls are destroyed, roof needs reparations)</td>
<td>Reparations</td>
<td>Reparations</td>
<td>Reparations</td>
</tr>
<tr>
<td>C13</td>
<td>413 m²</td>
<td>Pig barn</td>
<td>Damage: medium/ high (walls are destroyed, roof needs reparations, many structural parts are missing)</td>
<td>Reparations/ demolition</td>
<td>Reparations/ demolition</td>
<td>Reparations/ demolition</td>
</tr>
<tr>
<td>C14</td>
<td>292 m²</td>
<td>Pig barn</td>
<td>Damage: low (walls need reparations)</td>
<td>Reparations</td>
<td>Reparations</td>
<td>Reparations</td>
</tr>
<tr>
<td>C15</td>
<td>580 m²</td>
<td>Sheep barn</td>
<td>Damage: very high (building recently crashed)</td>
<td>Demolish, reuse materials</td>
<td>Demolish, reuse materials</td>
<td>Demolish, reuse materials</td>
</tr>
<tr>
<td>ID</td>
<td>Area (m²)</td>
<td>Type</td>
<td>Damage Description</td>
<td>Repair Action</td>
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<td></td>
</tr>
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<tr>
<td>C16</td>
<td>49</td>
<td>Shepard house</td>
<td>Original building destroyed</td>
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<tr>
<td>C17</td>
<td>698</td>
<td>Cow barn</td>
<td>Damage: medium (walls need repairs, cracks and water infiltration)</td>
<td>Reparations</td>
<td></td>
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</tr>
<tr>
<td>C18</td>
<td>667</td>
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<tr>
<td>C19</td>
<td>687</td>
<td>Cow barn</td>
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<tr>
<td>C20</td>
<td>634</td>
<td>Cow barn</td>
<td>Damage: low (walls need finishing, some structural parts missing)</td>
<td>Reparations</td>
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<tr>
<td>C21</td>
<td>39</td>
<td>Machine garage</td>
<td>Damage: medium (roof destroyed, cracks in walls)</td>
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<tr>
<td>C22</td>
<td>70</td>
<td>Machine garage</td>
<td>Damage: high (roof and walls destroyed)</td>
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<td></td>
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<tr>
<td>C23</td>
<td>70</td>
<td>Machine garage</td>
<td>Damage: high (roof and walls destroyed)</td>
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<tr>
<td>C24</td>
<td>91</td>
<td>Machine garage</td>
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<tr>
<td>C25</td>
<td>677</td>
<td>Nursery</td>
<td>Damage: medium (cracks in walls, walls need repairs, some structural parts missing)</td>
<td>Reparations</td>
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<td>C26</td>
<td>791</td>
<td>Cow barn</td>
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<td>Reparations</td>
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<tr>
<td>C27</td>
<td>616</td>
<td>Hey storage</td>
<td>Damage: medium (structure is losing stability)</td>
<td>Demolish, reuse materials</td>
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<td></td>
</tr>
<tr>
<td>C28</td>
<td>607</td>
<td>Hey storage</td>
<td>Damage: medium (structure is losing stability)</td>
<td>Demolish, reuse materials</td>
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<tr>
<td>C29</td>
<td>69</td>
<td>Chipper building</td>
<td>Damage: high (destroyed walls and roof)</td>
<td>Demolish, reuse materials</td>
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<tr>
<td>C30</td>
<td>386</td>
<td>Combined feed plant</td>
<td>Damage: medium (walls and interior are completely destroyed)</td>
<td>Reuse</td>
<td></td>
<td></td>
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<tr>
<td>F</td>
<td>60</td>
<td>Firefighters facility</td>
<td>Damage: medium (cracks in walls and roof)</td>
<td>Demolish, reuse materials</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*Figure 9: Detailed value assessment of the CAP Cojasca buildings (Source: author)*
2.1 General geographic and climatic aspects - Cojasca

*Figure 10: Map of Romania and its landscape*
COJASCA, ROMANIA

Altitude: 130-135 m
Landscape type: Plain (Wallachian Plain)
Soil: Chernozem (black-coloured soil; high percentage of humus (7% to 15%) and of phosphoric acids, phosphorus and ammonia; very fertile and produces a high agricultural yield)

Vegetation: Forest steppe
(-Temperate-climate habitat composed of grassland interspersed with areas of woodland or forest
- Downy and grey oak)

Climate: Temperate-continental (hot summers; long, cold winters; 4 very distinct seasons)
- Average temperature:
  summer 22 - 24 °C, winter -3 - -5 °C
- Low average rainfall: 450-600 mm/ year
- Frequent droughts in summer

Availability of materials
Breaza: 70.4 km - Stone quarry
Dobra: 13.5 km - Timber workshop (oak from 5km away)
Bilciuresti: 8.6 km - Aggregate (ballast, gravel, etc) extraction from Ialomita river
Cojasca: 0.5 km - Clay extraction from Ialomita river
Cojasca: 0.2 km - Straw and hey bale press from local production
2.2 Vernacular architecture in Southern Romania

Even though from the earliest times the most common materials used in Romania for buildings, furniture and clothing were materials that were fragile and would deteriorate over time (such as wood, earth, bricks, straw, cloth, wool, etc.), characteristic features and traditions can be distinguished that have survived from generation to generation to make up traditions, folk art and craftsmanship that are specific to Romania. Traditional Romanian arts, decorations and craftsmanship did not form out of nowhere, but through continuously using and enriching elements which can be traced back to ancient times. These elements are generally largely related to the geographic position, the landscape, the climate, the religious aspects and the daily needs and activities of each particular area.

From the earliest times until around the half of the XIX century, when urbanisation starts growing, Romania had a predominantly rural population, almost exclusively involved in agriculture and shepherding, therefore the main form of settlement was the village. The aspect and organisation of the village structure largely reflects these two main occupations and therefore two main types of villages can be distinguished: one with an agricultural character, the other with a pastoral character (Ionescu, 1957, p. 10). The appearance and features of the village was also greatly influenced by economic, geographic and demographic aspects. Therefore, in mountain areas the main settlement was the village with scattered houses and almost exclusive pastoral character, in hill areas the village with row houses and both agricultural and pastoral character and in plain areas the well settled village with dense, closely connected houses and households, with a mainly agricultural character. The villages in the hills and in the plains can also present variations in the forms of a valley village, a road village or a geometric one. For the purpose of this research, I will only present and discuss in further detail the vernacular architecture of the plain village, its characteristic settlement forms, the used materials and techniques of construction.
The village characteristic to plain areas usually has a compact cluster appearance, with houses arranged along its irregular streets and alleys. The size and borders of the village are usually determined by the property limits of rich peasants, who would always strive to keep as much available land for agricultural purposes. Some of its characteristics are: irregular placement of settlements, winding alleys, large yards and gardens with trees around the houses.

Figure 11: Village in plain area (Ionescu, 1957, p. 15)

The house
Even though there are variations in the used materials and techniques, geographic, climatic and living conditions, traditional Romanian houses mainly follow a general plan arrangement of unitary form and the volume of a rectangular prism. Generally, all houses have on one or two sides a porch.

The earliest dwelling typology is the hut, with some examples still in use today (Figure 12). Typically, it would be either composed of a living room and a passage with a cooking area, either of three rooms, with an entrance in the middle when the kitchen would be placed. More evolved versions of this type include up to 5 rooms, arranged in a cross or T-shape. The house is usually dug in the earth. The interior walls are wattle-and-daub walls, while the exterior walls are built from cob and covered with wooden planks. The roof is also built from wood and covered with a thick layer of rammed earth and reed (Ionescu, 1957, p. 21). The versions to follow the hut dug in the earth are the settlements above the ground.
Although it presents no architectural value, the cottage is a basic settlement, built by shepherds as temporary shelter in the mountain areas, is the first building type known in Romania above ground level. Many elements of the traditional houses have been borrowed from this type of settlement. In what concerns the construction, this shelter with one room (sometimes two/three) is built from timber beams and posts and covered by a roof made from timber beams and shingles or reed.

The first archaic traditional houses above the ground, even though they would borrow some elements from the cottage, would always exceed the limits of minimum functionality and the form, the colours and decorations show the peasant’s wish to enrich its house. These houses would typically have one room only and adjacent spaces for storage.

The next used typology is the archaic dwelling with two rooms (living + storage) and separate entrances.

Figure 12: Hut in Castranova village, Craiova region (Ionescu, 1957, p. 22-23)
The latest and most widespread archaic dwelling type is the **central passage house**, with two or three rooms. Most commonly, the central or smallest room is the entrance and kitchen of the house, while the side rooms are the living spaces. In the Southern part of Romania, the most widespread variant is the one with two rooms (Figure 14).

In later stages, other adjacent spaces were added to the structure of the house, such as the barn and the stable, leading to a more **elongated passage house**, with a long facade along which the different rooms or spaces were placed. Variations started appearing also in the roof typologies, where along the traditional hip roof, very high gable roofs started being built (Ionescu, 1957, p. 48).

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**Figure 13:** “Badanci” house, Cornesti village, Craiova region (Ionescu, 1957, p. 29)

**Figure 14:** “Albu” house, Fierbintii de Jos village, Bucharest region (Ionescu, 1957, p. 32)
In following stages, the development of settlement typologies in the plain areas of the South of Romania remained steady, while in other landscape areas they developed further and later on they started being used here as well. In the hill and valley regions, a typology of houses was built which were raised at least 1 meter above ground level, with living spaces and a porch upstairs and a storage for tools and/or supplies downstairs (Figure 15). In some cases, the upper level would be cantilevered. These houses were built entirely out of wood, sometimes with the exception of the foundation and base, which were built in stone cladding (Ionescu, 1957, p. 49). This later led to the two-storeyed houses, largely widespread in the Southern area of the country, but with the same functionality as its predecessor: upstairs - living, downstairs - storage. These houses were built completely in wood and sometimes (completely) plastered.

The type of house that derives from these is the two-storeyed patio house with three or more rooms.

**Figure 15:** Ioana Sincai’s raised house, Catunul Popii village, Pitesti region (Ionescu, 1957, p. 50)

**Figure 16:** Ion Popescu’s two storey house, Bradiceni village, Craiova region (Ionescu, 1957, p. 60)
The next typology was the **boyar house**, belonged to a wealthier class of people. Placed in the middle of a large yard with trees and surrounded by other small constructions (kitchen, barns, etc.), this two volumes, two-storeyed house follows on the footsteps of traditional patio houses. The ground floor was reserved for storage of goods, while the upper floor would be split into 2/3 bedrooms and a living room with a large open porch in front. This is the first house typology to feature, in a separate tower, a rudimental toilet. Ornamentation becomes rich.

A house typology of the wealthy specific for the region of Oltenia, Southern Romania, is **kula - the fortified house**, a house evolved from the boyar’s house, but initially with aspect of citadel and defensive purposes. The aspect of this house resembles the one of a square tower (kula - tower in Turkish). The arrangement of rooms on the upper floors resembles the boyar’s house. The ground floor, where the goods are stored, has few and small openings, reminding of its citadel-like purpose. This typology slowly evolved to become larger, more and more open and with two/ three storeys to become the **traditional house**, the typology closest to modern

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**Figure 17: Dinu Costea’s patio house, Traisteni-Cricov village, Ploiesti region** (Ionescu, 1957, p. 50)
PART II - ROMANIAN CONTEXT: HISTORY & ARCHITECTURE

The hut
(dug in the ground)

The archaic house
(one room only)

The archaic house
(two rooms, separate entrances)

The passage house
(two/ three rooms)

Cob, wattle-and-daub, reed, timber planks and beams, wool

Timber construction, cob, shingles/ reed

Timber construction, cob, shingles/ reed

Timber construction, cob, shingles/ reed

Figure 18: Evolution of Romanian vernacular architecture (Ionescu, 1957, p. 22-227)
**The elongated passage house**  
(two/ three rooms + barn, shed)

**The half-raised house**  
(about 1m above ground, storage downstairs)

**The two-storeyed house**  
(two levels, storage downstairs)

**The patio house**

Timber construction, cob, shingles/ reed

All timber (sometimes base in stone)

Timber, plaster

Timber, plaster (sometimes base in stone)
PART II - ROMANIAN CONTEXT: HISTORY & ARCHITECTURE

- **The merchandiser house**
  - (half house, half + upper floor shop)
- **The boyar house**
- **Kula - the fortified house**
- **The traditional house**
  - (central plan, 2/3 storeys, multiple rooms)

Timber, plaster  
Timber, stone, plaster  
Stone/ brick, timber, plaster  
Stone/ brick, timber, plaster

*Figure 18: Evolution of Romanian vernacular architecture (Ionescu, 1957, p. 22-227)*
Construction materials and techniques

Looking at Romanian vernacular architecture, it can be observed that throughout time the peasant has been both architect and constructor. By using locally available materials and adapting the architecture of the buildings to the local conditions, clear characteristics can be distinguished in the used materials and techniques in Romanian architecture. In the plain areas, the two most widespread types of constructions are those of: timber structure, with wattle-and-daub walls and shingles/straw roof and rammed earth/cob houses with straw/reed roof.

