

The Environmental Profile of Wood in the Building Industry Today: Comments on the Results of Some LCA Studies

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Abstract In the last years, following the technological progress in wood processing industry and the increased use of wood-based products in construction industry, the scientific community has investigated the environmental performances of wood-based building materials and their substitution potential of energy-intensive material.

The article describes and comments the results of a representative sample of LCA studies, most of them published in international journals or in free access research reports. All analyzed LCA studies compare wood, as a building system, with other materials and construction technologies (such as reinforced concrete, steel and masonry); these studies highlight the potential of wood-based building materials to improve the environmental performances of construction industry besides the possible negative aspects related to the wood product manufacturing and the construction process. Some methodological limits are considered comparing LCA results among selected studies, because of the variability of the case studies, the subjectivity of the system boundary definition and the differences between the referenced data sources. However the comparative purpose of this analysis provides an interesting framework of the current research and highlights how timber buildings and wood-based products could still improve their environmental performances during all life cycle stages. Wood, as construction material, could increase its competitiveness in building industry thanks to its environmental performances, starting from its renewable source and its carbon storing potential.

Keywords: wood, LCA studies, embodied energy, Global Warming Potential

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1. Introduction

Wood as renewable resource – when dealt with in a sustainable manner – is generally considered an «environmentally friendly» material [26] and such we often tend to consider its by-products, including products used in construction. However, progressive engineering of wood (engineered wood products) in the last decades has led to an intensification of industrial processes, aimed at improving its performances, in particular its mechanical endurance and its durability.

Today the increasing supply of wood-based construction materials leads to a multiplicity of products, different for environmental performances and also for technical performances, functional characteristics and woody species. However, there is a lack of information about wood products [10] and in particular about their environmental performances; advertising measures and product information are usually inadequate to allow customers and decision-makers to understand environmental consequences of their choices. Moreover it's difficult to evaluate environmental sustainability in

construction industry without a standardization of environmental assessment criteria and methodologies (see green building certification systems). So many environmental labels don't provide clear information on real environmental performances of building products.

The ISO 14000 family has become an international reference for environmental management systems and in particular ISO 14040:2006 describes the principles and the framework for Life Cycle Assessment (LCA).

LCA-guidelines were created in 1993 by SETAC (Society of Environmental Toxicology and Chemistry), which presents the name of the method and its general structure first. Life Cycle Assessment is a comprehensive method for estimating the environmental impacts of a product (in construction industry, building products as well as entire buildings) "from cradle to grave".

In order to understand the potential impact of using wood in construction, it is necessary to refer to the LCA tool (Life Cycle Assessment).

The LCA procedure, by its own nature, allows the carrying out of comparative studies between products as well as between whole buildings, provided that there is a correspondence between: the system boundaries, which establish the life cycle stages and related fluxes of

material and energy to be taken into consideration with respect to the prefixed target; the functional unit, that is to say the unity used for confrontation with the objects taken in exam and to which respect environmental impacts are computed; and eventually calculation procedures.

These characteristics make LCA a method particularly suited to the anticipated study, although some inherent constraints are present.

First of all, LCA studies, particularly those concerning buildings, are collected in papers containing hundreds of pages, often not available to the scientific community and made accessible to the public in a synthetic form through publications on reviews. Therefore most of the articles do not thoroughly describe the procedure followed and are only partially comparable between them [22].

To the purpose of this study this constitutes a constraint, as we aim to confront LCA procedures collected in literature, applied to buildings with wooden structure or other materials and structural systems.

Furthermore, it is useful to remember what a particularly complex object is a building, subject to variables (transport of material, execution of building works, maintenance cycles, users' behavior and so on) which entail the formulation of hypothesis which can influence the final result.

Industrial technology manufactory and efficiency can also evolve in time, thus determining a reduction of the necessary energy and polluting emissions [12-25].

These elements determine a substantial uncertainty when identifying data and when the comparative evaluation of data has a decisional purpose, that is to say one operates ex-ante and not ex-post the construction stage.

Since evaluated environmental impacts are not studied in their temporal and spatial development, then the methodology does not consider eventual toxic after-effects of prolonged exposition to chemicals [31].

Finally, Life Cycle Assessment usually doesn't take into account the environmental impacts of wood-based products related to land occupation and forestry activities as well as the benefits derived from forest ecosystem services, such as biodiversity conservation and air purification [31].

