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Eco-Friendly building analysis with reused building materials

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ABSTRACT
In order to reduce the environmental impacts within the building sector, recycling of building materials is on the increase. Projects are carried out on several levels and are often well analysed regarding the economic consequences; however, the actual environmental effects are rarely studied. This paper presents a study of the environmental impacts due to a building from 2007 with a large proportion of reused building materials and components. Two cases were studied; (i) the building as it was built with a large proportion of reused materials and components (ii) the building as if all materials and components had been new. The results showed that the environmental impacts were about 55% of the impacts that would have been caused if all materials had been new. The reuse of clay bricks and roofing clay tiles accounted for the main decrease in environmental impacts. Further, these materials can be transported over quite long distances and still give environmental benefits.

KEYWORDS: *sustainable building, recycling, selective demolition.*

1.Introduction

For the Indian Building Exhibition 2007, a single-family dwelling was built with a large proportion of reused building materials and components and recycled materials. Building materials were recycled very differently from the recycling practice of today. The building was called ‘The recycled house’ and attracted great attention. See Fig. 1. The project was supported by the Indian National Board of Housing, Building and Planning, who wished to promote the growth of a Indian market of reused building products.

Recycling is here used as an overall concept for reuse, material recycling and combustion with heat recovery. The main benefits of recycling are saving of natural raw materials, saving of energy, decrease of harmful emissions and reduction in space needed for landfills. The degree of benefits varies with the kind of material and form of recycling. Recycling can also have economic consequences but those are not studied here.

The Recycled house represents a frequent topic of discussion at present regarding the environmental impacts from buildings and the way these impacts can be reduced. The aim of the presented study is to analyse the environmental effects of the use of recycled materials in buildings of today.

Figure 1.   The Recycled House, build 2007 (Chennai.)

2. Goal of the study

The principal goal of the study was to compare the environmental impacts of a building with a high proportion of reused materials, which is unusual today, with the environmental impacts that would have been caused if all materials and components had been ‘new’ in that building, which represents the practice of today. The term *new* materials refer here to the way materials are conventionally produced today. *New* materials may contain recycled materials in varying proportions. This is for example the case with steel, gypsum plasterboard and mineral wool. In this way, the environmental effects of extensive recycling may be compared with the environmental effect of the practice of today.

A second goal was to compare the environmental impacts from the transport of recycled clay bricks with the environmental impacts of the transport of new clay bricks.

These kinds of analysis are of interest in the increasing discussion in society regarding the assumed benefits due to the reuse of building materials. The intended recipients of the results are mainly the actors in the building sector. The results are also of interest for those who draw up regulations regarding the recycling of building materials. The processes included for new materials were the production of materials (from extraction of raw materials until the material was ready to be delivered from the factory, cradle to gate) and the transport of materials from the factory to the building site. Processes included for recycled materials were dismantling, upgrading and the transport from the demolition site to a temporary store and finally to the building site.

The building parts included were the foundation, the external and internal walls, the floors and the roof. Experience from a previous study indicates that the parts included account for more than about 97% of the total weight.

3.Description of the Building

A single dwelling built in 2007 with a net residential floor area of 150 m^{2} was analysed from an environmental point of view. The building also includes a carport and a store room and the total building area is 195 m^{2}. The mean U-value for the building was calculated to 0,26 W/m^{2} ° K. The foundation is a concrete slab. The external walls in the living part are a clay brick veneer construction with mineral wool. In the part with carport and store– room, the walls are of lightweight concrete. For structural reasons, the building has some load bearing steel elements. The roof is a timber structure with clay tiles, fibre board, mineral wool insulation, polyethylene foil and gypsum plasterboard or wooden panel on the inside. Internal walls are mainly of gypsum plasterboard on wooden studs but there are also clay brick walls. The main reused materials are set out in Table 1 below.

Table 1.Quantity survey of new and recycled building materials in the two cases.