The materials

The main materials that have been used are: wood, stone, earth and brick.
- Wood: has been used in all forms, shapes and situations and is the only material that was used alone for complete construction, for structure, ceiling, roof, balustrades, floors, roof, walls, windows and of course furniture. It has been used in many different ways, from rough trunks, to peeled ones, squared beams, planks, shingles to the finest sculpted elements.
- Stone: used most commonly in the form of river boulders or gravel, laid in earth, mainly for foundations, bases and underground construction of walls.
- Earth: the cheapest and most widely available material, has been used mixed with straw and water, as cob or as rammed earth. Its applications have also been very varied, in walls, roofs, floors and interior elements.
- Brick: starting from the beginning of the XXth century, brick started being manufactured from a yellowish type of earth, rammed and baked, near by cities and urban areas. It was then used mainly in walls (Ionescu, 1957, p. 125).

The construction techniques

In what concerns construction techniques, there have been two main technical issues which needed to be solved - that of the support structure (walls, beams, posts) and the supported structure (ceilings, vaults, roofs).

Walls
- Wooden walls: Different systems have been developed throughout time in order to connect the different wooden elements. The elements were either peeled raw wood trunks or four-faced beams of different thicknesses.
- Earth walls: Either rammed earth walls, which were built with the help of a wooden form-work and would have thicknesses of around 400-600 mm or cob walls, a technique which was widely spread. Both types have proved very good results in what concerns durability and protecting against extreme temperatures.

- Stone walls: Mainly used in the underground constructions, for foundations and bases, for the interior walls close to the chimney and rarely used as exterior walls. The stones were laid in an earth mortar bed to provide stability.

- Wood and earth walls: Mainly wattle-and-daub technique, of timber posts and roof belts and knitted branches around the posts, on which a filling of adobe would be laid.

- Wood and brick walls: Much more recent constructions, they resemble the wood and earth walls in construction principles, with the same wooden skeleton, but with an infill of bricks instead of adobe.

Most wooden houses, and especially the archaic ones, did not have a foundation. The walls would be constructed on a belt made out of wooden beams and placed on large boulders dug in the ground, in order to keep moisture away from the wood. The floor would be made of gravel and rubble, topped with a layer of rammed earth.

**Beams**

The beams have generally been made out of timber, both main and secondary systems. Their ends usually are extended to the exterior, in order to support the eaves of the building.

**Posts and pillars**

Usually made out of timber, most often hard wood such

*Figure 19: Timber beams facade of Ion Tanase’s house, Cimpu-lui-Neag village, Huneadoara region (Ionescu, 1957, p. 126)*
as oak, ask or walnut, they support the weight of the entire construction and transfer it to the foundation or the belt under the house.

**Ceilings and vaults**

Generally made of timber, it consists of thick wooden planks laid on the system of beams and connected to each other. Sometimes, on top of them a layer of mud would be laid.

**Roofs**

Most common type of roof is the hip roof, with 4 faces. They are always built on a structure of timber and covered, in the plain areas, with straw or timber shingles.
3.1 Energy efficiency and embodied energy in constructions

Sustainability means “meeting the needs of the present without compromising the ability of future generations to meet their own needs” (Bruntland, 1987). One of the biggest challenges of the building sector at the moment is to take more sustainable steps for the present and future and this refers directly to the energy usage of this sector for the whole building mass. Nowadays, this sector consumes about 40% of the total energy used by the EU and US, while the EPBD Recast adopted by the European Parliament and the Council of the European Union in 2010 requires all new buildings at the end of 2020 to be nearly zero energy (Brophy & Owen Lewis, 2011, p. 36). The energy used nowadays comes mainly from fossil fuel, increasing the total production of green gas effect. This must change in the future to renewable energy sources.

The first step in order to design towards energy efficiency is identifying the main sectors in which the building industry uses energy, in order to then try to decrease this usage. Simply said, these two sectors are the construction and the operational phases of buildings.

The operational phase, or the use phase, comprises the energy consumed by the users of a building to achieve comfort conditions, through factors such as ventilation, lighting, acoustics, building services, etc.

The construction phase is often underestimated in terms of energy consumption, even though it greatly contributes to the total amount of energy used by a building. This energy is described as “embodied energy” and it comprises the total energy used for a product’s life-cycle, to extract or quarry a material, to cut and process it, to manufacture the finite product and transport it to the location of the building site, but also the energy used by builders through machinery to assemble/construct the building. The embodied energy of a building can be the equivalent of many years of operational energy. The lifespan of a building also affects the level of embodied energy, as a building that requires frequent maintenance or renovation will have a higher total level of embodied
A building constructed with low-impact materials with low levels of embodied energy won’t necessarily be sustainable if in the operational phase the energy demands are high in order to achieve comfortable living conditions. Similarly, a building which uses very low energy levels in the operational phase isn’t necessarily energy efficient if the materials used in the construction have very high embodied energy and a strong negative impact on the environment through their production. Only a balance between the two phases and reducing the amount of energy used in each one of them can lead to achieving energy efficiency.

In this chapter I would like to present and discuss a series of low-impact materials, generally with low levels of embodied energy, which can contribute to a significant reduction of energy usage in the construction phase and, if combined in a passive design, can generate energy reduction in the operational phase too.
3.2 Low-impact building materials

When looking to minimise environmental damage and carbon footprint of constructions, it is important to inform ourselves as architects about the benefits of using low-impact materials. These materials usually have one of more of the following characteristics: they are **locally available**, **renewable**, **natural**, **biodegradable** or have **low embodied energy** level.

Natural materials are materials which are endlessly renewable and for the greatest part biodegradable. Under this category, the following materials can be named: hemp/ hemp-lime/ hempcrete, hemp fibre insulation, flax, straw and straw composite boards, sheep’s wool, bamboo, cork, wood, timber composites and wood fibre, solid timber (Wooley, 2013, p. 21).

Low-impact materials refer more specifically to materials which are not per se renewable, but due to their large scale availability, they are effectively inexhaustible. Here, earth and lime can be named (Wooley, 2013, p. 23).

It is also important to look at vernacular architecture when making a selection of materials, as the answers for a more sustainable architecture could be found in a thorough look in the past (Mileto et al., 2015, p. 343). In part II, section 2.2 of this paper, it has been concluded that in Romanian vernacular architecture, more specifically in the Southern plain areas of the country, the main materials that have been used are earth, straw, timber, stone, lime and brick, due to their availability. Since a great deal of the embodied energy of a material is generated by transport costs, this constitutes an important factor for the selection of materials to be discussed in this paper.

The materials to be studied will therefore be divided into three groups, according to how many of the characteristics named above they accomplish.  
1. **In depth study** group (comply with most requirements)  
2. **Observation** (partly comply with requirements)  
3. **Comparison** (do not comply with requirements)  
The first group will be discussed in detail in the following pages, the second one will be described briefly and the third one will be only used for comparison (Figure 19).
Figure 23: Characteristics of low-embodied energy materials (http://www.bristol.ac.uk/eng-systems-centre/idc/projects/natasha-watson.html)
a) Biodegradable/ renewable materials

- Straw
- Wood
- Sheep wool
- Flax
- Cork
- Hemp
- Hempcrete

b) Effectively inexhaustible

- Earth
- Rubble
- Lime

C) Locally available

- Straw
- Wood
- Earth
- Stone
- Aggregates
- Rubble
- Reclaimed brick
**d) Low-embodied energy materials**

<table>
<thead>
<tr>
<th>Material</th>
<th>Description</th>
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<tbody>
<tr>
<td>Straw</td>
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<tr>
<td>Wood</td>
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<td>Stone</td>
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<td>Aggregates</td>
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<tr>
<td>Rubble</td>
<td></td>
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<tr>
<td>Hempcrete</td>
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As the main goal of this research is to determine how can a farm be redeveloped in a way which will enhance its energy efficiency and since the materialisation of the buildings determines their level of embodied energy, only certain materials will be chosen from this list to be studied in detail. There are a few main factors which greatly contribute to a building's energy efficiency in what concerns its materialisation: - the density of the materials
- the level of embodied energy of the materials
- the lifespan of the materials
- the required maintenance of the materials

Since a material's level of embodied energy is directly influenced by its availability and transportation will increase this level, this item plays an important role in the selection. A material's lifespan and maintenance will be a key factor at the end of this research and will be discussed in the conclusion chapter when comparing different materials. Therefore, the materials chosen for group 1. **In depth study** are: straw, earth, wood, stone, hempcrete.

The materials for group 2. **Observation** are: rubble, sheep wool, flax, cork, hemp.

The materials for group 3. **Comparison** are: brick, steel, concrete, aluminum, mineral wool.
3.2.1. Straw

General characteristics
Straw, or what is usually classified as waste after harvesting the grains from the plants, is the part of the plant structure between the root and the actual grain. It can come from almost any type of grass, but the one most suitable in constructions come from grains. The straw has typically a strong, circular structure, it contains components such as cellulose, ligning and silica, has bending capabilities, but at the same time a high tensile strength (King, 1996, p. 95). The most suitable grains from which straw can be harvested to use it in constructions are wheat, spelt and rye, as opposed to barley and oats, which are not so stable (Minke & Mahlke, 2005, p. 19). Reed is most suitable straw to use for thatched roofs.

Advantages and limitations
+ Straw is one of the most sustainable building materials, given its low-impact on the environment, biodegradability (natural recycling), its low embodied energy (mainly from the fuel used for harvesting) and subsequently its low carbon footprint production.
+ Due to its high insulating properties, straw constructions will save a lot of energy also in the use phase of the building. Houses can be built according to Passive house principles, which have annual heating energy consumption of at most 15 kWh/ m2 (Minke & Mahlke, 2005, p. 11).
+ Straw has been used for hundreds of years and has proven very durable if it receives appropriate maintenance.
+ It is also a renewable material, as it grows every year, using water and sun. It can become fireproof if sufficiently compressed or plastered.
+ It is widely available, especially in agricultural areas with fertile grounds where cereals are produced.
+ Due to its silica content insures, straw rots very slowly.
+ Low level of craftsmanship required in order to build with it. The material is great for community projects, self-taught builders and green building enthusiasts. It is also
a low-cost material, as long as transport to the site is not needed.

+ The costs of construction can be lower than those of a building with modern building materials.

+ Straw walls can provide a healthy living environment, enhancing the indoor air’s quality, due to its breathing capabilities.

- A few of the drawbacks of building with straw mainly concern the preservation of its qualities and form. When preparing the straw to be used in a construction, all grain heads must be removed, as these constitute food and may attract rodents and other bacteria or will rot if kept moist. However, if baled with a density of at least 90 kg/m³, no rodent can damage the straw.

- As straw is susceptible to moisture, constructions built with this material always need to have “a good hat and a good pair of boots”, meaning a roof with an overhang, which will provide weather protection for the walls and draining foundation and base, which will keep underground water from infiltrating in the rest of the construction. The moisture content of the straw should be lower than 15% and a vapour barrier should be installed on the inside (Minke & Mahlke, 2005, p. 12). Both clay and lime plasters can deal with the humidity, due to their capability to absorb excess moisture (Jones, 2015, p. 26).

- Together with earth, these two materials are very flexible and somewhat imprecise.

Figure 24. Construction of a new straw bale house (http://www.solarhaven.org)
a) Straw bales

**Definition**
Compressed blocks of straw, bound with steel wire or polypropylene twine and stacked like masonry (King, 1996, p. 11).

