# Comparison in terms of $CO_2$ footprint between RC and CLT buildings

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ABSTRACT: Concrete is the most used building material in the world: its fundamental component is clinker, which, only for the production process, represents 5-7% of the global $CO_2$ emissions (Coppola, 2019). Therefore, it is advantageous to replace the use of concrete with other more sustainable materials, as wood. From the point of view of the $CO_2$ emissions, wood not only has a limited release in the production phase, but even, in a balance that also considers the development phase of the tree, it appears to absorb rather than emit carbon dioxide. The objective of this study is therefore to compare, in terms of $CO_2$ emissions, the same building built in concrete rather than wood. The entire life cycle of structural materials is taken into consideration (production, transport, construction and finally deconstruction and disposal phases at the end of their life): the method used is the LCA analysis.

## 1 INTRODUCTION

The construction sector alone accounts for 39% of $CO_2$ global emissions, of which 9% is released by concrete during the production, transport and installation phases: therefore a transition towards technologies that are more respectful of the climate and the environment are necessary (Global ABC IEA, 2019). In recent decades, a growing number of studies have been conducted to introduce recycled materials into the cement mix, reducing the impacts deriving from the use of virgin raw materials, or attempts have been made to reduce the quantity of clinker in the cement, however, it cannot be reduced under a certain limit (Somma, 2022). This last essential component, clinker, is the source of most carbon dioxide emissions: it is clear that, even by optimising the composition of concrete, it will never be possible to achieve neutrality. The solution to this problem is represented by the use of more sustainable materials, which can guarantee mechanical performances substantially coinciding with those of concrete. An example is the technology of CLT panels, cross-laminated wood, which in recent decades has become widespread in Central Europe. Wood is a natural material that stores carbon dioxide during its life cycle, removing it from the atmosphere; furthermore, thanks to its excellent mechanical properties, it allows for the construction of buildings up to 9 floors high in highly seismic areas. The panels are obtained by gluing a variable number (usually 3 or 5 for ordinary buildings) of wood layers with the fibers oriented orthogonally to each other, thus obtaining good resistance in each of the two directions. The material is preliminarily shaped in the factory, therefore on site it is only necessary to lay and anchor it, drastically reducing the construction times of a structure compared to a traditional one. The aim of this study is to compare the $CO_2$ emissions, through a Life Cicle Assesment analysis, of two buildings actually built in Northern Italy with almost identical dimensions, built respectively in concrete and CLT.

## 2 LCA IN BUILDINGS

The methodology that has been adopted for the assessment of the environmental impact of buildings is the LCA, which allows to define, for each material, the amount of incorporated $CO_2$. The reference standard for carrying out the calculations is UNI EN 15978, which specifies how to apply the LCA analysis to buildings. The boundaries for the system, in terms of time, start from the moment in which the materials are produced until the demolition of the structure. Therefore, all the phases concerning production, transport, construction and finally disposal at the end of their life were analyzed: the emissions related to the use of buildings are not taken into consideration, as they are considered similar, and expecially because the intention of the authors is to highlight the impact of the structural materials. Figure 1 specifies the phases taken into consideration in the analysis are described.

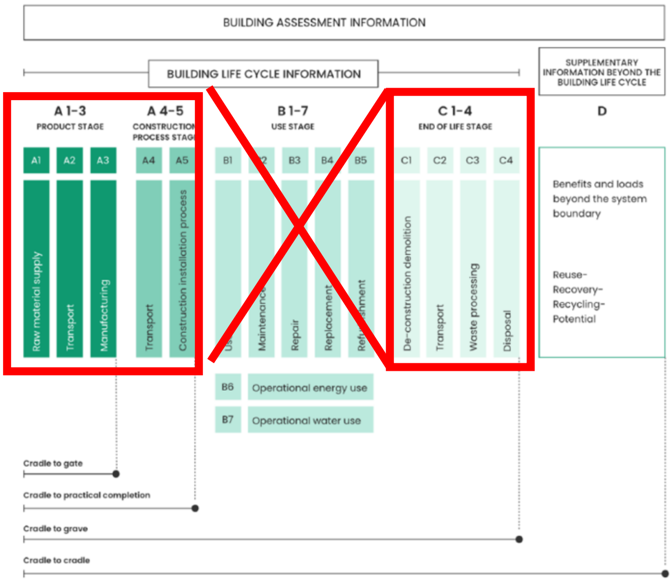



Figure 1. Definition of the phases considered in the LCA analysis.