2. Analysis

Once exposed the fundamental constraints to the environmental evaluation tool, here follows the description of a study with a comparative purpose, starting from the analysis of selected cases from specific literature.

Table 1. Information on LCA surveys on buildings, concerning authors, year of publication, place of the study and a comparison between building technologies

	AUTHORS	YEAR (PUBLICATION)	GEOGRAFICAL CONTEXT	CONSTRUCTION TECHNOLOGY							
				TIMBER (X-LAM)	TIMBER (FRAME)	REINF. CONC.	CONC. BLOCK	STEAL	BRICK	MIXED	
1)	Bramati, Mazzoleni	2010	Italy								
2)	Buchanan, Levine	1999	New Zealand								
3)	Camponovo et al.	2006	Swiss								
4)	Cole, Kernan	1996	Canada								
5)	Eriksson (Adalberth)	2003 (2000)	Sweden								
6)	Eriksson (Björklund, Tillman)	2003 (1997)	Sweden								
7)	Eriksson (Meil et al.)	2003 (2002)	USA								timber- conc. block
8)	Eriksson (Norén, Jarnehammar)	2003 (2001)	Sweden								prefab conc.-steal
9)	Eriksson (Scharai- Rad, Welling)	2003 (2002)	Germany								
10)	Eriksson (Trusty, Meil)	2003 (1999)	Canada								
11)	Gerilla et al.	2007	Japan								
12)	Gustavsson, Joelsson	2010	Sweden*								
13)	Gustavsson, Pingoud, Sathre	2006	Sweden-Finland*								
14)	John et al.	2009	New Zealand								
15)	Lippke et al.	2004	USA*								
16)	Martínez, Casas	2012	Spain								
17)	Nässén et al.	2012	Sweden								
18)	Peuportier	2001	France								timber- stone
19)	Scharai-Rad, Welling	2002	Canada								timber-steal
20)	Scharai-Rad, Welling (Baier)	2002 (1982)	Germany								
21)	Thiers, Peuportier	2012	France								

NOTES

12) * : Among the eleven case studies compared by the authors, only Växjö case study is considered.

13) * : The authors compare two couple of buildings, starting from two case studies in Sweden and Finland.

15) * : The authors compare two couple of buildings, starting from two case studies in Minneapolis (timber-steal) and Atlanta (timber-concrete).

We have taken into consideration a LCA study sample at building's scale, recorded through publication of reports, proceedings or articles on specialized reviews. Each considered evaluation compares wood, as a building system, with other materials.

First of all, it has been necessary to gather information about 'surrounding conditions' which were at the base of the evaluations, in particular the life cycle stages analyzed and the functional unit. Those data have been summed up in the following tables, specifying year of publication,

geographical location of the study and building technologies (wood or not) object of the analysis.

As shown in Table 1, studies have mostly been carried out in Europe and United States (exceptionally also in New Zealand and Japan); these are countries where timber building tradition is more rooted and the practice of Life Cycle Assessment is currently more developed in comparison to other countries considered by this study.

Moreover, it is worth observing that most of the LCA analysis consider wood frame constructions (rather widespread in Northern Europe and America) almost a 'conventional' building method; only one survey, particularly recent, starts from the evaluation of a massive X-Lam panels system, a technology which only recently has seen a major diffusion in Europe.

Among other building technologies examined we find reinforced concrete and steel constructions and those in brickworks and blocks of concrete, chosen for their level of diffusion in the country where the study has been carried out. Although frame structures need various kind of infill walls, variable also depending on the different

national building custom, indication of a technological 'mixed' system has been judged necessary only when the structural part of the building is actually made of different materials (for example, steel beams and precast concrete panels).

It must be clear that some studies refer to more than two buildings at the same time. Anyway, highlighted final results (see Table 4) refer to aggregative collected data.

Table 2 and Table 3 clarify the so called 'surrounding conditions', which have been adopted and signaled in the articles and, in particular, the referred functional unit (necessary in order to compute obtained results) and evaluated life cycle stages.

One observes how buildings themselves are often considered functional units by comparing buildings as organisms which fulfill the same functions, such as to enable the carrying out of specific activities and secure a certain standard of internal comfort [23]. Nevertheless, for a better comparability of final data, aggregated results for environmental impact are usually compared with the surface unit calculated for the buildings themselves.