**Production technique**
In order to produce straw bales, there are several steps that need to be taken (these steps also have an influence on the embodied energy of the final product):
- preparation of the field with the use of machinery
- planting, watering and fertilizing the crops
- harvesting of the crops, while the straw gets left on the field
- baling the (dry) straw using a bale press
- storing the straw in a dry location, as moist straw bales can cause decomposing under the plaster layer (Offin, 2010, p. 36).

The straw bales are most commonly produced in three sizes: small: 32-35cm x 50cm x 50-120cm, medium: 50cm x 80 cm x 70-240cm and jumbo 70cm x 120cm x 100-300cm. The most common size is the medium. They are pressed to achieve a density between 80-120 kg/ m³ and tied with two or three wires or twines, depending on their size. The larger sizes are usually only used for load-bearing structures and have densities between 180-200 kg/ m³. They can be used for larger buildings, such as warehouses (Minke & Mahlke, 2005, p. 19).

**Application**
Walls, roofs, floors, insulation material

**Walls**
When building straw bale walls, there are two main construction systems: non load-bearing and load-bearing walls. Also, they can be used as exterior or interior
insulation material to retrofit an existing building, by fixing them to the existing walls or by supporting them through a new structure.

In the **non-load bearing construction system** the walls are made of a usually timber post-and-beam frame structure with an infill of straw bales. The straw bales can be placed on the interior, exterior or between the timber structure (Figure 25). In this system, the structural task is performed by the timber frame and not by the straw bales. However, the reinforcement structure can be made of timber, steel or reinforced concrete (Minke & Mahlke, 2005, p. 23).

![Figure 25. Non load-bearing straw bale wall system (Minke & Mahlke, 2005, p. 22)](image1)

![Figure 26. Load-bearing straw bale wall system (Minke & Mahlke, 2005, p. 21)](image2)
In the **load-bearing straw bale wall**, the forces are transmitted to the foundation directly via the straw bale structure or through its reinforcement (Figure 26). The bales are stacked on each other, resembling masonry. However, this system limits the height of the construction to one storey. This system also requires the use of a ring beam on top, as a connection between the wall and the roof, to ensure even distributions of the forces throughout the wall. Even though this system is far more economic, due to its limitations it is not widely used today (Minke & Mahlke, 2005, p. 22).

**Roofs**

Straw bales can be used to efficiently insulate a roof, whether it is a standard or a green roof. In both cases, the design has to be carefully planned, so as the bales match the dimensions of the timber structure and its rafters. When building a green roof, special care needs to be taken to keep the straw bales dry, through correctly placing water- and root-proof barrier membranes on them.

**Floors**

Straw bales can also be used to insulate floors, provided they are sufficiently protected from ingress and formation of moisture. This can be achieved by elevating the floor and creating a ventilated space under it. This can be done in an economic manner through the use recycled timber pallets or car tires (Minke & Mahlke, 2005, p. 27).

![Figure 27. Green roof with straw bales insulation build up (up left), recycled timber pallets and tires floor with straw bales insulation (up right), straw bales wall and floor build up (down right) (Minke & Mahlke, 2005, p. 26-31)]
b) Straw panels

**Definition**
Manufactured blocks of compressed straw in a wide range of densities, strengths, finishes (King, 1996, p. 11).

**Production technique**
These panels are produced without the use of glue. When they were first produced in 1920 in Switzerland and France (Solomite), they were tied with wire. Now they are simply produced by pressing them under the use of heat and then coated with cardboard (Stramit). Their main purpose and application is in interior elements, such as partition walls, insulation or plaster base. The standard dimension of a panel is 120cm x 360 cm. Their strength is similar to that of chipboard panels and have thicknesses of up to 20 cm (Minke & Mahlke, 2005, p. 20).

Due to the manufacturing process, straw panels have a much higher embodied energy level than straw bales. The products are patentable and therefore there is a wide variety of types:
- low-density: these are non-structural elements, rather lightly bound and only for decorative or fencing application.
- medium-density: rather strong elements, they follow up the Stramit manufacturing system and they are the most widespread type. On the two sides they have cardboard layers, attached with adhesives. The straws have a direction, they are not randomly oriented.
- high-density: these products are highly similar to wood fibre panels, due to their composition of chopped-straw or longer-length stems, held together by adhesives.
- sandwich panel: straw is not the only material in their composition, they are very strong products with OSB structural facings (King, 1996, p. 136).
c) Thatch

**Definition and application**
Straw layered as roofing material.

**Production technique**
In the earliest times, thatched roofs were made from any wild vegetation (reeds, rushes, broom, heather), until the extensive cultivation of barley, wheat and rye straw and, most commonly used nowadays, reed, which is the most durable material for thatching (Rural Development Commission, 1988, p. 1). The material used for thatching has been closely related to the local building materials available. Long straw thatch is preferable for this roofing technique. The straw has a direction, as bunches of straw are tied together to form layers. Several bunches of tied straw are placed next to each other on the roof and secured into position to the framework on top of the structure of the roof. An overhang of half the length of a bunch is provided. The sides of the roof are eventually cut to an even length, still providing an overhang of at least 100 mm of the roof (Rural Development Commission, 1988, p. 44). Depending on the type of straw used for thatching, the layer of straw will usually have a thickness of the coat between 200 and 450 mm. Eaves can be installed in 3 ways: A. Close board raking type, B. Close boarded soffitte, C. Open eaves (Figure 28).

*Figure 28: Eaves treatment* (Rural Development Commission, 1988, p. 224).
d) Insulation

**Definition and application**
Loose or bundled straw to fill cavities and holes in any other type of wall, floor or roof (King, 1996, p. 11).

**Production technique**
This is a very straightforward technique. A usually timber structure laid on the floor is filled with loose straw, which is compressed and aligned to form an insulated floor. As in the case of all other systems using straw as building material, special attention in design is required to keep the straw dry and away from moisture.

e) Leicht lehm

**Definition**
Also known as straw-clay or light clay: coating loose straw with clay slurry (King, 1996, p. 11).

**Production technique and application**
On a post-and-beam timber structure, commonly with an OSB board on one side, a mixture or loose straw and clay slurry is applied and compressed with the use of another board on the open side. This system provides insulation and can be finished with an earth or lime render to provide weather protection.
3.2.2. Earth

**General characteristics**

Earth is one of the oldest building materials known to mankind, with constructions discovered that date back to 8000-6000 BC (Russian Turkistan - mud-brick houses). It has been always used mainly in hot-dry areas and moderate climates. Nowadays, one-third of the population still lives in earth houses, given the availability, costs and technique required for construction (Gernot, 2000, p. 9). Especially in developing countries, this material is the only one able to provide shelter through the use of local materials and unskilled workers.

As it is a largely widespread material, available in almost all regions of the world, it can usually be extracted directly from the site. Given the current uprisings concern for environmental protection and energy and cost effective constructions, earth is gaining nowadays more and more interest as a building material. New techniques are being developed in order to revive this natural material and demonstrate its value.

- Earth is not a standardized building material
- The earth mixtures will shrink after drying
- Earth is not a water-resistant building material
- Earth can balance interior air humidity
- Earth can store heat
- Earth reduces environmental pollution and saves energy in the construction phase
- Earth is reusable
- Earth saves material and transportation costs
- Earth preserves timber’s and other’s organic materials qualities that come in contact with it
- Earth absorbs polluting agents (Gernot, 2000, p. 12)
Figure 29: Life cycle of earth as building material (Schroeder, 2016, p. 27)
a) Rammed earth

**Definition and application**

Rammed earth is mainly used for building walls and it is a type of unbaked earth. It can also be used for floors, roofs and foundations, yet its use is not as extensive for these building parts (Joe et al., 2005, p. 2). This material is a mix of inorganic sub-soil, aggregates (clay+silt - min. 20-25%, max. 30-35%; sand+gravel - min. 50-55%, max. 70-75%), water and possible additives (Portland cement, natural fibres), mechanically compacted into forms that are then stripped off (Bruce, 1996, p. 9) (Sustainable Building with Earth, pg. 157).

**Production technique**

In order to create rammed earth walls, layers of 100-150 mm of loose moist soil are placed in formworks and then manually or pneumatically compacted, to become layers of 50-100 mm. The typical wall is 300-450 mm thick, but can be adjusted to design requirements. Due to compression of the successive layers the finished wall has an appealing appearance (Joe et al., 2005, p. 9).

**Footing and base details**

Given rammed earth’s susceptibility to water damage, the construction of a plinth as part of the footing detail...
is a must. This plinth must be at least 225 mm high and constructed of concrete, limecrete, rubble masonry, cement-stabilised earth, etc. This will ensure protection from water ingress and damage. A damp-proofing barrier is also required to prevent rising damp (Joe et al., 2005, p. 64).

**Roof protection**
The roof is the main building element to protect the rammed earth wall from direct water. An overhang of at least 400 mm will limit the walls direct exposure to precipitation, unless the wall in cladded, in which case the overhang must be adapted to the specific cladding material (e.g. timber) (Joe et al., 2005, p. 69).

**Openings**
Openings in rammed earth walls must follow certain guidelines and must be planned carefully beforehand, as they cannot be easily cut out of the solid wall, given its high density and strength. The easiest way to form an opening in such a wall in by extending the opening to the full size of the wall. Nevertheless, partial-height openings can be created through the use of incorporated lintels (solid timber, concrete, stone, etc.) or using boxed shuttered forms (Joe et al., 2005, p. 51).

![Figure 31: Roof detail (Joe et al., 2005, p. 69)](image1)

![Figure 32: Openings (Joe et al., 2005, p. 51)](image2)
Advantages and limitations

+ As rammed earth is a natural material, it can greatly contribute to a sustainable construction, due to its low embodied energy and low carbon dioxide content, in addition to no processed additives in its composition.
+ At its end-of-life, the main material - the sub-soils - can be re-used, recycled or disposed, due to the inexistent risk of pollution or contamination of the environment. +
+ Due to its abundance, the material can be considered inexhaustible, even though by a strict definition it is non-renewable. The main source of embodied energy for rammed earth is constituted by its transportation. If the material can’t be extracted on site, the energy used to transport the raw material will decrease its sustainable value.
+ Another advantage of earth walls is their ability to regulate the internal relative humidity to values between 40% and 60%, improving the quality of the air in the interior of a building (Gernot, 2000, p. 54).
+ If it is compared to other types of earth constructions, rammed earth has a clear advantage in what concerns the strength and stiffness of the building elements, being able to act as both load-bearing and non-loadbearing (Joe et al., 2005, p. 13).
+ Provided the weather is favourable, the speed of construction with this material is rather high and the walls require little attention after removal of the framework.
+ On the other hand, there are a few drawbacks to using rammed earth as a construction material, out of which the most important is its durability - due to its decay in the presence of water. This aspect can be extended by proper planning, design and construction and attentive maintenance of the rammed earth walls throughout their service life. This building material is not suitable for sites likely to get flooded, as it can’t sustain this type of damage. A correct overhang of the roof will protect the exterior walls from direct rain or water. Nevertheless, rammed earth walls are most suitable as interior walls.
- Even though rammed earth has high thermal mass storage qualities, its thermal resistance is poor. Walls as thick as 700 mm can provide the minimum insulation conditions required by current building regulations (Joe et al., 2005, p. 15).
- Another disadvantage is the complexity of the in-situ construction, which imposes particular demands on the design and the construction. The walls are constructed in
form-works (movable or static), which must be assembled and disassembled multiple times on site and they require a lot of space for storage and installation. The form-work also adds to the consists of the construction of this type of wall, making up for as much as 25-50% of the total costs and also of the construction time (Joe et al., 2005, p. 47).

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b) Gunearth (gunned earth/ pise)

**Definition**

Another type of rammed earth is stabilised rammed earth, in which Portland cement - as stabilising agent - is added in order to improve the material’s physical characteristics (Joe et al., 2005, p. 9).

**Application**

Similar to rammed earth, only it is applied pneumatically through hoses using adapted gunite.

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Figure 33: Chapel of Reconciliation, Berlin. Architect: Sassenroth & Reitermann Photography: Alan Wylde, 2014
c) Adobes (mud bricks)

**Definition and application**
Adobe bricks are unfired bricks of clay with possible addition of sand and straw, usually laid in mud (adobe) mortar (King, 1996, p. 9). Their application is usually for walls, floors, vaults and domes.