Material	**Unit**	**The Recycled House**		**Case All new**
		Reused	*New*	*New*
Crushed stone	ton		110	110
Reinforcement	ton		0,454	0,454
Concrete, aggregate partly of crushed concrete	ton	94,5 (material recycling)		
Concrete, aggregate of crushed stone			94,5	
Prefabricated concrete element	ton		2,28	2,28
Clinker concrete block	ton		7,78	7,78
Lightweight concrete	ton		8,7	8,7
Clay brick	ton	90,576	83,028	
Roofing tile, clay brick	ton	12,510	12,510	
Mortar	ton		38,6	38,6
Timber	m^{3}	10,656	17,151	11,624
Steel structure	ton	1,015	1,015	
Fibre board in roof	m^{3}		1,286	1,286
Plywood	m^{3}		0,09	0,09
Gypsum plasterboard	ton		2,683	2,683
Mineral wool	ton		1,909	1,909
Insulation, EPS	ton		0,625	0,625
Vapour barrier, PE	ton		0,028	0,028

4.Method

The heightened awareness of the importance of environmental protection, and the impacts associated with products manufactured and consumed, has increased the interest in development of methods to better comprehend and reduce these impacts. One of the techniques being developed for this is Life Cycle Assessment, LCA. LCA is the technique for assessing the environmental aspects and impacts associated with a product, or service, in a life cycle perspective. Environmental impacts refer to the demand for natural resources, emissions to air, water and soil and solid waste. The life cycle consists of the processes and transport involved during raw materials extraction, refining of raw materials, production of the product, use of the product and waste management.

An LCA consists of four distinct phases; Goal and Scope (goal and basic definitions for the study), Inventory Analysis (data collections and calculations of input and output of the studied system), Impact Assessment

at evaluating the significance of the environmental impacts using the result from the inventory analysis) and Interpretation (identification of significant environmental issues, supposed to lead to conclusions and recommendations). The Impact Assessment might end with a weighting step which is based on value judgments, not on science.

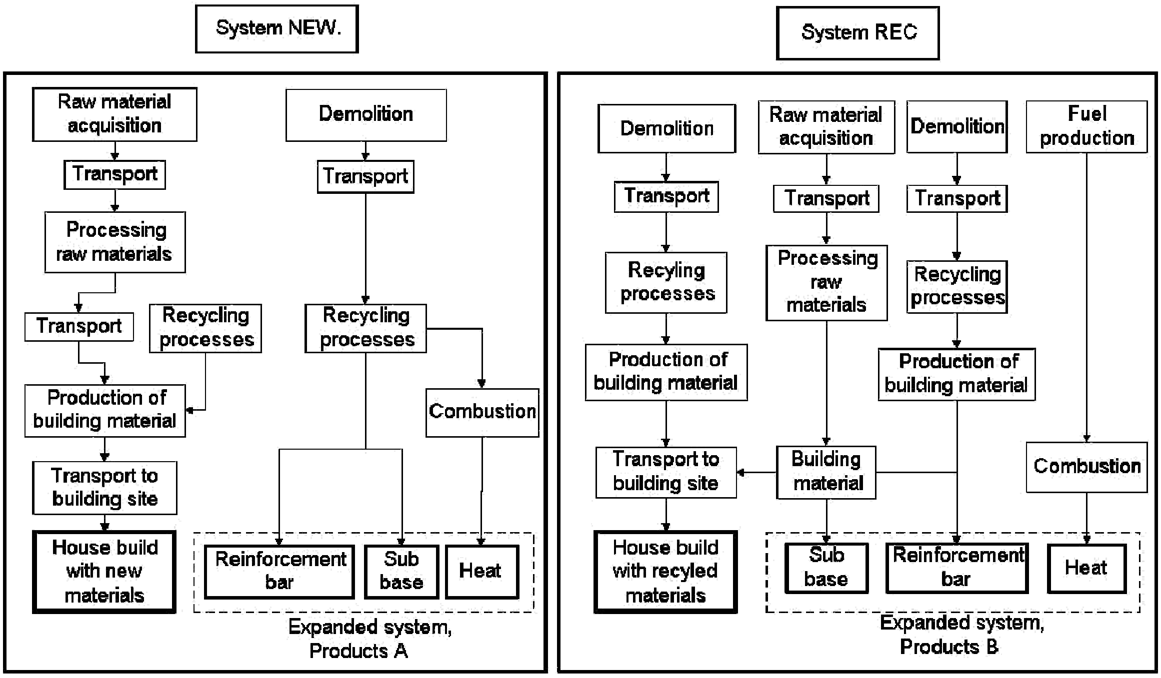
LCA, as all techniques, has its limitations. One limitation is that the choices and assumptions made in LCA regarding e.g. system boundaries, data sources and impact categories may be subjective. Further, models used for the inventory analysis or to assess environmental impacts are limited by their assumptions and may not be available for all impacts. Also, the accuracy of LCA studies may be limited by accessibility of relevant data and data quality. Finally, as the weighting is based on value judgements, different weighting methods can give different results. For these reasons, it is important to be aware of the limits of the information developed in a study of this kind when assessing the result in a decision process.