The method used for calculating the emission for each phase considered (i) is to multiply the corresponding carbon emission factor of every single material, $ECF_{mat,i}$, defined on the basis of the EPDs provided by the individual producers, by the quantity of material, $Q_{mat}$:

$$EC_{mat}=Q_{mat}\times\sum_{i} ECF_{mat,i} \qquad (1)$$

Where:
- $EC_{mat}$ is the embodied carbon of the single, expressed in kg/$CO_2$e;
- $Q_{mat}$ is the amount of the single material, expressed in kg;
- $ECF_{mat,i}$ is the carbon emission factor, expressed in kg$CO_2$e per kg of material for the phase i.

The sum of the contributions $EC_{mat}$ of all the structural materials composing the reinforces concrete and RC structures provides the actual carbon footprint of the building.

## 3 DESCRIPTION OF BUILDINGS

The buildings analyzed are two new nursing home built in Northern Italy (Friuli Venezia Giulia) and are developed on two floors above ground: a ground floor and a first floor, for a total surface area of approximately 550 $m^2$ per floor. Both are characterized by a wall structure with shallow foundations with inverted concrete beams and a roof made of laminated wood beams and OSB planking. The comparison between the two buildings is therefore conducted considering only the elevated structures, one with solid reinforced concrete walls and the other with CLT panels, and the floors, one with prefabricated concrete lattice slabs and the top in CLT panels, as the remaining portion of the building is substantially the same in terms of typology, quantity and size.

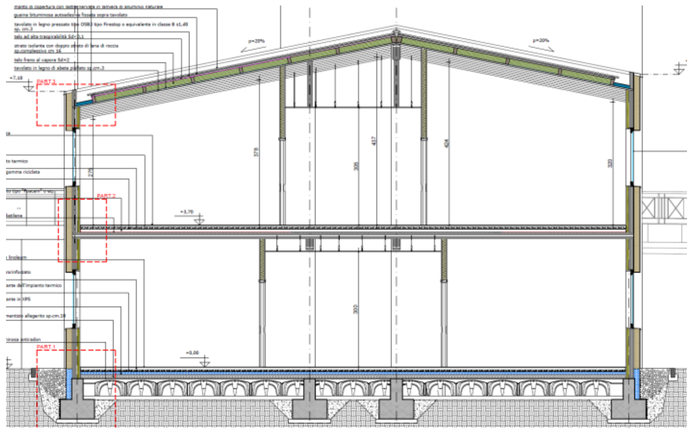


Figure 2. Section of the building.

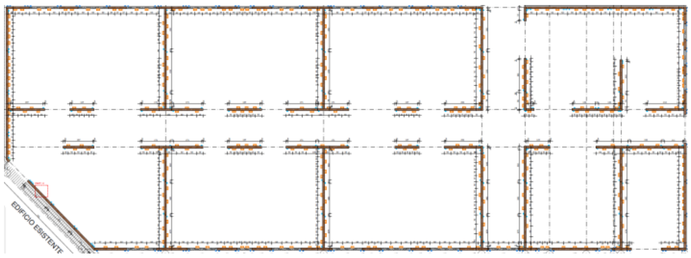


Figure 3. Plan of the building.