**Production technique**
Moist earth is being either fitted or thrown in a form-work, which is later on removed and the bricks are left to dry in the sun. The moulds are usually made from timber. After the moulds are filled, the surface of the bricks can be smoothed with the help of a timber piece, a trowel, a wire or by hand. Nowadays, hydraulic presses have been introduced to facilitate the process and their advantage is that they can produce bricks with a much lower water content, despite the fact that that their rate of production is at most half compared to the traditional method (150-200 bricks/day compared to 500 bricks/day) (Gernot, 2000, p. 70). Fully automatic presses can reach up to 1500-4000 bricks/day, yet they are only economic if used extensively and for a long time.

Earth bricks are usually laid in mud (adobe) mortar or hydraulic lime mortar, in layers that are thinner than usual in order to avoid shrinkage probability. The mortar should also contain a percentage of sand, in order to avoid the formation of shrinkage cracks and a clay content between 4%-10% (Gernot, 2000, p. 73). Pure cement mortar is not an suitable mortar, due to its rigid characteristics. Another option in order to stack the adobe bricks is to not use any mortar at all, but just water the edges of the bricks and stick them together. However, this procedure requires a more skilled worker in order to guarantee precision and quality of construction.

In what concerns finishing an adobe brick construction,
there are several options. Plastering is not advisable, since it will limit the earth’s capability to regulate internal air humidity. However, the bricks can either be smoothened by watering them or can be given a wash of slurry stabilised earth.

d) Compressed blocks

**Definition**
Similar to adobes, only rammed into the molds for greater density, strength and durability.

e) Earth-filled tyres

**Definition**
Structures formed by stacking used tyres, packing the centres with stabilized or rammed earth.

**Production technique and application**
Another way of building walls with earth is by collecting discarded car tires, filling them with earth or rammed earth and layering them to the desired wall height. Michael E. Reynolds, in buildings in New Mexico, USA would only fill the top tyre with concrete to which a wooden ring anchor was fixed (Minke, 2000, p. 126).
f) Cob and Wattle-and-daub

**Definition and application**
Wall construction that in one way or another involves laying and packing dense clots of mud, often with a reinforcing of sticks (wattle) or straw reinforcing (most common form of residential construction along adobe) (King, 1996, p. 9).

**Production technique**
Wattle-and-daub, besides being one of the oldest technique of construction, is still one of the most widespread, especially in developing countries. The structure is a grid-like support, made from a woven lattice of stakes (wattle) combined with timber (in European systems). The stakes are placed close to each other, at a distance of approximately 6 cm up to a maximum 10-15 cm if the stock is not sufficient. A mix of slurry or light slurry (daub) is then applied on the two sides of the structure in layers of approximately 2 cm and pushed together to form an even wall and fill the gaps between the wattle. This technique can be applied for both walls and ceilings (Schroeder, 2016, p. 328). In order to extend the life of the daub component, horse urine is mixed in the composition in certain areas of the world, with very successful results (Houben & Guillaud, 2008, p. 189).
g) Earthbags

**Definition**
Structures formed by stacking textile bags filled with earth (mud, cob), sand or gravel.

**Production technique and application**
Compared to other techniques of building with earth, when building with earth bags the quality and composition of the soil is not of great importance. The earth is manually rammed into textile bags and then used to construct foundations or walls. The technique requires few tools and a low level of skill of the workers and is very economic. The most efficient way to construct buildings with earth bag walls is if they are dome shaped, using arches, as the structure is then self-supporting and there is no need of an additional (timber) structure (Wojciechowska, 2001, p. 12). The main materials used in these constructions are bags, local earth and barbed wire, which is used between the layers of bags to provide grip between them. Natural stabilizers can be added to the earth, such as wheat flour paste, to increase its stability.

The walls built of earth bags are eventually plastered, therefore the bags are merely a temporary enclosure for the earth, while the plaster is the permanent casing. The plaster can be lime, earth, cement, papercrete, etc. Special attention must be paid to the lower level of walls when building with earth bags, as this must not contain high levels of clay, since it will absorb moisture. The foundation should be dug until under the frost level and can be filled with gravel in a trench or gravel bags up until about 30 cm above ground level. Only from there on earth bags may be used, regardless of their clay content. The bags can also be used filled with gravel, sand or earth to fulfill the role of foundations or bases for straw bale or
Alternative options for the foundations are rammed earth tires, mortared rubble/stone or gabions. The tires replace the earth bags, with the difference that they are permanent forms. A foundation which will provide even better drainage can be made from recycled rubble. Large piece of rubble can be placed in a dug trench, with bent metal rods on top to provide a connection point for the rest of the wall build up. Mortar can be then poured to further stabilize the foundation. Similarly, gabions can be used for the foundation work, without needing additional mortar, as the galvanized steel will maintain the stones.

In what concerns roof constructions, standard timber roofs, thatched roofs or even green roofs can be installed on top of an earth bag wall construction.
3.2.3. Hempcrete

**General characteristics**
Hemp-lime was first produced in France and Belgium, in the early 1990s, but it has since extended to many areas within Europe and America (Bevan & Woolley, 2009, p.2). The hemp plant produces an external fibrous material, which is used in the food industry, for production of hemp fiber or hemp insulation. After the process of deorticication, the woody core is left and it is considered a by-product or waste product. This is now used to produce hemp-lime, by chopping it into small particles and mixing it with a binder (Ganotopoulou, 2014, p.121).

**Definition**
Hempcrete (or hemp-lime) is a composite building material produced through mixing a bio-fibre (hemp hurd or shiv) with a mineral binder (lime) and water. As the materials are mixed, a chemical reaction occurs between the lime and the water, causing the binder to harden around the hemp shivs. It is largely used as insulation material (Magwood, 2016, p. 3).

**Application - building component**
Hempcrete is mainly used as insulation material in walls, floors and roofs. There are two main forms in which hempcrete can be used as building material: as bulk material - in-situ cast or in-situ sprayed and precast block, bricks or panels.
Production technique

Although normally hempcrete is obtained by mixing hemp shivs, lime and water, the shivs can also be mixed with hydraulic lime based binder for greater strength (Greenspec, 2013).

When speaking of the bulk material, this can be applied in two ways in a building: by tamping it into wooden molds which are then removed after about 12-24 hours (more suitable for small scale buildings) or by spraying and flattening it in order to construct walls between an existing wooden structure (more suitable for large scale buildings). Either way, this technique produces a monolithic structure, with high qualities in what concerns both insulation and thermal mass values (Magwood, 2016, p.67-77).

Precast block or bricks are elements that are manufactured in a company and are usually ready to be used in walls and floors. There are two types of precast elements, depending on their characteristics: structural blocks or thermal blocks. The precast panels are used as insulation in walls and they are hanged on the structure of the building (Ganotopoulou, 2014, p.121). The elements are produced by casting them into molds and then air-drying them.

The walls can be rendered, after an appropriate drying time, which is usually about four weeks, depending on the mix used and its density, but also on natural conditions (Bevan & Woolley, 2009, p.3). The most common renders that are used, since they preserve and enhance the qualities of a hempcrete wall element are earth and lime based plasters.

Figure 38: Production of in-situ cast hempcrete insulation (Magwood, 2016, p. 3)
Advantages and limitations

+ Hemp is a renewable material, it grows and is ready for harvesting very quickly (about 90 days)
+ During its cultivation it creates a positive CO2 balance due to its fast growth and sequestration of CO2.
Moreover, hemp’s roots aerate the soil and it can absorb heavy metals from it, making it a suitable rotation crop to improve soil quality or gradually clean the contamination with metals (Blackburn, 2005, p.59-60).
+ It is a hygroscopic and breathable material, it provides a great degree of humidity control while improving indoor air quality and reducing temperature fluctuations.
+ Due to the lime in its composition, it provides high levels of thermal mass for the building, helping to decrease indoor temperature fluctuations
+ It is a flexible material and it can be adapted to any castable shape
+ It is fire resistant and also resistant to pests and rot
+ At its end-of-life, it can be crushed and casted into a new construction, making it recyclable and reusable.
- Due to the required time for drying of hempcrete, the construction time can vary. As the drying time depends on weather conditions (temperature, rain, moisture, frost), drying can take from 12-24 hours to 100-120 days. However, throughout the whole drying period, the material must be protected from frost and direct rain fall.
- Even though hempcrete deals well with humidity and moisture on short-term, long-term exposure to it can cause damage and decay. To reduce the risks, maintenance to the plaster coating or wall finishes is required.
- A large amount of lime is required in order to produce this material, which produces large amounts of CO2. Luckily, hemp is carbon positive and the amount of CO2 sequestered by hemp during cultivation roughly equals that released by lime production, making the material carbon neutral (Greenspec, 2013).
3.2.4. Wood

**General characteristics**

Wood is one of the most common materials used in the building sector, be it as timber, timber composites or wood derived products. Its characteristics made it very popular in the industry: it is light, strong, durable, easy to work, aesthetic and renewable. However, not all wood is considered renewable, depending on the forestry practices, as deforestation is one of the most concerning problems at the moment and the pace at which wood is grows back is much slower than that of other renewable materials such as hemp or straw (Brophy & Owen Lewis, 2011, p. 112). For timber to be considered renewable, it needs to be FSC (Forest Stewardship Council) certified and/ or ideally to be locally sourced or to be reclaimed wood (Wooley, 2013, p. 16).

Wood products know a large variety, from raw timber - soft or hardwood, to chipboard or fibre-board, which use waste cut-offs and chips of timber. There are two main categories of timber products: sawn timber and engineered wood.

Sawn timber products require little processing to form a building material. It is the most common use of wood resources and prefabrication and standardization of timber and harvest processes has significantly reduced the energy demand of sawn timber products. It is common to classify wood as either softwood or hardwood. The wood from conifers (e.g. pine) is called softwood, and the wood from dicotyledons (usually broad-leaved trees, e.g. oak) is called hardwood. These names are a bit misleading, as hardwoods are not necessarily hard, and softwoods are not necessarily soft. The main difference between soft and hard wood is targeted at their production process. Engineered or reconstituted wood products are produced mainly from leftovers of sawn wood applications or wood wastes.
Sawn timber products

**a) Softwood**

To produce softwood the first step is the plantation of seeds into tube stock for planting out and transplanting into prepared fields. After the plants are mature enough they are being harvested. All the timber from this phase is utilised for paper and timber panels. The procedure of harvesting includes felling, trimming, debarking and loading. After this phase the products are transferred with vehicles to the mill where the procedures of slabbing, drying and milling to profiles are followed.

Fossil fuels, electricity, gas and bio-mass are the main sources of energy for the machinery but this is not the basic energy consumption section of timbering. The procedure of the drying process of the soft timber wood is consuming nearly 75% of the all the required energy. The energy requirements for the whole process described above are approximately 7.4 MJ/Kg of dry products.

**b) Hardwood**

Hardwood is produced the same way with softwood but it has different energy requirements. Due to its physical properties it is not possible to be dried artificially. It can only been dried after it has manually reached a level of 25% of natural saturation. This way hardwood demands less energy for the drying process. On the other hand though the machinery used for harvesting is much more energy demanding from the ones of softwood. It is considered significantly difficult to collect precise information for both kind of timbering because of the great diversity of machines used, distances from the site and fuel sources. It is estimated though that hardwood demands approximately 10.4 MJ/Kg.
c) Glued laminated timber

**Definition**
Glued laminated timber is a type of engineered wood product comprising a number of layers of dimensioned lumber bonded together with durable, moisture-resistant structural adhesives.

**Production technique**
Glulam is used for the creation of structural elements and detail joinery. Stress-graded soft or hardwood sections are laminated with glue to form long structural elements. It is possible to create various shapes and forms depending on the demands of the design. The thickness (number of planks glued) also depends on the design values of the elements to be achieved.

d) Plywood

**Definition**
Plywood is used for joining details, wall cladding and lining, concrete molds, flooring etc.. It consists of sliced hardwood veneers and formaldehyde resin adhesives.