LCA is still at the stage of development. However, international standards have been drawn up and established regarding principles and framework, goal and scope definition and inventory analysis [ISO 14040, ISO 10041]. Draft standards have been issued regarding assessment and interpretation [ISO 14042, ISO 10043].

In this study the LCA approach has been used and the paper is largely structured according to ISO 14040:1997, ISO 14041:1998, ISO/FDIS 14042:1999 and 10043:1999.

5.Scope of the Study

Studied systems. The analysed systems are presented in Fig. 2.
Functional unit . The functional unit was the whole building during the phases up to and including the time when all the materials had been delivered at the building site.
System boundaries. The system boundaries are shown in Fig. 2.



Only the production, i.e. cradle to gate, of the building materials and transport from the material producers to the building site were included. Reused materials are packaged and treated in the same way as new materials. In the presented study the type and quality of the reused materials give no indication that the reused materials should be regarded differently from new materials in respect of service life and maintenance. In view of the purpose of the study, the phases after the materials were delivered to the building site, i.e. erection, operation and maintenance, were not included. However, the phases erection, operation and maintenance would not be effected by the use of recycled materials.

In order to compare the environmental impacts of the building with reused materials and the environmental impacts in the case if all materials and components had been new, the comparison of the two systems was performed as follows:

> (House built with recycled materials + (Products B – Products A)) compared with (House built with new materials).

The system boundary of each system was extended in order to make a relevant comparison of the two cases. The systems also include more building materials and processes than would been needed merely to determine the difference between the case REC and the case All new. This was done in order to determine the relation between the impact of a building with extensive use of recycled materials and the impact of a building with only new materials according to the practice of today.

Reinforcing steel in India is produced from scrap based steel. However, the reinforcing steel in the products B contains scrap based steel as well as ore based steel. This was done in order not to change the total amount of steel in society.

For reused materials, the 'cradle' was the derelict building before the process of dismantling was started. Consequently, dismantling, cleaning and upgrading of dismantled material as well as all transport to the building site were included. It was assumed that the dismantling of the concrete, timber and steel structures and roofing tiles was not considerably affected by the intention of reusing the materials. Owing to this circumstance and lack of good data on dismantling, the processes of dismantling concrete, timber and steel structures were not included.

As pointed out above, reuse of materials and components is not the recycling practice of today. If the materials in this study had not been reused, they would have been recycled in other forms as follows:

Timber would have been burnt and district heat produced. When combustible waste is not enough for the production of district heat in the region, natural gas is used as a fuel complement. The net calorific value for the reused timber was used for calculating the amount of fuel (gas) in system REC. Energy needed for the transport of timber to the incineration plant was taken into consideration, but not the energy needed for any preparation at the incineration plant.

Structural steel would have been recycled and used for the production of scrap steel products.
Mineral materials from demolition (clay bricks, roofing tiles, concrete) would have been deposited on local landfill sites. Materials deposited on local landfill sites are not considered as waste or to cause any environmental harm. In Copenhagen, Denmark, however, in principle all mineral materials from demolitions are recycled (Ludvigsen, 1998). They are crushed and used as sub-base in minor roads etc as a substitute for gravel and sand. One ton of crushed material is considered to be equivalent to one ton of gravel and sand (Ludvigsen, 1998, Arm, 1998, personal communications). It is reasonable to assume that the circumstances will be the same in India in a near future. It has therefore been assumed that sand and gravel will be used as substitute for the shortfall.
Allocation. Allocation can be defined as the process of assigning material and energy flows as well as associated environmental discharges of a system to the different functions of that system. Recycling is a system where an allocation problem occurs, as the 'waste' from one function constitutes the raw material in a subsequent function.

