Contribution to Sustainability in Construction: Recycling and Reutilization of Materials

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Abstract: In recent years there is a risk of depletion of natural resources and the need to find new materials and construction techniques. Thus, we seek to build with more responsibility, thinking in the future, or in other words looking for sustainable construction. Within the theme of sustainability are important concepts such as recycling which is the reuse of materials by using them as raw material for a new product, reutilization, which is the reuse of materials, such as recycling, but without going through industrial processes and is therefore a more advantageous solution and deconstruction, or selective demolition to facilitate the processes of recycling and reutilization, with economic and environmental benefits. Sustainable materials must have all the benefits of a conventional product and still have a sustainable performance. So, there are starting to appear on the market several new examples of sustainable constructive solutions, which is a fast-growing market.

Keywords: Sustainability, Deconstruction, Recycling, Reutilization.

1. Introduction

The theme of this article focuses on sustainability, specifically in the recycling and reutilization, issues in vogue around the world. Given that the construction sector is one that consumes more natural resources and is also a major generator of solid waste, the deepening of this issue becomes crucial for the future of mankind.
As mentioned in the abstract, in recent years there is a risk of depletion of natural resources and the need to find new materials and construction techniques. This industry, despite its contribution to improve the quality of life, has a great share of responsibility for polluting the planet. Thus, we seek to build with more responsibility, thinking ahead and not just in the present, or in other words seeking for sustainable construction.
Within the theme of sustainability is recycling, that is the reuse of materials by using them as raw material for a new product. Thus, in the area of construction and taking into account the huge amount of waste, this should be the solution for the production of new materials, saving the planet's natural resources. Another way to save these resources is through reutilization, which is the reuse of materials, such as recycling, but without having to go through industrial processes. Finally, another notion in this article to retain is the notion of deconstruction, or selective demolition to facilitate the processes of recycling and reutilization, with economic and environmental benefits.
This is then the future of construction around the world and the notions of recycling, reutilization and deconstruction are still not accepted in the field, but will surely have a very significant progress in the coming years.

2. Sustainability

2.1 Sustainable Construction

The construction industry is one of the largest and most active sectors throughout Europe representing 28.1% and 7.5% of employment in industry and in the entire European economy, respectively. (Pacheco, 2010) This sector has an annual billing of 750 million Euros, representing 25% of all European industrial production, being the largest exporter with 52% market share. (Pacheco, 2010) Moreover, the industry consumes about 3000 Mt/year of raw materials, which represents almost 50% in mass and is responsible for 30% of carbon emissions. Finally, the housing stock consumes 42% of the energy produced. (Pacheco, 2010) For all this, the sector is clearly unsustainable.
Thus, sustainable construction is the response of the construction industry to the need for sustainability on the planet. In 1994, the International Council of Building (ICB) has defined sustainable construction as "responsible for creating and maintaining an healthy built environment based on the efficient use of resources and the project based on ecological principles." (Kibert, 2005) According to the CIB, there are seven key principles for sustainable construction. They are:
• Reduced consumption of resources;
• Reuse of resources;
• Use of recyclable resources;
• Protection of nature;

• Elimination of toxic substances;
• Application of life cycle analysis in economic terms;
• Emphasis on quality.

The Sustainable Construction seeks to follow the premises of sustainable development to not deplete the planet's resources and develop environmentally correct methods of production and consumption, to ensure the survival of ecosystems without sacrificing the evolution of technology and by addition increased pollution.

2.2 Sustainable Materials

For a material to be considered sustainable, it must have all the benefits of a conventional product and still have a sustainable performance. In this context of sustainable materials, the choice must be based on materials: (Pacheco, 2010)

• Not toxic;
• With low embodied energy;
• Recyclable;
• That would allow the reuse of waste from other industries;
• That comes from renewable sources;
• Durable;
• Whose choice is carried out according to a life cycle analysis.

2.3 Life Cycle Analysis of Materials

It is not possible to know from various materials which are the most environmentally correct. It goes through several phases in which they differ widely, with positive and negative aspects to withdraw.

Therefore it is necessary to make an accounting of all environmental impacts caused by a given material, since the beginning of the extraction of raw materials (cradle) to the deposition stage (grave). So, emerged in 1990 in the United States of America, a methodology known as life cycle analysis (LCA). One of the first precursor studies of this "quantified the resource requirements, emissions and waste generated by various beverage packaging" (Pacheco, 2010) being conducted by Midwest Research Institute for the Coca-Cola in 1969.

The life cycle analysis of a material "includes the complete life cycle of the product, process or activity, i.e., the extraction and processing of raw materials, manufacturing, transport and distribution, use, maintenance, recycling, reutilization and final disposal". (SETAC, 1993)

2.4 Life Cycle of Buildings

The life cycle is a term used to refer to all stages and processes of a system to generate products or services. Specifically in the case of a building, the phases are design, construction, lifespan and demolition. By increasing the lifespan, it ensures the reduction of material consumption and the reduction of environmental impacts. Then, it should be taken several measures in all stages of the cycle, to ensure this increase.