## 4 EMISSIONS CALCULATION

### 4.1 *Reinforced Concrete results*

For the concrete building, all the phases concerning the production, transport, installation, demolition and disposal at the end of the life of the elevated structure and of the floors were considered, distinguishing between the contribution of the concrete and the reinforcing steel. The carbon factors adopted in the calculation of emissions were defined on the basis of the manufacturers' EPDs as in Table 1:

Table 1. ECF values for each material.

| | ECF (kg$CO_2$e/kg) | | | | |
|---|---|---|---|---|---|
| **Material** | **A1-A3** | **A4** | **A5w** | **C2** | **C3-C4** |
| **Concrete** | 0,12 | 0,005 | 0,008 | 0,05 | 0,013 |
| **Steel** | 0,684 | 0,0213 | 0,038 | 0,05 | 0,013 |

After having counted the quantities of concrete and steel needed for the construction, it was possible to obtain, for each type of structural element and for each phase of the manufacturing life, the $CO_2$ produced as is possible to see in Table 2.

Table 2. Calculation of $EC_{mat}$ for each construction phase for each material.

| Structural element | Material | $Q_{mat}$ (ton) | ECmat ($tonCO_2e$) A1-A3 | A4 | A5w | C1 | C2 | C3 | C4 | Total |
|---|---|---|---|---|---|---|---|---|---|---|
| Walls | Concrete | 686,93 | 106,3 | 4,2 | 6,5 | 2,6 | 10,8 | 6,6 | 2,8 | |
| | Steel | 34,83 | | | | | | | | |
| Slabs | Concrete | 185,95 | 29,7 | 1,2 | 1,8 | 0,7 | 3,0 | 1,8 | 0,8 | |
| | Steel | 10,82 | | | | | | | | |
| Beams | Concrete | 71,14 | 12,5 | 0,5 | 0,8 | 0,3 | 1,2 | 0,7 | 0,3 | |
| | Steel | 5,73 | | | | | | | | |
| Stairs | Concrete | 4,32 | 0,8 | 0,0 | 0,0 | 0,0 | 0,1 | 0,0 | 0,0 | |
| | Steel | 0,4 | | | | | | | | |
| | | | 149,2 | 5,8 | 9,2 | 3,6 | 15,0 | 9,1 | 3,9 | 195,8 |

The phase with the greatest impact in Table 2 is the one related to the production of the material, while transportation, construction of the building and disposal of construction site waste have a limited contribution to emissions.
The production of carbon dioxide at the end of the building's life in Table 2 has been calculated assuming that 30% of the materials is sent to landfill and that 70% of the steel is recycled, with 70% of the concrete reused as coarse aggregate.

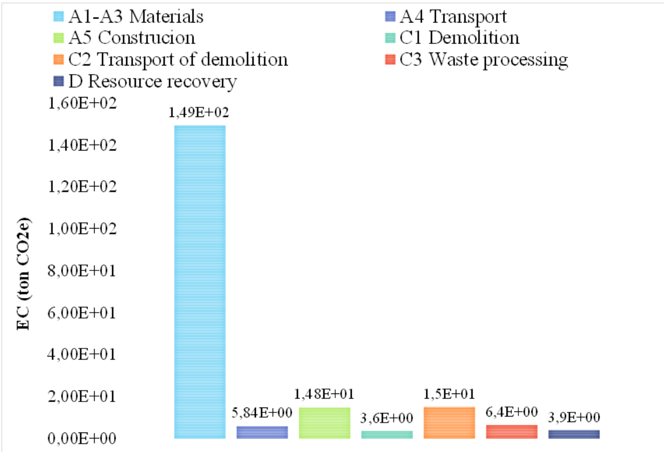



Figure 4. Production of $CO_2$ of each construction phase.

From Table 2 and Figure 4 is evident that, under the hypotheses formulated, the $CO_2$ impact related to the production of the material is much more significant than that emitted during the other phases.
Although the use of concrete aggregate reduces the $CO_2$ emissions, the demolition, crushing and transport phase of the recycled material to a new site always provides values greater than zero (Figure 4 phase C4).