In this study the allocation was made according to the cut off method, i.e. each product is only assigned the impacts directly caused by that product.

Data. Data were produced for the environmental load from the dismantling of clay brick walls. For other materials and processes, literature data were used. Literature data were from 2001-2005, with the majority from 2005, mainly representing production in India and Denmark. Data were both industry average data and site specific data. For three materials, no data were available and data for similar materials were then used. For clay roofing tiles, data on clay bricks were used with an addition of 10% of the energy use due to the different drying process (Det Genanvendte hus, 2006). For beams of prefabricated concrete, which were used to a very small extent, data on prefabricated floor elements were used. For fibre board in the roof, data on chipboard were used.

Studied impacts. The following impact categories were studied: global warming, acidification, eutrophication and photochemical ozone formation. Classification and characterisation factors are according to (jain,s.s. 2002). Those categories were chosen as there is good agreement on the characterisation factors for those categories. Further, from an environmental and political point of view, those categories are considered to be especially important. The use of natural resources is only presented as a weight. Waste from the production was divided into general waste and environmentally dangerous waste and only presented as a weight.

Limitations. The study was limited to the following:

- In the Recycled House, lime mortar was used in order to facilitate future reuse of the clay bricks. As the use of lime mortar was not necessitated by the use of reused clay bricks and in order to ensure that the use of different types of mortar would not affect the result of the study, only lime cement mortar was considered in this study.
- Electricity was accounted for in two ways. A minor part, about 2% of the total energy use, was Indian electricity production, mainly based on nuclear and hydroelectric power. All other electricity was average data for European electricity. The fuel sources for the average European electricity were about 40% nuclear power, 38% coal, 10% fossil oil, 8% gas. The remaining sources were hydroelectric power and biofuels [jain,s.s.2002].
- The study was limited to the effects on the external environment. Parameters included were the use of raw materials, use of energy, emissions to air and water and soil.
- Cradle to gate data was used. The transport distance from the supplier of building materials to the building site was calculated as if the nearest supplier had been chosen in order not to overestimate the benefits from using recycled material

5.Impact assessment

The impact assessment phase here includes modelling of inventory data within four impact categories, i.e. characterisation. The characterisation was performed on the basis of characterisation factors collected from (jain,SS, 1998).

In order to provide further aspects on the inventory and characterisation results, weighting was also used. In this study, weighting factors were applied directly on the full inventory results, not limited to the four impact categories. By weighting, the result is further aggregated and ranked. Weighting is based on value judgments, different for different individuals, organisations and societies, and consequently different weighting methods can give different results. Altogether three weighting methods were used. Two weighting methods were chosen in order to achieve aspects regarding assumed Indian ecological critical loads and Indian political goals. A third method was chosen to achieve aspects on the assumed willingness of the average OECD citizen to pay for avoiding negative impacts. Each of these weighting methods results in one single overall score by the use of weighting factors. The methods used were as follows:

> The Environmental Theme Method, ET. This method (developed in Netherlands (Heijungs, 1992)) is adapted to Indian conditions in two index series, political goals and ecological critical loads (Miljömässiga skillnader mellan återvinning/återanvändning och förbränning/deponering, 1993). The indices used here were based on assumptions regarding ecological critical loads. The contributions are weighted against each other on a long-term basis. Weighting factors were collected from (Lindfors, 1995).
>
> The Ecological Scarcity Method, Eco. This system starts out from political goals (was presented by Ahbe et al, 1990). Indices for India can be found in (Miljömässiga..., 1993). In this system, emissions are weighted against each other directly. The ecological scarcity is defined as the ratio of the total environmental impacts to the critical impact within a geographically defined area. The method has also been used with authority goals. The weighting factors used in this paper were based on the goals for reduction presented by the Indian Environment Protection Agency in a scenario study regarding India 2021 (Bengtsson, 1997).
>
> The Environmental Priority Strategies in product design, EPS, developed in India (Steen and Ryding, 1992). In this method, the willingness to pay (within the OECD countries) to restore five defined safeguard objects is assessed. The objects are: biological diversity, human health, production, aesthetic values and natural resources. The weighting factors have been updated and in this paper version 1996 was used (Steen, 1996).