**Production technique**
Plywood is produced from logs, softened in steam or hot water and then depending on the desirable result they are sliced to veneers of 0.3-6mm thickness. Veneers are dried, glued and stuck together into sheets depending on the demanded final dimensions of the product. Then the sheets are covered with the adhesive, pressed and cut to the desired size.
e) Hardboard (HDF)

**Definition**
Hardboard consists of wood that has been broken down to its fibres and then reformed in a way that they form a hard pane. It has many application such as floor underlay, external cladding, structural bracing, doors.

**Production technique**
The wood fibers in its composition are cellulose (strength) and lignin (natural binder). Hardboard is unique among manufactured wood products because it uses only these materials to be formed with no chemical additions. Trimming the wood is achieved by heating wood chips either with steam or under pressure and then grinding them between special plates to tear the fibres apart.

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f) Medium density fiber board (MDF)

**Definition**
MDF is used mainly for stair constructions, joining details, skirtings, moldings, etc. It consists of wood fibres and chemical add-mixtures like formaldehyde resin adhesive.

**Production technique**
Softwood and mill residues are pressed in the same way as in hardboard production to create a solid wood element. The only major difference is that at MDF production wood fibres are combined with resin adhesives to form a strong bond.
3.2.5. Stone

General characteristics
Building stone is a material that has been used for ages for shelters, tools and many other purposes. It is durable with very high tension and compression strength. There is a very large variety of natural stone in nature. Stone also needs to be used carefully to prevent deterioration. Nowadays it has a lot of applications like paving, non-loadbearing wall facades, load-bearing walls and columns, joining details, roof tiles etc..

One beautiful characteristic of natural stone is that there are no two pieces of natural stone alike. Some stones may have extreme variation in color and veining from tile to tile or slab to slab.

Building stone is also an environmentally friendly material when it is locally sourced. Its embodied energy comes from procedures of excavation, transportation, packaging and treatment.

Definition
Natural stone is a material found in nature in different varieties and it can be divided into three categories depending on its form: igneous, sedimentary and metamorphic. These three forms have different shapes, strength and durability. The igneous, (e.g. granite) are hard and of high endurance; the sedimentary (e.g. sandstone) are less hard and durable and the metamorphic (e.g. marble) somewhere in between the two other categories.
Production technique

Natural stone extraction and treatment differs from place to place around the world. In general it is quarried out of rock masses like mountains or underground, cut into blocks. They are then processed in plants, sawn and finished to the desirable product. Depending on the kind of rock there are various cutting widths and finishing techniques. The energy source for these processes is almost entirely electricity.

Application - building component

For the purpose of this research, it is interesting to study how can stone be used in a form in which it is not greatly processed. Therefore, only a few application will be taken into discussion: raw material -which can be used for paving or cladding, gabions with stone and gravel, which can be used as aggregate or in gravel bags foundations.
3.2.6. Rubble

**Definition**
Rubble is the material obtained from demolishing existing buildings. Instead of ending its life cycle, it can be recycled/reused to create new materials.

**Application - building component**
Depending on the composition of the rubble, this can be used in foundations, walls or floors, either as pavement or as interior flooring.

**Production technique**
*Foundations:* Stone or rubble can be used in a rubble trench foundation. This type of foundation minimizes the use of concrete through replacing it with rubble, as well as improves the water drainage capabilities while providing structural bearing (Chappell, 1998, p.9). A trench is dug until the frost level in the soil and then filled with loose stone or rubble.

As an option, it can also be filled with rubble gabions, where the gabions are made of heavy-duty wire mesh that will maintain the rubble into position. (Stanwix & Sparrow, 2014, p.149).

As mentioned in paragraph 3.2.2. g) *Earthbags* of this research paper, (mortared) rubble filled bags can also be used to build foundations.

*Walls:* The same technique of rubble filled bags can be used for construction of walls as for foundation. Optionally, a masonry wall can be built by adding bedding mortar to the rubble. Mortar can also be used in combination with cement or concrete to create blocks which can build a wall.

*Floors:* Rubble can be crushed and used to build flooring elements, be it exterior or interior. As it has been
researched, leftover materials and binders can be crushed to desired sizes and then mixed with 20-30% new cement, in order to produce bricks with lifespans of up to 100 years.

Advantages and limitations

+ Material is generally available on site and is effectively inexhaustible
+ It prologues the life cycle of otherwise disposable building materials
- Difficult to obtain building permits
- It requires sorting to leave out unwanted building materials and it also needs further crushing

3.2.7. Flax

Definition
Flax is a food and fiber crop, mainly cultivated for the production of linen and linseed oil. Recently, flax started being largely used also for the production of insulating building components. The plant is most suitable for cultivation in wet temperate climates.

Application - building component
Flax insulation products are available in the form of rolls, panels, feltings, fleeces, strips and shives for infill of cavities. It can be used for both thermal and sound insulation in breathing wall construction, ventilated pitched roofs and in ceilings and floors (Greenspec, 2013).
3.2.8. Hemp

Hemp is an easy to cultivate crop in almost all climates of Europe, fast growing and without a need of fertilizers. Hemp insulation products are produced in different shapes and forms, such as boards, sheets or rolls. Other building elements are produced under the name of Hempcrete, with the addition of lime (see Hempcrete paragraph).

**Production technique**
Flax insulation products are made from the plant’s fibers. After harvesting, the bonds between the fibers are being loosened and the plant is left to dry. It is then processed with machinery to extract the fibers and then treated and manufactured into the desired shape.

**Advantages and limitations**
- During its cultivation it creates a positive CO2 balance, due to sequestration of CO2
- Due to its resistance to alkalis it can handle moisture and condensation, making it resistant to rot and fungal infestation. However, long periods of wetting should be avoided, as this will lead to decay (Peters, 2011, p.108).
- It has great acoustic and thermal insulation properties due to its natural moisture and temperature regulating properties.
- If polyester binder is used and this is usually the case for reinforcement reasons, it becomes more difficult to compost since the product’s biodegradability is reduced.
- It may contain borate salts, which make it difficult to use as compost. Moreover, borates will leach if exposed to permanent wetting (Greenspec, 2013).

**Definition**
Besides a vast amount of other uses, flax is used to produce building materials, more specifically insulation. Hemp is an easy to cultivate crop in almost all climates of Europe, fast growing and without a need of fertilizers.

**Application - building component**
Hemp insulation products are produced in different shapes and forms, such as boards, sheets or rolls. Other building elements are produced under the name of Hempcrete, with the addition of lime (see Hempcrete paragraph).
Production technique

Hemp insulation products are made from the fibers of the fibrous crop plant, bound with a polyester binder and treated for fire resistance. The process of harvesting and manufacturing is in great lines similar to the one of flax insulation products. It can be used for both thermal and sound insulation in breathing wall construction, ventilated pitched roofs and in ceilings and floors (Greenspec, 2013).

Advantages and limitations

+ During its cultivation it creates a positive CO2 balance due to its fast growth and sequestration of CO2. Moreover, hemp’s roots aerate the soil and it can absorb heavy metals from it, making it a suitable rotation crop to improve soil quality or gradually clean the contamination with metals (Blackburn, 2005, p.59-60).
+ From all natural fibers, the mechanical properties of hemp insulation have some of the highest levels (Carus et al., 2013, p.4).
+ Hemp is a very sturdy and resistant material
+ It is naturally resistant to mold, pest and insects infestation, therefore it doesn’t require an additive
+ It is a hygroscopic and breathable material, it provides a great degree of humidity control while improving indoor air quality and reducing temperature fluctuations.
- If polyester binder is used and this is usually the case for reinforcement reasons, it becomes more difficult to compost since the product’s biodegradability is reduced. However, a natural alternative to polyester binder can be used in the form of PLA or corn-starch.
- It may contain borate salts, which make it difficult to use as compost. Moreover, borates will leach if exposed to permanent wetting (Greenspec, 2013).
- Long periods of exposure to wetting or UV radiation lead to decay
3.2.9. Sheep Wool

Definition
Sheep wool insulation is produced from the by-product of sheep, their fleece. As their fleece regrows every year, it can be considered a renewable product.

Production technique
In order to collect the wool, a sheering process takes place, followed by a sorting one according to colour, quality, density, length, etc. After packing the according categories into bales, they are scoured in a washing plant, using detergent and hot water and then treated under the process of carding, to separate and laid them into a desired thickness. The final step is the cutting and packaging of the specific products.

Application - building component
Sheep’s wool insulation can be produced in different shapes, such as: rolls, batts, fleece. The products contain usually about 60-95% wool fiber, 5-30% melt polyester support fibers and 0.2-0.3% additives (fire retardant, pests repellent) (Grätz & Indriksone, 2011). The product can be used both as thermal and sound insulation in roofs, floors, ceilings and wall cavities.

Advantages and limitations
+ It is a hygroscopic and breathable material, it provides a great degree of humidity control while improving indoor air quality and reducing temperature fluctuations.
+ It is resistant to compaction over time
- Swelling of wool occurs if water is absorbed (Tuzcu, 2007, p.86).
- It can contain borate salts to prevent larvae of certain moths, which make it difficult to use as compost. Moreover, borates will leach if exposed to permanent wetting (Greenspec, 2013).
- Wool can degrade under attack of bacteria, fungi, moths (Tuzcu, 2007, p.11).
3.2.10. Cork

**Definition**
Cork is used in constructions mainly as insulation material and it is produced from cork bark, which is harvested from cork oaks every 9-11 after the tree’s first 25 years (Greenspec, 2013).

**Production technique**
In order to produce cork insulation, first the material needs to be harvested through stripping from the tree and to be dried for at least 6 months. Then it can be crushed to use as loose infill or further glued for natural granulated cork sheets. The cork granules can also be treated under heat steams in order to expand up to 20-30% their volume, while the Suberin in the composition of cork will act as a natural binder. It can then be shaped into blocks or boards. In this process additives can be added to increase binding strength (Hegger, M. et al., 2006, p.138).

**Application - building component**
Cork insulation can be produced in different shapes, such as: boards, rolls, tiles, strips, bands, loose infill. It can be applied in roofs, ceilings, suspended floors and walls as thermal or acoustic insulation.

**Advantages and limitations**
- It is very light, elastic, compressible
- It is fire resistant and self-extinguishing
- It is impermeable - water and gas resistant
- It is not affected by pests
- It is an expensive building material
- It has a very strong smell, especially right after installing it in the building (Ganotopoulou, 2014, p.157-158).
3.3 Comparison

10 low-impact materials have been studied in this research paper and they each have their advantages and disadvantages for using in the construction of a building. My main goal is to identify the materials and their best use in order to improve energy efficiency.

As it has been discussed before, energy is used in the construction sector in two phases: the construction phase and the operational phase. Both phases influence each other, since the decisions made in the design and construction process will greatly influence the amount of energy used in the operational phase. The main goal is to eventually reduce environmental damage by reducing CO2 emissions and unneeded energy expenditures. Last but not least, I will keep in mind that I am studying this from the point of view of the area of Southern Romania, more specifically the village of Cojasca and the conditions and availability of materials in that area.