## 4.2 *CLT Results*

In the evaluation of the carbon dioxide emitted by the construction of the CLT building, all the phases from construction to the end of the structure's life were considered, as in the previous case. In particular, two different cases were taken into consideration at the end of the building's use:
a) The first case considers disposal through combustion and energy recovery;
b) The second case assumes that all the panels would be used again for a new construction.
This second case is possible by the CLT construction system, being prefabricated and assembled on site with screws, can easily be dismantled at the end of its life. The panels guarantee, if correctly protected from humidity and subjected to maintenance, an operating period well over 50 years and therefore can be used several times for the construction of buildings before having to be disposed of through combustion. A fundamental precaution to ensure easy reuse of the material is to prefer the use of screws rather than nails in the plate connections, since the latter would be difficult to extract without damaging the panels themselves.
For calculating the amount of $CO_2$ emitted by the CLT building during the various phase Equation (1) has been adopted. The adopted carbon emission factors $ECF_{mat,i}$, are provided directly by the manufacturers' EPD certificates as we see in Table 3.

Table 3. $ECF_{mat,i}$ coefficients adopted

| Material | $ECF_{mat,i}$ ($kgCO_2e/kg$) | | | Case a | | | | Case b | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | A1-A3 | A4 | A5w | C1 | C2 | C3 | D | C1 | C2 | C3 | D |
| CLT | 0,437 | 0,011 | 0,006 | 0,020 | 0,008 | 1,65 | -0,56 | 0,020 | 0,008 | 0,00 | -0,19 |
| LVL | 0,512 | 0,011 | 0,007 | 0,020 | 0,008 | 1,65 | -0,56 | 0,020 | 0,008 | 0,00 | -0,19 |
| Steel for connections | 2,72 | 0,000 | 0,000 | 0,0006 | 0,0047 | 0,044 | -1,167 | 6E-04 | 0,0047 | 0,044 | -1,167 |

Zero coefficients were adopted in the case of steel connection plates for phases A4 and A5w since this emission is already taken into account in the coefficients relating to wood. In the case a), assuming incineration, it is necessary to take into account that all the carbon incorporated in the wood is released back into the atmosphere together with emissions related to combustion; however, it is taken into account that the heat generated is used to heat water, thus resulting in energy savings. The steel plates are recycled.

Table 4. Calculation of $CO_2$ emitted in the a) case.

| Element | $Q_{mat}$ (ton) | ECmat ($tonCO_2e$) A1-A3 | A4 | A5w | A5a | C1 | C2 | C3 | D | Total |
|---|---|---|---|---|---|---|---|---|---|---|
| Walls | 85,48 | -102,8 | 0,9 | 0,5 | 3,3 | 1,7 | 0,7 | 141,1 | -48,2 | |
| Slabs | 42,65 | -51,3 | 0,5 | 0,2 | 1,7 | 0,9 | 0,4 | 70,4 | -24,0 | |
| Beams | 14,44 | -16,3 | 0,2 | 0,1 | 0,6 | 0,3 | 0,1 | 23,8 | -8,1 | |
| Steel for connections | 1,9008 | 5,2 | 0,0 | 0 | 0,1 | 0,0 | 0,0 | 0,1 | -2,2 | |
| | | -165,3 | 1,6 | 0,8 | 5,6 | 2,9 | 1,2 | 235,5 | -82,6 | -0,3 |

Table 5. Calculation of $CO_2$ emitted in the b) case.

| Element | Qmat (kg) | ECmat (tonCO2e) A1-A3 | A4 | A5w | A5a | C1 | C2 | C3 | D | Total |
|---|---|---|---|---|---|---|---|---|---|---|
| Walls | 85,48 | -102,8 | 0,9 | 0,5 | 3,3 | 1,7 | 0,7 | 0,0 | -16,3 | |
| Slabs | 42,65 | -51,3 | 0,5 | 0,2 | 1,7 | 0,9 | 0,4 | 0,0 | -8,1 | |
| Beams | 14,44 | -16,3 | 0,2 | 0,1 | 0,6 | 0,3 | 0,1 | 0,0 | -2,8 | |
| Steel for connections | 1,9008 | 5,2 | 0,0 | 0,0 | 0,1 | 0,0 | 0,0 | 0,1 | -2,2 | |
| | | -165,3 | 1,6 | 0,8 | 5,6 | 2,9 | 1,2 | 0,1 | -29,4 | -182,5 |