Table 2. Information on LCA studies on buildings, concerning considered functional units and buildings' characteristics

	AUTHORS	FUNCTIONAL UNIT	BUILDINGS' CHARACTERISTICS
1)	Bramati, Mazzoleni	square meter of floor area	three-storey buildings, within 672 mq of built-up area each, average height of 10 m, operation phase of 20 years
2)	Buchanan, Levine	square meter of floor area	94 mq of floor area for each building
3)	Camponovo et al.	entire building	three-storey buildings, within 280 mq of built-up area each, buildings' lifespan of 60 years
4)	Cole, Kernan	square meter of floor area	three-storey buildings, with 4620 mq of floor area each, buildings' lifespan of 25/50/100 years
5)	Eriksson (Adalberth)	square meter of floor area	multi-storey residential buildings
6)	Eriksson (Björklund, Tillman)	square meter of floor area	multi-storey residential buildings
7)	Eriksson (Meil et al.)	square meter of floor area	two-storey and single-storey buildings*
8)	Eriksson (Norén, Jarnehammar)	square meter of floor area	four-storey buildings
9)	Eriksson (Scharai-Rad, Welling)	square meter of floor area	single-family homes
10)	Eriksson (Trusty, Meil)	square meter of floor area	223 mq of floor area for each building
11)	Gerilla et al.	kg of emission per year per square meter	150 mq of floor area for each building, design life of 35 years
12)	Gustavsson, Joelsson	square meter of floor area	four-storey buildings, buildings' lifespan of 50 years
13)	Gustavsson, Pingoud, Sathre	entire building	four-storey buildings, buildings' lifespan of 100 years, 1190 mq of floor area each in the first comparison and 1175 mq of floor area each in the second one
14)	John et al.	entire building	six-storey buildings, 4247 mq of floor area each, buildings' lifespan of 60 years
15)	Lippke et al.	entire building	buildings' lifespan of 75 years, two-storey buildings with 190 mq of floor area in the first comparison and single-storey buildings with 200 mq of floor area in the second one
16)	Martínez, Casas	entire apartment/single-family home	an apartment with 90,88 mq of floor area and two two-storey single-family homes with 158,16 mq of floor area each
17)	Nässén et al.	square meter of floor area	four-storey buildings with 1190 mq of floor area each, operation phase of 100 years
18)	Peupartier	square meter of floor area	single-storey buildings with 212 mq of floor area each
19)	Scharai-Rad, Welling	square meter of floor area	three-storey buildings with 9750 mq of covered area each
20)	Scharai-Rad, Welling (Baier)	entire building	1000 mq of covered area and 6000 mc of volume for each building, average height of 6 m, operation phase of 20 years
21)	Thiers, Peupartier	square meter of floor area per year	a two-storey building with 132 mq of floor area and a five-storey building with 4500 mq of floor area

NOTES:

7) * : The authors compare separately two two-storey buildings (timber-frame construction and steel construction) and two single-storey buildings (timber-frame construction and timber and concrete combined construction).

LCA studies usually start from an existing timber building (mainly wood frame construction), which is

translated by the authors into different construction technologies, changing building structural systems and

construction materials (reinforced concrete, steel, masonry, etc). Then LCA studies compare the environmental performances of alternative building technologies.

Otherwise (8 studies out of 21) the studies consider a standard building, according to typical designs (considering the nationality of the research institute), sometimes basing on national surveys.

In these cases, functional equivalence of different buildings (different construction technologies) is ensured by common conditions, such as load carrying capacity, energy consumption during the operational stage and thermal properties of building envelope, according to authors' intention. For example, several studies consider the same thermal transmittance value of the building envelopes [4,6,7]; other studies consider the same

windows characteristics or the same plants for all case studies [12,13,16,23].

Life cycles stages which are definitely more studied are those concerning the production of materials suited to building construction, including intermediate means of transport. Only few surveys are inconclusive in the 'cradle to gate' stage for lack of information (see question marks in Table 3).

In these first steps, studies take advantage of national data from abroad have been contextualized for some product categories). For example, some LCA studies refer to Ecoinvent ([6,20,30]), Oekoinventare database ([23]), ICE and IBO databases ([4]), CORRIM from America ([19]), Forintek from Canada ([5,7]) and NZ dataset from New Zealand ([16]).