So, designers must implement a durability project and prescribe the maximum number of sustainable materials. They must also ensure savings and reuse of water by, for example, the reuse of rainwater and also ensure that the construction is efficient and energy renewable. To prolong the lifespan of the construction it is essential to be created a Maintenance Management System to prevent material degradation and get rehabilitation when necessary. At lifespan and demolition, there will be wastes that should be minimized, recycled and reutilized if possible, to avoid looking for new materials and benefiting the environment.

3. Recycling

3.1 Importance of Recycling

The word recycling began to be widespread in the media since the 80´s in order to alert people to the need to recycle, when it was found that the sources of oil and other raw materials were being rapidly depleted and that there was lack of space for disposal waste and other droppings of nature. Recycling is known as the reuse of materials as raw material for a new product.

Recycling has numerous environmental, economic and social benefits. In the environment, recycling reduces the progressive accumulation of garbage and the production of new materials. On the economic side, it contributes to more rational use of natural resources and the replacement of those assets that are likely to be reused. In the social sphere, recycling not only provides better quality of life for people by improving the environment, but also has generated jobs in the area.

3.2 Strategies for Recycling Materials

To ensure an efficient recycling, there are certain strategies that should be followed and that are being studied at this time, to maximize the recycling process, i.e., to ensure less waste and more recycling of materials.
The strategies for the recycling of materials are: (Couto, 2006)

- Use recycled materials - the use of recycled materials will encourage governments and industry to investigate new technologies to recycle and to create a wider support network for further recycling and reuse;
- Minimize the number of different types of materials - simplifies the process of organizing materials and reduce transportation;
- Avoid toxic and harmful materials - reduces the potential for contamination of materials that are segregated for recycling and also reduces the potential risk to human health during disassembly;
- Develop a separate installation of materials with different potential for use - prevents large amounts of material to be contaminated with small amounts of a material that cannot be separated;
- Avoid coatings when possible - such coatings may contaminate the source material and make recycling less convenient;
- Provide permanent identification of the types of material - many materials such as plastics, are not easily identified and should have some identification mark "not removable" and "non-polluting" to facilitate their future organization;
- Minimize the number of different types of components - simplifies the process;
- Use mechanical connections rather than chemical - allows easy separation of components and materials and reduces contamination of materials and component damage;
- Implement chemical connections weaker than the parts to be connected - when chemical connections are used, they should be weaker than the components. For example, the mortar should be much weaker than the bricks.

4. Reutilization

4.1 Importance of Reutilization

Reutilization is the act of using again a given material. Therefore, it is an important tool in the field of sustainable construction, since "reduces the need for exploration of new resources that would be needed for the production of new products." (Wikipedia, 2011)
The big difference to the recycling is that to recycle a product, it has to be re-introduced into the productive system, giving rise to a different product from the start, or in other words it has to go through an industrial process. At reutilization the material will be used at least a second time, regardless of whether or not the same function.
In conclusion, the reutilization process is environmentally better than recycling because it requires no industrial processes and it is the future (or should be) of construction, if we create the conditions for such.

4.2 Strategies for Reutilization Materials

So now, we seek conditions for making reutilization an attractive process for key stakeholders. This requires strategies to make this possible, such as: (Couto, 2006)

- Choosing to use an open space building - this will allow changes in the partitioning of the building through the replacement of components without significant construction work;
- Use assembly technologies that are compatible with standard building practices - the use of specific technologies will make disassembly difficult to perform and may require hand labor and special equipment which makes it less attractive;
- Separate the inner walls of the structure of coatings - to allow the parallel dismantling of the building where some parts can be removed without affecting other parts;
- Provide access to all parts and all components of the building - ease of access will facilitate disassembly. If possible it allows the recovery of components within the building, done without the use of specialized equipment;

• Use components that allow easy handling operations - allowing the handling at all stages: disassembly, transportation, processing and reassembly;
• Use the means necessary to deal with the various components during disassembly - the handling may require connection points for lifting equipment or devices for temporary support;
• Provide realistic tolerances to allow the necessary movements during disassembly;
• Use the minimum number of different types of connectors - the connector will facilitate standardizing disassembly, making it faster and requires fewer types of tools and equipment. Even if it results in over sizing of some connections, it will surely be compensated by the time of assembly and disassembly;
• Use a hierarchy of disassembly related to the life expectancy of the components - use components with lower life expectancy in areas with easier access;
• Provide a permanent identification of the type of components - the identification of materials with bar codes with international standards may facilitate the spread of deposit banks and marketing of materials and components existing in various locations.

5. Deconstruction

5.1 Definition

Historically, the process of demolition was associated with only one principle, which was to minimize the time spent on this operation because it would also minimize the costs, but which had the consequence of the construction and demolition residues (CDR) getting mixed in a landfill. However, in recent years, with the need to maximize recycling and reutilization of CDR, was born a new technique for demolition, called selective demolition or deconstruction. Deconstruction is then a new technique used in the demolition of buildings. It consists in a careful dismantling, enabling the recovery of materials, promoting reutilization and recycling.