Comparison criteria - energy efficiency

There are a few factors that have a great importance in the design and construction phase which will help limit or reduce the total amount of energy used by a building throughout its whole life cycle:

- using locally sourced or readily available materials to limit transport costs, energy, CO2 emissions
- using materials with low levels of embodied energy
- being critical about materials and their densities, as this will eventually greatly influence the embodied energy of the building
- providing sufficient thermal insulation
- providing sufficient thermal mass
- choosing materials and construction methods which are durable, have a long life-span and require minimum maintenance
- using materials which are recyclable or even better, biodegradable in order to limit future energy consumption
The materials will first be compared in the table below, where all the important findings of the research will be included to have an overview of the use of low-impact materials compared to traditional/most common building materials. Afterwards, a comparison will be made per building element, in order to provide a “toolbox” as to which materials can be used in every part of the building and what is the most suitable option according to the criteria on the previous page. The analysed building elements will be:

a) Foundation  
b) Structure 

c) Walls 

d) Roofs 

e) Insulation 

By doing so, conclusions can be drawn and be implemented in next chapter in scenarios for redevelopment and, later on, in the design of a sustainable agrotouristic farm in Cojasca, Romania.
<table>
<thead>
<tr>
<th>Material</th>
<th>Application</th>
<th>Building component</th>
<th>Embodied energy (EE) (MJ/kg)</th>
<th>CO2 emissions level in production</th>
<th>Thickness (mm)</th>
<th>Density (kg/m³)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1) Straw</td>
<td>a) Straw bales</td>
<td>- loadbearing/ non-loadbearing walls</td>
<td>a) 0.24</td>
<td>Harvesting, baling/manufacturing, transport</td>
<td>a) 500-1200</td>
<td>a) M:80-120 XL:180-200</td>
</tr>
<tr>
<td></td>
<td>b) Straw panels</td>
<td>- insulation</td>
<td>b) 0.91</td>
<td></td>
<td>b) 200</td>
<td>b) 200-720</td>
</tr>
<tr>
<td></td>
<td>c) Thatch</td>
<td>- roofs</td>
<td></td>
<td></td>
<td>c) 200-450</td>
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<tr>
<td></td>
<td>d) Insulation</td>
<td>- floors</td>
<td></td>
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<tr>
<td></td>
<td>e) Leicht lehm</td>
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</tr>
<tr>
<td>2) Earth</td>
<td>a) Rammed earth</td>
<td>- loadbearing/ non-loadbearing walls</td>
<td>a) 0.7</td>
<td>Excavation, transport</td>
<td>a) 200-650</td>
<td>a) 1700-2200</td>
</tr>
<tr>
<td></td>
<td>b) Gunned earth</td>
<td>- flooring</td>
<td>b) 0.8</td>
<td></td>
<td>c) 1600-1900</td>
<td></td>
</tr>
<tr>
<td></td>
<td>c) Adobes (mud bricks)</td>
<td>- renders</td>
<td>c) 0.42</td>
<td></td>
<td>d) 1900-2200</td>
<td></td>
</tr>
<tr>
<td></td>
<td>d) Compressed blocks</td>
<td></td>
<td>d) 0.47</td>
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<td>e) Earth-filled tyres</td>
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<td></td>
<td>f) Wattle-and-daub</td>
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<td></td>
<td>g) Earthbags</td>
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<td></td>
</tr>
<tr>
<td>3) Hempcrete</td>
<td>a) in-situ casting</td>
<td>- walls</td>
<td>a) 2-5</td>
<td>Harvesting, crushing, transport</td>
<td>a) 250-400</td>
<td>a,b) 220-330</td>
</tr>
<tr>
<td></td>
<td>b) in-situ spraying</td>
<td>- roofs</td>
<td></td>
<td></td>
<td>c) 100-300</td>
<td>c) 1100-1200</td>
</tr>
<tr>
<td></td>
<td>c) structural block</td>
<td>- floors</td>
<td></td>
<td></td>
<td>d) 530</td>
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<tr>
<td></td>
<td>d) thermal block</td>
<td>- insulations</td>
<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td></td>
<td>e) panels</td>
<td></td>
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</tr>
<tr>
<td>4) Wood</td>
<td>a) Softwood</td>
<td>- structure</td>
<td>a) 7.4</td>
<td>Cutting, processing and transport</td>
<td>Largely differs on purpose</td>
<td>500-800</td>
</tr>
<tr>
<td></td>
<td>b) Hardwood</td>
<td>- walls</td>
<td>b) 10.4</td>
<td></td>
<td></td>
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</tr>
<tr>
<td></td>
<td>c) Glued laminated timber</td>
<td>- flooring</td>
<td>c) 11</td>
<td></td>
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<tr>
<td></td>
<td>d) Plywood</td>
<td>- roofing</td>
<td>d) 10.4</td>
<td></td>
<td></td>
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<tr>
<td></td>
<td>e) Hardboard (HDF)</td>
<td>- details</td>
<td>e) 24.2</td>
<td></td>
<td></td>
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</tr>
<tr>
<td></td>
<td>f) MDF</td>
<td>- moulds</td>
<td>f) 11.9</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>g) Shingles</td>
<td>- cladding</td>
<td>g) 9</td>
<td></td>
<td></td>
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<tr>
<td>Life span (years)</td>
<td>Insulation properties (U-value: W/m²K)</td>
<td>Craftmanship</td>
<td>End-of-life</td>
<td>Local: Availability (km)</td>
<td>Handling moisture</td>
<td>Renewable</td>
</tr>
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<td>------------------</td>
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</tr>
<tr>
<td>100+</td>
<td>a) 0.20 c) 0.29 - Very good insulator - Low thermal mass - Hygroscopic</td>
<td>a) Labour intensive, low skilled workers b) Manufactured, medium skilled worker for assembly c) Labour intensive, experienced workers</td>
<td>Compost</td>
<td>0.2 km (Cojasca)</td>
<td>If plastered</td>
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<td></td>
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<td></td>
</tr>
</tbody>
</table>
| 100+             | a) 1.7-3.3 - Not a good insulator - High thermal mass - Hygroscopic | a,c,d,f) Labour intensive, little/ medium experienced workers, d) Labour intensive, medium experienced workers, efficient management e, g) Low skilled workers | Re-use/ Recycle/ Dispose | 0.5 km (Cojasca) |         | Effec-

| 100+ (5-7: plaster) | a) 0.15-0.23 - Very good insulator - High thermal mass - Hygroscopic | Labour intensive, low-medium skilled workers | Recycle | 0.2 km -hemp 78 km -lime (Malcoci) | If plastered | Lime: Effec-

<p>| 50-200+          | - Good insulator | a-b) Specific machinery, medium skilled workers for construction c-g) Manufactured in factory/ workshop, medium skilled workers for construction | Re-use/ Recycle | 13.5 km (Dobra) |         |           |         |          |</p>
<table>
<thead>
<tr>
<th>Material</th>
<th>Type</th>
<th>Use</th>
<th>Unit Cost (€/m²)</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>5) Stone</strong></td>
<td>a) Raw material (local)</td>
<td>- foundation</td>
<td>a) 0.79</td>
<td>Quarrying/ extraction, transport</td>
</tr>
<tr>
<td></td>
<td>b) Raw material (imported)</td>
<td>- walls</td>
<td>b) 6.8</td>
<td></td>
</tr>
<tr>
<td></td>
<td>c) Gabions</td>
<td>- cladding</td>
<td>d) 0.02</td>
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</tr>
<tr>
<td></td>
<td>d) Gravel (river - local)</td>
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<tr>
<td><strong>6) Rubble</strong></td>
<td>a) aggregate</td>
<td>- walls</td>
<td>b) 0.5</td>
<td>Demolition, processing</td>
</tr>
<tr>
<td></td>
<td>b) bricks/ blocks</td>
<td>- foundation</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>c) gravel bags</td>
<td>- floors</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>d) gabions</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>e) pavement</td>
<td></td>
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<tr>
<td><strong>7) Flax</strong></td>
<td>insulation (rolls, sheets,</td>
<td>- thermal and</td>
<td>11-30 (depending</td>
<td>Harvesting, dressing, chemical treatment,</td>
</tr>
<tr>
<td></td>
<td>panels, fleece, strips,</td>
<td>sound insulation</td>
<td>on binder)</td>
<td>manufacturing, transport</td>
</tr>
<tr>
<td></td>
<td>shives)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>8) Hemp</strong></td>
<td>insulation (rolls, sheets,</td>
<td>- thermal and</td>
<td>10-33 (depending</td>
<td>Harvesting, dressing, chemical treatment,</td>
</tr>
<tr>
<td></td>
<td>boards)</td>
<td>sound insulation</td>
<td>on binder)</td>
<td>manufacturing</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
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</tr>
<tr>
<td><strong>9) Sheep wool</strong></td>
<td>insulation (rolls, batts,</td>
<td>- thermal and</td>
<td>20.9</td>
<td>Harvesting, dressing, chemical treatment,</td>
</tr>
<tr>
<td></td>
<td>fleece, infill)</td>
<td>sound insulation</td>
<td></td>
<td>manufacturing</td>
</tr>
<tr>
<td><strong>10) Cork</strong></td>
<td>insulation (rolls, tiles,</td>
<td>- thermal and</td>
<td>1.38-6.3</td>
<td>Harvesting, processing, manufacturing,</td>
</tr>
<tr>
<td></td>
<td>strips)</td>
<td>sound insulation</td>
<td></td>
<td>transport</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
| 200+ | - Not a good insulator  
- High thermal mass | a,b,d) Specific machinery for quarrying  
c) Medium skilled workers | Disposal/ Re-use as rubble | 8.6 km  
(Bilciuresti) |  |
| b)100+ | - Not a good insulator  
- High thermal mass | Labour intensive, low skilled workers | Disposal/ Re-use as rubble | 0 km  
(on site) | Depends on composition | Effectively inexhaustible |  |
| 0.16-0.70 | - Very good insulator  
- Low thermal mass  
- Hygroscopic | Low skilled workers for harvesting and assembly, manufactured in factory | Recycle/ compost | Bucharest-Imported from Germany |  |
| 600+ (study) | 0.16-0.78 | - Very good insulator  
- Low thermal mass  
- Hygroscopic | Low skilled workers for harvesting and assembly, manufactured in factory | Recycle/ compost | 339 km  
(Pianu de Jos) | If plastered |  |
| 0.16-0.78 | - Very good insulator  
- Low thermal mass  
- Hygroscopic | Manufactured in factory, experienced workers | Recycle/ Compost | 219 km  
(Independenta) |  |
<p>| 0.20-2.00 | Manufactured in factory, experienced workers | Recycle/ Compost | Bucharest-Imported from Portugal |  |</p>
<table>
<thead>
<tr>
<th>A) Brick</th>
<th>- bricks/ blocks</th>
<th>- walls</th>
<th>2.5</th>
<th>Extraction, processing, burning and transport</th>
<th>1922-2400</th>
</tr>
</thead>
<tbody>
<tr>
<td>B) Steel</td>
<td>a) General steel</td>
<td>- structure</td>
<td>a) 24.4</td>
<td>Extraction, crushing materials, production in furnace, alloying, galvanizing.</td>
<td>a)7850  f)7480-8000</td>
</tr>
<tr>
<td></td>
<td>c) Coil (sheet-galvanized)</td>
<td>- roofs</td>
<td>c) 38 d) 33.2 e) 36 f) 56.7</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>d) Plate</td>
<td></td>
<td></td>
<td></td>
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</tr>
<tr>
<td></td>
<td>e) Wire</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>f) Stainless</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>C) Concrete</td>
<td>a) Blocks</td>
<td>- foundation</td>
<td>a) 1.5</td>
<td>2250-2400</td>
<td></td>
</tr>
<tr>
<td></td>
<td>b) In situ</td>
<td>- walls</td>
<td>b) 1.9</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>c) Precast (+ reinforcement)</td>
<td>- floors</td>
<td>c) 2.33</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>- structure</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>D) Aluminium</td>
<td>a) Extruded</td>
<td>- roofing</td>
<td>a) 227</td>
<td>2550-2750</td>
<td></td>
</tr>
<tr>
<td>E) Glass mineral wool</td>
<td>insulation (rolls, batts, strips)</td>
<td>- insulation</td>
<td>16.6</td>
<td>Batch, melting, fiberizing, forming, cutting, packaging</td>
<td>50-270  18-25</td>
</tr>
</tbody>
</table>

*Figure 40: Comparison between the 10 studied material and common building materials (Source: author)*
<table>
<thead>
<tr>
<th>100-500</th>
<th>2.00</th>
<th>Manufactured in factory, experienced workers</th>
<th>Disposal/Re-use as rubble</th>
<th>62 km (Campina)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Manufactured in factory, experienced workers</td>
<td>Re-use/Disposal</td>
<td></td>
</tr>
<tr>
<td>50+</td>
<td></td>
<td>Manufactured experienced workers</td>
<td>Disposal/Re-use as rubble</td>
<td>42 km (Bucharest)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Manufactured in factory, experienced workers</td>
<td>Re-use/Disposal</td>
<td></td>
</tr>
<tr>
<td>0.17-0.24</td>
<td></td>
<td>Manufactured in factory, experienced workers</td>
<td>Recycle/Disposal</td>
<td>Bucharest-Imported from Germany</td>
</tr>
</tbody>
</table>
**a) Foundation**

The main scope of a building’s foundation is to support and transmit to the sub-soil all loads coming from the building itself or from temporary loads. A foundation should be rigid enough as to withstand non-evenly distributed temporary loads. Also, it should be dug sufficiently deep in the ground as to protect the building from damage, frost, swelling or shrinkage of the sub-soil.