Table 3. Information on LCA studies on buildings, concerning considered life cycle stages

AUTHORS	LIFE CYCLE STAGES						
	EXTRACT.	MANUF.	TRANSP.	CONSTR.	USE	MAINTEN.	END LIFE
1) Bramati, Mazzoleni							
2) Buchanan, Levine							
3) Camponovo et al.					*		
4) Cole, Kernan							
5) Eriksson (Adalberth)							
6) Eriksson (Björklund, Tillman)							
7) Eriksson (Meil et al.)							
8) Eriksson (Norén, Jarnehammar)							
9) Eriksson (Scharai-Rad, Welling)							
10) Eriksson (Trusty, Meil)							
11) Gerilla et al.	*	*	*	*		*	*
12) Gustavsson, Joelsson							
13) Gustavsson, Pingoud, Sathre							
14) John et al.							
15) Lippke et al.					**	**	**
16) Martínez, Casas							
17) Nässén et al.			?				
18) Peuportier							
19) Scharai-Rad, Welling	?		?				
20) Scharai-Rad, Welling (Baier)	?						
21) Thiers, Peuportier							

NOTES

3) * : The use stage is equal for all case studies

11) * : The EE indicator is not evaluated for these life cycle stages.

15) ** : In these stages authors consider the same EE and GWP values for all case studies.

The subject of maintenance instead, although being potentially relevant in the field of wood construction, has been dealt with only by a third of the analyzed studies. Several studies signal the poor relevance of environmental impacts during this stage and the insignificance of differences between different constructive solutions [5,7,12,13,16]. These are the reasons why the maintenance

stage is often neglected or assumed as identically affecting all the compared buildings.

However, some analyzed studies highlight that building maintenance and refurbishment could weigh on environmental impacts of buildings. For example, the replacement of building elements made of energy-intensive materials, such as MDF and plywood panels,

could significantly increase the total lifetime energy use and GWP of a building [16]; furthermore, such kind of materials are commonly used in wood constructions.

The construction and the operational site are others generally omitted life cycle stages.

The former often considered as scarcely affecting the total amount of energy and total emissions, such that

according to some sources the construction stage represents 5% of the materials' embodied energy ([8] and [29] cited in: [12]). In general, consumption's variance between different construction technologies is considered negligible [21].

Table 4. Synthesis of buildings' LCA final results, expressed in the form of favorable/unfavorable outcomes compared with other materials

	AUTHORS	ENVIRONMENTAL INDICATORS	
		EE	GWP
1)	Bramati, Mazzoleni	-	+
2)	Buchanan, Levine	+	+
3)	Camponovo et al.	-	+**
4)	Cole, Kernan	+	
5)	Eriksson (Adalberth)	+	
6)	Eriksson (Björklund, Tillman)	+	+
7)	Eriksson (Meil et al.)	+	+
8)	Eriksson (Norén, Jarnehammar)	+	+
9)	Eriksson (Scharai-Rad, Welling)	+	+
10)	Eriksson (Trusty, Meil)	+	+
11)	Gerilla et al.	+	+
12)	Gustavsson, Joelsson	+	+
13)	Gustavsson, Pingoud, Sathre	+	+**
14)	John et al.	-/+*	+
15)	Lippke et al.	+	+
16)	Martínez, Casas	-/+*	-/+*
17)	Nässén et al.	+	+
18)	Peuportier	+	+
19)	Scharai-Rad, Welling	+	+
20)	Scharai-Rad, Welling (Baier)	+	+
21)	Thiers, Peuportier	+	+

NOTES:

3) **: The authors don't evaluate the GWP indicator but consider several damage categories whom are aggregated into a single environmental score (Ecoinvent database).

13) **: The GWP calculation also considers the carbon stock of wood products and the contained emissions due to the energy produced by biomass during the manufacturing process.

14) * : The EE value for the timber construction is worse than the EE value for the concrete construction but better than the steel one.

16) * : The EE and GWP values for the timber construction are worse than the EE and GWP values for concrete construction but better than the masonry ones.

The operational stage is often not evaluated as it goes beyond considerations concerning only the use of wood and other construction materials. It is considered only where it puts in evidence energy performances of the buildings object of the study and in order to evaluate his effect on consumptions' total level.

During the end of life stage different perspectives are brought about for wood, which make it a particularly virtuous material compared to others, among which

prevails demolition waste incineration [12,16,28] or its recycling [21]. In particular, estimates about the recycling potential of a building differ considerably in the literature; some analyzed studies assume recycling rates up to 80% (see studies cited by [21]), reducing waste creation [23].

Eventually, the last table shows results for comparative LCA studies, meant as favorable (+) or unfavorable (-) to wood, compared to other construction technologies previously indicated (see Table 1).