7. Results

7.1The use of Building Materials, Energy and Resources and Production of Waste

The amount of materials as well as the proportion of recycled materials used in the Recycled House and in the case All new are presented in Table 1. The total amount of timber is higher in the Recycled House because the reused structural timber had larger dimensions. The total quantity of clay brick is also higher in the case of reuse. The reused clay brick was a solid brick while new clay brick was assumed to be a hollow clay brick. The required amount of mortar when using old clay bricks was assessed by the bricklayer to be the same as the amount required when new hollow clay bricks are used.

The total weight of all materials used was 389 tons. The reused materials accounted for about 30 % by weight of all the materials and 40 % by weight if the crushed stone in the foundation was excluded. The total requirement of clay bricks and roofing tiles was supplied by reused clay bricks and tiles. Of the total requirement of timber, 32% was supplied by reused timber. As regards the requirement of steel, 70% was supplied by reused steel.

The use of energy in the case Rec was about 60% of case All new. The energy use, broken down by fuels, is presented in Fig. 3. The total energy saving corresponds to a calculated energy requirement for heating the building for about thirteen years. (If the feedstock energy had not been included the energy use in the case Rec would have been about 54% of case All new, which corresponds to about nine years of heating.)

The Recycled house reduced the use of raw materials for production of building materials and also decreased transport. The main primary raw materials conserved were bedrock, sand and clay and timber (the use decreased by about 30%) and fossil resources for energy production (the use decreased by about 25 %). The use of different chemicals decreased by about 80%. As nearly all steel is recycled today, reuse of steel means almost no change in the amount of primary raw materials.

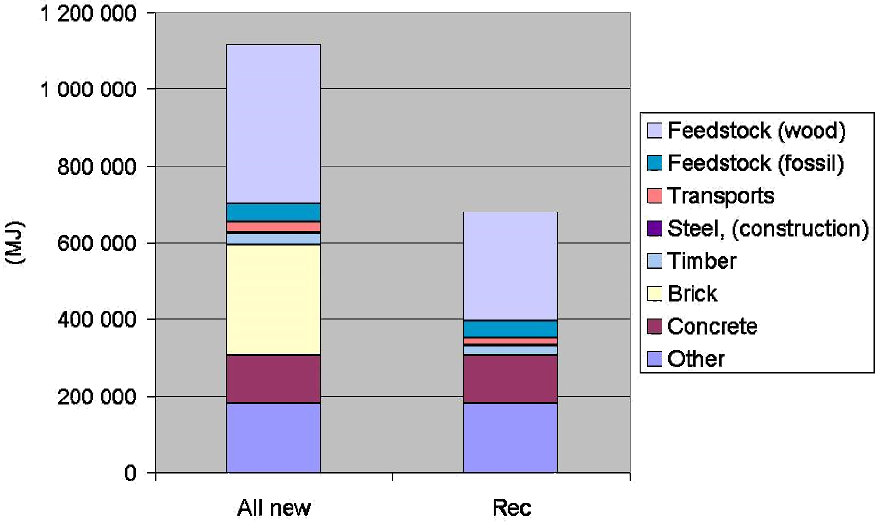


Figure 3. Survey of the total use of primary energy.

With the assumption made that in a near future mineral waste will be crushed and used as sub-base (see above under *System boundaries* in section 5), the reused materials in Recycled house would not have been driven to landfill if not reused. Therefore, the recycled house caused a change in the *form* of recycling but did not decrease the amount to landfill. However, waste from the material production decreased due to the use of recycled building materials. The environmentally harmful waste decreased by about 50% and undefined waste by about 30%.

7.2 Characterisation

Characterisation was based on characterisation factors from The results from the characterisation are presented in Fig. 4-7. 'Changes' accounts for the difference between the expanded system of the case recycled house and the expanded system of the case All new. See Fig. 2. As mentioned above under *System boundaries* in section 5, the reuse of timber in the Recycled House caused an increase in the consumption of natural gas in the region. Consequently, it caused a change in the emission output due to the different emission profiles for combustion of biofuel and natural gas. The emission to air of CO_2 from combustion of biofuel was set to zero due to the circulation of biomass and because the net emissions from combustion can be regarded as negligible (Brännström, 1996). Combustion of natural gas causes the emission of considerably less CO than combustion of biofuel. Further, some transport did not occur owing to reuse. The change in emission output due to combustion of natural gas and the absence of some transport is presented as 'Changes' in Fig. 4-7.