**Most suitable solutions (low-impact materials):**
- stone (raw material) - rubble trench foundation
- gravel (raw material) - rubble trench foundation
- rubble - rubble trench foundation
- gravel bags foundation
- stone ( gabions)
- rubble ( gabions)

Comparing these solutions, it can be observed that **rubble** applied in a rubble trench foundation complies with all foundation requirements, while using a material which is ready available, on site, with low levels of embodied energy and no need for maintenance if sorted properly.
### Low-impact building material

#### STONE (raw material - rubble trench foundation)

<table>
<thead>
<tr>
<th>Renewable</th>
<th>Recyclable</th>
<th>Biodegradable</th>
<th>Locally available</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Embodied energy: 0.79 MJ/kg

Density: 2500 kg/m³
Minimum embodied energy/m³: 1975 MJ
U-value: n.a. (Very low)
Specific heat capacity: 840 J/kg.K
Thermal conductivity: 1.8 W/m.K
Thermal mass effectiveness: High
Locally available: yes - 8.6 km
Lifespan: Lifetime

+ minimizes the use of concrete
+ improves the water drainage capabilities
+ provides structural bearing
+ long-lasting material
- less rigid than concrete

#### RUBBLE (on-site - rubble trench foundation)

<table>
<thead>
<tr>
<th>Renewable</th>
<th>Recyclable</th>
<th>Biodegradable</th>
<th>Locally available</th>
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<tbody>
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</table>

Embodied energy: 0.5 MJ/kg

Density: 1048 kg/m³
Minimum embodied energy/m³: 524 MJ
U-value: n.a. (Very low)
Specific heat capacity: 820 J/kg.K
Thermal conductivity: - (not found)
Thermal mass effectiveness: High
Locally available: yes - on site
Lifespan: depends on composition

+ uses considerably less energy to build than concrete
+ minimizes the use of concrete
+ improves the water drainage capabilities
+ provides structural bearing
+ through recycling, it prolongues the life-cycle of an already available material which would otherwise go to waste
+ it it directly available on site - no transport required
+ less rigid than concrete
+ requires careful sorting in order to make sure the composition is adequate and long-lasting
b) Structure

The design of a building’s structure must satisfy three basic requirements: provide stability, strength and serviceability. This means a structure should be able to withstand the action of loads, to resist the stresses they induce and to have a sufficiently satisfactory performance during its service life.

Most suitable solutions (low-impact materials):
- timber frame
- timber skeleton structure
- solid timber construction

Comparing these solutions, it can be observed that the timber frame structure is a very good alternative to the common concrete structure. Even though the energy use is comparable, timber is a natural, renewable and biodegradable material, meaning that at the end of its life it can prevent energy consumption for its disposal. It also constitutes a much more lightweight option than concrete.

<table>
<thead>
<tr>
<th>Renewable</th>
<th>Recyclable</th>
<th>Biodegradable</th>
<th>Locally available</th>
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</table>

Embodied energy: 1.9 MJ/kg

Density: 1922-2400 kg/m³
Minimum embodied energy/ m³: 4845 MJ
Specific heat capacity: 880 J/kg.K
Thermal conductivity: 1.13 W/m.K
Thermal mass effectiveness: High
Locally available: yes - 42 km
Lifespan: 80-100+ years
**Low-impact building material**

**TIMBER FRAME** (softwood-oak)

<table>
<thead>
<tr>
<th>Renewable</th>
<th>Recyclable</th>
<th>Biodegradable</th>
<th>Locally available</th>
</tr>
</thead>
</table>

Embodied energy: 7.4 MJ/kg

Density: 705 kg/m³
Minimum embodied energy/m³: 5217 MJ
Specific heat capacity: 1200 J/kg.K
Thermal conductivity: 0.14 W/m.K
Thermal mass effectiveness: Low
Locally available: yes - Oak - 13.5 km
Lifespan: 70-100+ years

+ lightweight structure
+ end-of-life: recycle/ compost - energy savings
- no thermal mass

PART III - LOW-IMPACT CONSTRUCTION (COMPARISON)
c) Walls

The main scope of a building’s exterior walls/ facades is to provide protection from the exterior, to create a air-, water-, thermal- and acoustic barrier, while still creating a connection with the exterior surroundings.

Most suitable solutions (low-impact materials):
- rammed earth (+insulation, plaster)
- earth bags (+insulation, plaster)
- straw bales (+plaster)
- hempcrete cast in-situ (+plaster)

Comparing these solutions, it can be observed that hempcrete cast in-situ is the best solution, given its properties. It’s main quality is the ability to provide both thermal mass (due to lime) and thermal resistance (due to hemp). Moreover, it is a durable material, which forms a monolithic, rigid, strong wall element after drying. It also had the capability to produce a positive CO2 balance, due to the sequestration of CO2 during its cultivation. It is a lightweight material, creating walls which provide both thermal and acoustic insulation within limited dimensions.

Most common building material

**BRICK**

<table>
<thead>
<tr>
<th>Renewable</th>
<th>Recyclable</th>
<th>Biodegradable</th>
<th>Locally available</th>
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</tbody>
</table>

Embodied energy: 2.5 MJ/kg

Density: 2550-2750 kg/m³
Minimum embodied energy/ m³: 6375 MJ
U-value: 2.0 W/m²K (Low)
Specific heat capacity: 840 J/kg.K
Thermal conductivity: 0.73 W/m.K
Thermal mass effectiveness: High
Locally available: no - 62.5 km
Lifespan: 100-500 years (depending on circumstances)
Low-impact building material
RAMMED EARTH

<table>
<thead>
<tr>
<th>Renewable</th>
<th>Recyclable</th>
<th>Biodegradable</th>
<th>Locally available</th>
</tr>
</thead>
<tbody>
<tr>
<td>Inexhaustible</td>
<td></td>
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</tbody>
</table>

Embodied energy: 0.7 MJ/kg

Density: 1700-2200 kg/m³
Minimum embodied energy/m³: 1190 MJ
U-value: 1.7-3.3 W/m²K (Very low)
Specific heat capacity: 1260 J/kg.K
Thermal conductivity: 0.81-0.93 W/m.K
Thermal mass effectiveness: High
Locally available: yes - on site
Lifespan: 100+ years (Maintenance: plaster 5-7 years)

+ directly available on site
+ hygroscopic and breathable material, provides humidity control, improves indoor air quality, reduces temperature fluctuation
+ flexible material, can be adapted to any castable shape
+ clear advantage in what concerns the strength and stiffness of the building elements, being able to act as both loadbearing and non-loadbearing
+ high thermal mass
- poor thermal resistance
- damage and decay from long-term exposure to (direct) water
- complex in-situ construction

Low-impact building material
HEMPCRETE (cast in-situ)

<table>
<thead>
<tr>
<th>Renewable</th>
<th>Recyclable</th>
<th>Biodegradable</th>
<th>Locally available</th>
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<tbody>
<tr>
<td>Partly</td>
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</table>

Embodied energy: 2-5 MJ/kg

Density: 220-330 kg/m³
Minimum embodied energy/m³: 524 MJ
U-value: 0.15-0.23 W/m²K (High)
Specific heat capacity: 1500-1700 J/kg.K
Thermal conductivity: 0.12 W/m.K
Thermal mass effectiveness: Medium
Locally available: yes - 0.2 km
Lifespan: 100+ (Maintenance: plaster 5-7 years)

+ fast cultivation and harvesting process: approx. 90 days
+ creates a positive CO2 balance due to its fast growth and sequestration of CO2
+ hygroscopic and breathable material, provides humidity control, improves indoor air quality, reduces temperature fluctuation
+ provides good levels of thermal mass for the building
+ flexible material, can be adapted to any castable shape
+ It is fire resistant and also resistant to pests and rot
- due to drying process, construction times can vary
- must be protected from long-term exposure to moisture through good maintenance of plaster
d) Roofs

The main scope of a building’s roof is to provide protection from the exterior, to create a air-, water-, thermal- and acoustic barrier, while being able to resist external loads.

Most suitable solutions (low-impact materials):
- timber (shingles - oak)
- long straw/ water reed (thatched roof)

Comparing these solutions, it can be observed that reed applied in a thatched roof complies with all roof requirements, while using a material which is locally available and with low levels of embodied energy. It is a material found in vernacular architecture in the area too, it provides high insulation values and a very aesthetically pleasing appearance. The large overhang it provides (approx. 300 mm) is a great advantage, since it can protect facades from direct rainfall and therefore damage.

Most common building material

**STEEL** (galvanised sheets)

<table>
<thead>
<tr>
<th>Renewable</th>
<th>Recyclable</th>
<th>Biodegradable</th>
<th>Locally available</th>
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</table>

Embodied energy: 38 MJ/kg

Density: 7800 kg/m³
Minimum embodied energy/ m³: 296400 MJ
U-value: - (Low)
Specific heat capacity: 480 J/kg.K
Thermal conductivity: 45 W/m.K
Thermal mass effectiveness: Low
Locally available: no
Lifespan: 20-50 years
### Low-impact building material

**TIMBER (shingles-oak)**

<table>
<thead>
<tr>
<th>Property</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Density:</strong></td>
<td>705 kg/m³</td>
</tr>
<tr>
<td><strong>Minimum embodied energy/m³:</strong></td>
<td>6345 MJ</td>
</tr>
<tr>
<td><strong>U-value:</strong></td>
<td>0.97 W/m²K (Medium)</td>
</tr>
<tr>
<td><strong>Specific heat capacity:</strong></td>
<td>1200 J/kg.K</td>
</tr>
<tr>
<td><strong>Thermal conductivity:</strong></td>
<td>0.14 W/m.K</td>
</tr>
<tr>
<td><strong>Thermal mass effectiveness:</strong></td>
<td>Low</td>
</tr>
<tr>
<td><strong>Locally available:</strong></td>
<td>yes - Oak - 13.5 km</td>
</tr>
<tr>
<td><strong>Lifespan:</strong></td>
<td>15-30 years</td>
</tr>
<tr>
<td><strong>+ lightweight material</strong></td>
<td></td>
</tr>
<tr>
<td><strong>+ end-of-life: recycle/ compost</strong></td>
<td>energy savings</td>
</tr>
<tr>
<td><strong>- no thermal mass</strong></td>
<td></td>
</tr>
<tr>
<td><strong>- rather short lifespan</strong></td>
<td></td>
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</tbody>
</table>

### Low-impact building material

**STRAW/REED (thatched roof)**

<table>
<thead>
<tr>
<th>Property</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Density:</strong></td>
<td>80-180 kg/m³</td>
</tr>
<tr>
<td><strong>Minimum embodied energy/m³:</strong></td>
<td>19.2 MJ</td>
</tr>
<tr>
<td><strong>U-value:</strong></td>
<td>0.29 W/m²K (High)</td>
</tr>
<tr>
<td><strong>Specific heat capacity:</strong></td>
<td>1660-1710 J/kg.K</td>
</tr>
<tr>
<td><strong>Thermal conductivity:</strong></td>
<td>0.055-0.075 W/m.K</td>
</tr>
<tr>
<td><strong>Thermal mass effectiveness:</strong></td>
<td>Low</td>
</tr>
<tr>
<td><strong>Locally available:</strong></td>
<td>yes - 0.4 km</td>
</tr>
<tr>
<td><strong>Lifespan:</strong></td>
<td>40-70+ years (Maintenance: roof ridge 8-14 years)</td>
</tr>
<tr>
<td><strong>+ material used in vernacular architecture</strong></td>
<td></td>
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<tr>
<td><strong>+ high thermal resistance</strong></td>
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<tr>
<td><strong>+ can accommodate a green roof</strong></td>
<td></td>
</tr>
<tr>
<td><strong>+ durable material, provided it benefits from correct maintenance</strong></td>
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</tr>
<tr>
<td><strong>- requires skilled workers for correct installation</strong></td>
<td></td>
</tr>
</tbody>
</table>
e) Insulation

The main scope of a building’s insulation is to provide a continuous protective layer of thermal- and acoustic barrier. It is part of the building components c) Walls or d) Roofs, depending on the materials used in their composition. If the facade uses a material with low thermal resistance or a cavity wall system with cladding materials, then an additional layer of insulation is required (similarly for roofs).