In particular, two indexes are shown which are considered the most significant: Embodied Energy (EE) and Global Warming Potential (GWP). The first one “refers to total consumed energy during the raw materials’ various stages: acquisition, transport from sampling to production point, transformation of raw materials into final product, products’ setting up (including all kinds of on-site processing and installation). [...] Moreover, it is necessary to consider that a building’s Embodied Energy increases in time because of maintenance and replacement operations which are determined by different techno-constructive solutions” [18]. The Global Warming Potential (GWP) Index, expressed in CO₂ equivalent mass, assesses the emission of all gases which contribute to greenhouse effect along with CO₂.

Provided the poor comparability of the analyzed studies due to the considered ‘surrounding conditions’ and insufficient gathered data [22], it is impossible to provide quantitative results concerning environmental wood performances compared with other materials employed. The same results’ representation in the table (shown by + and -) intentionally aims to express a generic framework without vertically comparing the exact numeric values. Nevertheless, this is proof of how wood construction technology shows higher performances, environmentally speaking, compared with ‘conventional’ solutions, such as concrete (reinforced and cast or in blocks), steel and blockwork. In particular, it should be noted that low embodied energy content and reduced polluting emissions are attributed to wooden buildings during the ‘cradle to gate’ stage; this is due to the controlled consumption of the industrial production activity and the biomasses’ ability to stock carbon.

For this reason, major environmental impact is related to energetic consumption for the process of wood drying, for which wood waste is often employed as energy source [27].

This is why wood is considered by most of the studies as a perfect substitute of others functionally equivalent materials in the construction industry; not only in residential sector, but also in tertiary sector construction [7,16] and the industrial sector [28].

In particular, comparisons in which wood has proven disadvantageous are those related to concrete [16,20], although these results may have partially been influenced by the authors’ choices in relation to the buildings characteristics. This particularly happens when pre-existent building case studies are taken into consideration (see, for example, the case study of [20]) which, by their very nature, are not completely comparable.

3. Conclusions

According to this study, it is possible to highlight some limits of LCA application to wood constructions. With respect to results emerged from LCA studies, it is worth mentioning that the use of wooden building products necessarily implies an influence on forest soil exploitation and, consequently, on its ecosystem [6]; therefore, it would be appropriate to consider ecosystem services when assessing total environmental impacts, although this makes the analyses even more complex [24] and unfortunately not all LCA studies include such aspects to

this day [31]. If LCA procedure took into account the impacts of forest management practices on environmental services, sustainable forest management could be rewarded, rather than irresponsible timber harvest or other destructive forms of manufacturing processes.

The increasing number of wood-based construction materials and wood construction technologies asks the databases to be more quickly updated; for example, in the case [4], the LCA of X-Lam building bases on environmental data of laminated wood (ITC-CNR database) because of the lack of environmental data of cross-laminated timber panels (X-Lam); so the LCA results of X-Lam building are distort and environmental impacts of the building increase significantly [4]. In this sense, manufacturers should be encouraged to provide environmental information of their products openly, so as to simplify information management and updating system and also provide a green marketing opportunity.

According to LCA results, in the production area wood proves to be already competitive compared with other materials, though there surely is room for improvement. For example, it seems useful to increase renewable sources usage for energetic purposes within industrial processes, above all in cases where raw material is combined with energy intensive materials or is subject to wasteful processes (let’s think of X-Lam, [4]). Furthermore, although opinions contrast about transport effect on the life cycle of timber buildings, it is generally accepted that these cannot constitute a negligible variable. Most importantly if we consider contexts (for example, Italy), where wood and building based industry is underdeveloped and the raw material employed is mostly retrieved beyond the Alps. Careful consideration of displacements among the stakeholders in the chain becomes essential for all those geographical areas where wood-based industry is not present [20]. This also leads to considerations about the ecological advantages which could be determined by the development of local wood-based industries (among others) and the diversification of forestry production.

Finally, although several studies signal the poor relevance of environmental impacts during building maintenance, some practices could be highlighted for improving environmental performances. Firstly, these practices should combine the concerns about materials’ embodied energy with deepened studies of maintenance cycles and their actual energy consumption. For example, the studies [7] and [16] highlight that there are some building elements made of energy-intensive material (for example, aluminum) which need for frequent replacement over the building life cycle (windows, external finishes, etc); so they could be replaced with wood products, reducing embodied energy and pollution emissions related to the maintenance stage. Then some analyzed studies suggest that future researches should focus on the durability of building materials and the ability to replace elements within a total building assembly [7,12].

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