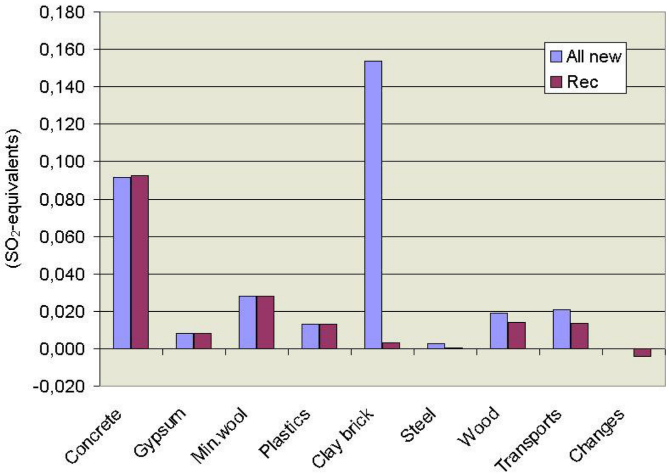
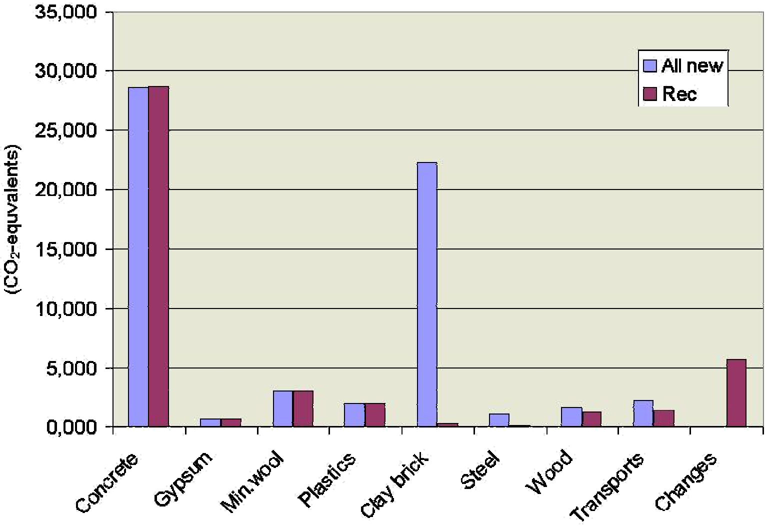


Figure 4. The contribution to acidification, broken down by materials and transport. 'Changes' represents the difference between product B and product A of the expanded systems, see Fig.



Conclusions

All techniques for assessing the impacts caused by an object, or a process, have their limitations. It is important to be aware of the limits of the information developed in a study of this kind when assessing the result in a decision process.

The results of the study show that there are considerable environmental benefits to be derived from the use of reused clay bricks and roofing tiles instead of new bricks and tiles. Reuse of these materials can contribute to a considerable reduction of the environmental impact from a whole building. An important issue, however, is how far the bricks are transported. The length of the feasible transport distance for reused bricks ought to be assessed in each case. The main factors that affect the reasonable distance are distance to the producer of new bricks, the quality of the new bricks and all means of transport. When reused bricks from the local region are used, however, there seems always to be considerable environmental effects.

As regards the environmental benefits due to reusing materials which would otherwise have been used as fuel for district heating, these greatly depend on the combustion capacity and the fuel substitute in the region.

The amount of waste is not always decreased by extended recycling when the region has a well developed handling of building 'waste'. Only the *form* of recycling changes and consequently the environmental benefits.

The proportions and kind of natural resources that are saved by recycling building materials vary considerably with the building material that is recycled. They also depend on the resource used as substitute for the reused material.

As the reuse of building materials affects a complex system, it can be difficult to make broad generalisations. Each material has to be assessed separately. Consideration of the potential benefits to be derived from recycling and a recycling approach ought to form an integral part of the design phase of new buildings, in order that buildings should be designed so as to offer the opportunity of future recycling.

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