In the case b) of reusing panels and plates, the only emission is generated by the transport and dismantling of the building, since in the other phases a saving in terms of carbon dioxide production is guaranteed.
On the basis of the quantities calculated for each type of material, the emissions during the life phases of the structure have been calculated for the two different cases represented in Figure 5 and in Figure 6.

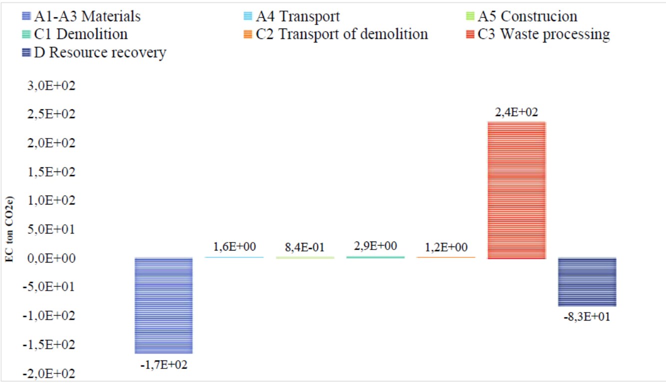



Figure 5. Emission of $CO_2$ for case a).

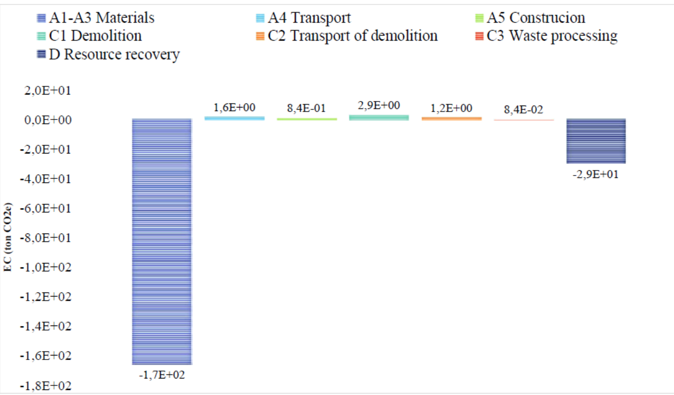



Figure 6. Emission of $CO_2$ for case b).

The graphs show how with combustion all the carbon incorporated by the wood is released back into the atmosphere, strongly impacting the total balance, while with energy recovery there is a subsequent saving. With the reuse of the panels the carbon dioxide saved (therefore with a negative value) is lower than in the previous case, however, in this case, this reduction must be added to the incorporated carbon, with a more sustainable overall balance. In both cases it is observed how the emissions associated with the phases between A1-A3 and C3 are negligible compared to the others.

## 4.3 *Comparison between RC and CLT*

The comparison between the two buildings is conducted for both the wood combustion scenery and the recycling cases. For the case a), as Figure 7, the CLT is more impactful only in the combustion phase, while for all the others it is well below concrete. Not evaluating the single phase, but taking into consideration the overall emission of the structure, CLT appears to be more sustainable, even resulting "negative": it means that the use of CLT permits the absorption of $CO_2$.