**Most suitable solutions (low-impact materials):**
- hemp insulation
- flax insulation
- sheep wool insulation
- hempcrete insulation

Comparing these solutions, it can be observed that **hempcrete** is the ideal material to use, since it provides high insulation values and it has a very low environmental impact (see paragraph c)Walls). If insulation in the form of rolls or batts is needed, **flax and hemp** insulation are the best solutions according to the comparison criteria.

---

**Most common building material**

**MINERAL WOOL** (rolls)

<table>
<thead>
<tr>
<th>Renewable</th>
<th>Recyclable</th>
<th>Biodegradable</th>
<th>Locally available</th>
</tr>
</thead>
</table>

Embodied energy: 16.6 MJ/kg

Density: 18-25 kg/m³
Minimum embodied energy/ m³: 298 MJ
U-value: 0.17-0.24 W/m²K (High)
Specific heat capacity: 1000 J/kg.K
Thermal conductivity: 0.032-0.044 W/m.K
Thermal mass effectiveness: Low
Locally available: no
Lifespan: 100+ years
Low-impact building material
HEMP (rolls)

<table>
<thead>
<tr>
<th>Renewable</th>
<th>Recyclable</th>
<th>Biodegradable</th>
<th>Locally available</th>
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</tbody>
</table>

- Embodied energy: 10-33 MJ/kg

- Density: 20-70 kg/m³
- Minimum embodied energy/m³: 200 MJ
- U-value: 0.16-0.78 W/m²K (Medium)
- Specific heat capacity: 1600-2350 J/kg.K
- Thermal conductivity: 0.040-0.047 W/m.K
- Thermal mass effectiveness: Low
- Locally available: no (339 km)
- Lifespan: 100+ years

+ creates a positive CO2 balance due to its fast growth and sequestration of CO2
+ Hemp is a very sturdy and resistant material
+ It is naturally resistant to mould, pest and insects infestation, therefore it doesn’t require an additive
+ Hygroscopic and breathable material, provides humidity control, improves indoor air quality, reduces temperature fluctuation
  - Polyester binder is used for reinforcement reasons, it becomes difficult to compost
  - It may contain borate salts, which make it difficult to compost and they leach if exposed to permanent wetting
  - Must be protected from long-term exposure to moisture

Low-impact building material
HEMPCRETE (cast in-situ)

<table>
<thead>
<tr>
<th>Renewable</th>
<th>Recyclable</th>
<th>Biodegradable</th>
<th>Locally available</th>
</tr>
</thead>
<tbody>
<tr>
<td>Partly</td>
<td>Partly</td>
<td></td>
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</tr>
</tbody>
</table>

- Embodied energy: 2-5 MJ/kg

- Density: 220-330 kg/m³
- Minimum embodied energy/m³: 524 MJ
- U-value: 0.15-0.23 W/m²K (High)
- Specific heat capacity: 1500-1700 J/kg.K
- Thermal conductivity: 0.12 W/m.K
- Thermal mass effectiveness: Medium
- Locally available: yes - 0.2 km
- Lifespan: 100+ (Maintenance: plaster 5-7 years)

+ Fast cultivation and harvesting process: approx. 90 days
+ Creates a positive CO2 balance due to its fast growth and sequestration of CO2
+ Hygroscopic and breathable material, provides humidity control, improves indoor air quality, reduces temperature fluctuation
+ Provides good levels of thermal mass for the building
+ Flexible material, can be adapted to any castable shape
+ It is fire resistant and also resistant to pests and rot
- Due to drying process, construction times can vary
- Must be protected from long-term exposure to moisture through good maintenance of plaster
3.4 Conclusions low-impact materials

From the comparison made in the previous paragraph, it can be observed that there are 3 categories of low-impact building materials:

1) **Insulating materials, (semi-) flexible**: high - very-high insulating properties, low tensile strength:
   - hemp insulation, sheepwool insulation, flax insulation,
   - straw insulation, cork insulation

2) **Insulating materials, rigid**: high - very high insulating properties, can be self-supportive:
   - hempcrete blocks/ bulk material, straw bales, timber

3) **Thermal mass, rigid, low insulating**: high - very high thermal mass properties, self-supportive, very low-medium insulating properties:
   - earth (rammed, blocks, adobes, earthbags, etc), stone/gravel/ rubble (raw, gabions), timber, hempcrete. The last 2 materials have medium-very good insulating properties.

All 10 materials listed and studied in this research are suitable for design and use in a sustainable building, reducing energy consumption and improving energy efficiency of the building. As it can be noticed, the materials can be divided into 3 different categories, which shows there is a great diversity in their properties and they are suitable for designing a complete building using mainly low-impact materials, from foundation to roof.
Although the comparison and calculations shown in the previous chapter do not give an perfectly exact number of what the energy consumption would be for a building that uses low-impact materials, it does prove that such a building can save even more than half of the energy used by building with traditional materials. The findings of the comparison chapter also show a single material as the best solution, but in practice the best solution when taking into account factors like orientation of the building, may be to combine different materials in order to achieve the highest energy efficiency according to the requirements and the functionality of the building to be designed.

If the findings of this research in what concerns materialisation are combined in the design process with the principles of passiv haus, buildings can be constructed which are highly energy efficient or even energy neutral.
The conclusions of the research about low-impact construction can be tested on the needs for redevelopment of the farm in Cojasca.

According to the value assessment presented in part I, section 1.2, three different areas and approaches can be distinguished in regards to the current buildings on the site:

**I Demolition of old buildings**
These buildings are in an advanced state of decay and have completely or partly collapsed already.

**II Reparation and refurbishment**
These buildings are in a good state and, even though they may require structural or aesthetics
reparations, they can be afterwards refurbished to be used in the new farm.

**III Demolition of old buildings and construction of new buildings**

These buildings are in an advanced state of decay and it is easier, given their structural damage, to demolish them and re-use part of the materials for the construction of the new facilities.

As can be observed in the figure on the right, the predominant building material which could be reused from the demolished buildings is brick, along with some small quantities of steel and timber. However, not all the brick is in a good/very good state, therefore part of it can be used in the available state and part of it can be transformed to rubble and used as a new material.

Given the state of the buildings on site, two different strategies can be developed, one for dealing with the existing buildings and one for the new constructions.

*Figure 41: Building materials on site (to be demolished buildings)*
PART IV - SCENARIOS FOR REDEVELOPMENT

a) Existing buildings (reparations & refurbishment)

The existing buildings which are not in such an advanced state of decay as to not allow re-use are for the majority barns. They have brick walls, steel structures, concrete floors and roofs made of asbestos-cement tiles. The walls mainly need reparations on the lower/top layers of brick, which have been damaged by rain and water infiltration. Here, reclaimed brick from the (to be) demolished buildings can be used to replace the missing or damages ones. The roofs needs to be replaced, given the asbestos content they have and its negative consequences. Furthermore, the buildings need to be refurbished to become completely water tight and insulated. Therefore, the best option of renovation which will also ensure energy efficiency is to create a continuous water-tight, insulating outer skin. With regards to the conclusions of the low-impact materials research, the ideal solution would be to construct a thatched roof made from reed and hempcrete cast in-situ walls, which will provide sufficient insulation and are resistant to pests and rot.

Figure 42: Scenario for redevelopment (to be demolished buildings)

b) New buildings

For the new buildings, different strategies of construction can be developed with regards to different factors which influence energy efficiency. On the next pages four different strategies are illustrated, all using low-impact materials.
Construction phase
LOWEST LEVEL OF EMBODIED ENERGY

Foundation: Rubble gabions (rubble trench foundation)
Structure: Timber frame (softwood - oak)
Walls: Hempcrete (cast in-situ) + earth plaster
Roof: Reed (thatched roof)
Floors: Earth (rammed) + straw insulation

Operational phase
HIGHEST LEVEL OF THERMAL PERFORMANCE
(thermal resistivity + thermal mass)

Foundation: Rubble gabions (rubble trench foundation)
Structure: Timber frame (softwood - oak)
Walls: Earth (rammed) + earth plaster + hemp/ flax insulation
Roof: Reed (thatched roof)
Floors: Earth (rammed) + hemp/ flax insulation
PART IV - SCENARIOS FOR REDEVELOPMENT

Maintenance

MOST DURABLE/ LEAST MAINTENANCE

Foundation: Gravel gabions
Structure: Timber frame (softwood - oak)
Walls: Hempcrete (cast in-situ) + lime plaster + timber cladding
Roof: Reed (thatched roof)
Floors: Timber frame + hemp/ flax insulation

End-of-life

MOST BIODEGRADABLE

Foundation: Rubble (rubble trench foundation)
Structure: Timber frame (softwood - oak)
Walls: Straw (bales) + earth plaster
Roof: Reed (thatched roof)
Floors: Timber frame + straw insulation
All four scenarios of redevelopment that have been proposed aim to reduce overall energy consumption, but each one of them focuses on a different phase of the life of a building, from construction to end-of-life.

A general “best solution” scenario, which would fit everywhere does not exist and cannot be proposed, but these strategies can serve as a guidelines for anyone who is interested in designing a building with low impact materials and decreasing the construction’s environmental impact.

In the case of the former CAP farm in Cojasca, Romania all of these strategies are suitable, since they mainly use locally sourced materials and they aim to enhance energy efficiency. However, this research’s aim is to provide a “toolbox” for the design process, a number of “best case scenarios”. When taking into account all design requirements, such as functions, orientation, indoor temperature requirements, shape and size of the building, etc., only then the best solution can be proposed for this specific design location. The conclusions of this research constitute a solid basis for the general guidelines of the design, its timeline and phasing and most importantly solutions for the materialisation of the buildings.

A great advantage of using low-impact materials in a rural environment and specifically in the south of Romania, is the fact that the buildings are not only energy efficient, but they also integrate in the rural landscape and can constitute a modern reinterpretation of vernacular architecture.

In my opinion, energy efficiency can definitely be improved through the use of low-impact materials, which don’t only save energy in the construction and operational phase of the building, but can also become endlessly recycled materials, preventing large amounts of energy from being consumed in the future.
Conclusions

The collectivization of Romanian agriculture has been a long, dark process which left the rural population impoverished, the agricultural sector has seen a strong decrease in productivity, property rights were forcibly ceased and are still problematic to regain up to the present day. Yet, most importantly, the process of transformation of agriculture after a Soviet model has left a large scar in the population’s conscience, leaving the former CAP farms abandoned and in need of reintegration. Luckily, recent interest and growth of the agricultural sector brings new opportunities for these farms to be redeveloped and integrated into today’s modern society.

In order to better understand the rural life and the way constructions have always been a reflection of the activities of the peasants, vernacular architecture in the South of Romania has been studied in this paper. The evolution of the construction typologies, the materials and techniques used have always been in a tight relation with the direct environment, with local materials as the main building source. People have started with houses dug in ground, then build small settlements above ground, evolved to multiple rooms houses, added a second storey, until they reached fortified houses and dwellings with a central plan, closer to the ones we know and build today. The materials have mainly been materials the people could ready use from nature, such as straw, earth, timber, stone and only later on brick, once industrialisation arose. “The value of history is the one that teaches us something about the future” (Jackson, 1984). This means that in order to build for a more sustainable future, we must first look back to our past. The lesson we can learn from the past is that the potential of using natural and renewable materials, locally sourced, must now be recognized in order to reduce and minimise environmental damage.

Studying more in detail the category or low-impact materials shows that a building can be energy efficient also in the construction phase, if materials with low level of embodied energy are used. Energy efficiency in the operational phase can be achieved during design phase,
through applying several strategies or principles, such as those of passive building. But this first requires a thorough understanding of building techniques and acknowledging of the fact that the energy that is embodied in the construction itself is also part of and influences the final energy efficiency of a building.

The materials studied have shown that a complete building can be built using only this type of low-impact materials, while being able to achieve what can be described as comfortable living environment, high levels of thermal comfort through insulation and natural regulation of indoor air quality due the characteristics of these natural materials and, last but not least, pleasant aesthetic features.

These strategies can be applied in the case of the former CAP farm in Cojasca, which can turn into a beautiful design, closely related to its function and surroundings and can revitalise therefore the life of the village. This farm can turn into a redevelopment example for similar farms throughout the whole country.
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Figure 40: Comparison between the 10 studied material and common building materials
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