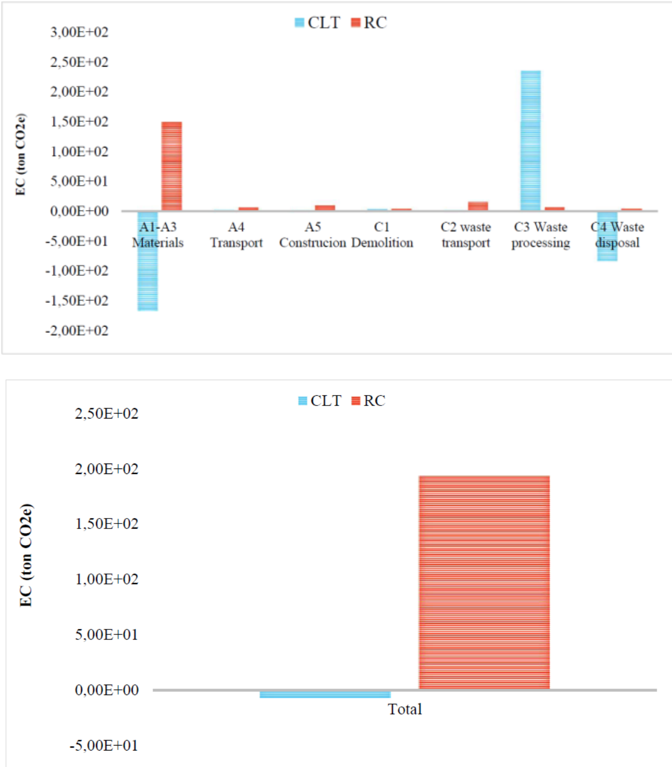
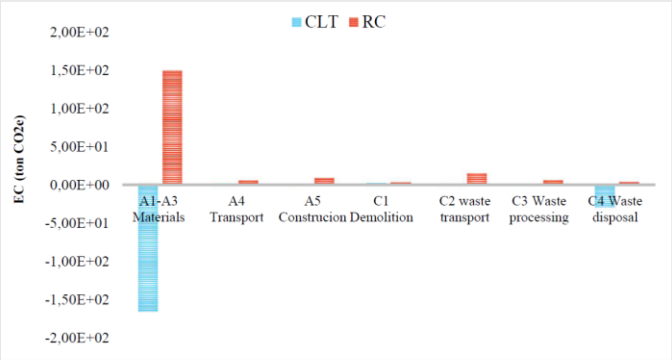



Figure 7. Comparison between RC and CLT case a).

By consideratings the recycle of CLT panels (case b), $CO_2$ emission lower than with concrete has been obtained in each phase of the structure's life cycle as is possible to see in Figure 8.



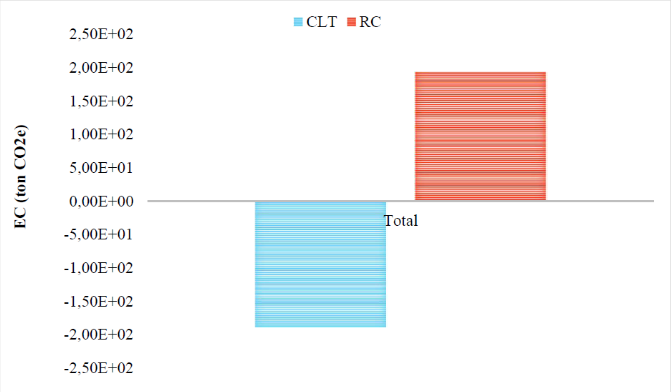




Figure 8. Comparison between RC and CLT case b).

In this case, the carbon incorporated by the wood during its growth phase as a plant is also taken into account, leading to an overall impact that is much lower than zero as is possible to see in Figure 8.

## 5 CONCLUSIONS

Nowadays, concrete is the most widespread building material in the world, however, during its production process, a huge amount of carbon dioxide is released into the atmosphere. This study has provided a possible alternative to the use of this material: wood, in the form of CLT panels. This technology, widely established in many European countries, guarantees very high performance, comparable to that of concrete. The results obtained from a comparison of emissions in terms of $CO_2$ demonstrate how the use of wood panels guarantees enormous savings compared to a traditional building and, in an optimum of sustainability in the construction world, an absolute balance of negative carbon dioxide production, and therefore the amount released into the atmosphere is lower than that which is incorporated by the material during its life cycle. It is therefore essential that designers increasingly try to propose these innovative technologies to clients, in order to reduce the environmental impact of the construction world.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