5.2 Principals of Deconstruction

To fully utilize the potential of deconstruction, it must be respected the following principles: (Kibert, 2005)
• Minimize the number of types of materials;
• Avoid composite materials and products that cannot be separated;
• Provide a permanent identification of various materials;
• Minimize the number of different components;
• Emphasis on mechanical over chemical connections;
• Use buildings open systems with parts that can change function;
• Using modular construction;
• Use of deconstruction technologies compatible with the construction practices;
• Separate structure of the coatings;
• Allow access to all components of the building;
• Project components to be used manually;
• Provide tolerances that allow the deconstruction;
• Minimize the number of rivets or other connectors;
• Minimize the types of connectors;
• Design connectors and repeated operations to support the construction and deconstruction;
• Allow parallel deconstruction;
• Provide permanent identification of each component;
• Use standard structural solutions;
• Use lightweight materials;
• Identify the area of permanent deconstruction;
• Provide replacement parts and place for storage;
• Save the information building and construction process.

6. Examples of New Constructive Solutions

6.1 Thermo Poly Rock

A company of Wales, Affresol, builder specialized in modular homes, built a house through a new technology, using 18 tons of recycled plastic. This was done with a new compound called Thermo

Poly Rock (TPR) which consists in the use of recycled plastic mixed with minerals (undisclosed) to build environmentally correct homes.

Figure 1 – Thermo Poly Rock (Ambiência, 2011)

The company says that the process has low energy and the material is lighter and more resistant than concrete, and is non-flammable, waterproof, with excellent thermal insulation and does not rot. TPR plates form the supporting walls of the house, which can be covered externally with brick or stone, while inside can be placed a layer of insulation and keep the same look of a traditional house.
The tiles are also made from recycled material. The company estimates that the lifespan of the houses is about 60 years, but the elements of TPR can be recycled again after this time. (Globo.com, 2011)
Besides all the advantages mentioned above, there is still to highlight two relevant facts, according to the company. This is up to 12% cheaper than conventional construction and much faster, because the house will be ready at the customer's taste in just 4 days. (Ambiência, 2011)
Currently the company is awaiting approval of a pilot project to build 19 homes in Merthyr, Wales, and it is expected that in coming years, this new material meets the expectations and grow into the market, with positive effects for everyone. (Globo.com 2011)

6.2 ISOPET

PET is a thermoplastic polymer material that has high chemical and mechanical resistance. PET bottles are the typical plastic bottles, in great abundance in the market, that with this solution can be reused directly, without going through a process of recycling, also preventing the illegal dumping of waste in landfills. The project was developed by students of Centro Federal de Educação Tecnológica do Paraná, Brasil. (Artigos.com, 2011)
This solution consists in the production of blocks for the construction called ISOPET. They use internally, plastic bottles, positioned vertical or horizontally and covered with a thin layer of lightweight concrete. The blocks have grooves on the sides that generate these inter-locking so it is not necessary to use mortar to their unions, except the first row. (Artigos.com, 2011)

Figure 2 – ISOPET (Recicla, 2011)

Using these blocks, it reduces the need to extract natural resources such as coarse and fine sands. This practice also reduces the consumption of electricity, which it substantially reduces the final value of the work. In addition, this block has other great advantages in the execution of a constructive project, for its light weight, easy handling of the elements, the improvements in the thermo-acoustic characteristic and also for being an eco-block, bringing benefits not only to the construction but also to the environment and to the life quality.

For the production of 365 blocks, it is needed 875 plastic bottles of 2 liters and 17 m^3 of polystyrene. (Artigos.com, 2011)
In 2001, only in Brazil were consumed 270,000 tons of PET and according to the Brazilian Association of Manufacturers of PET Packaging, only 89 000 of these were recycled. Thus, this product can bring great added value to market, avoiding waste and mitigating the impact to the environment.

7. Case Study

7.1 Criteria for choice of materials

In fact, besides the common architectural criteria in choosing materials for construction, other criteria must be respected like:
• Embodied energy into the material - should be taken into account the energy expenditure related to the embodied energy of the material in its life cycle;
• Potential for reutilization and recycling of materials – There are materials that can be reutilized and recycled and there are others that don´t have that potential.
• Toxicity of the material - There are certain materials that shouldn´t be used in construction, because are toxic to the environment and to the humans;
• Economic costs associated with the life cycle of materials - Most designers choose materials only taking into account the purchase price, ignoring for example the costs of maintenance, rehabilitation, demolition and disposal. These should not be neglected, because sometimes a higher initial investment may even mean in a long turn, more profitable work.
Despite all these criteria are essential, the last before mentioned shall not be taken into account in this case study, because it would be too complicated to get economic costs of the materials chosen throughout its life cycle. However, it is an important factor.

7.1.1 Embodied Energy

The embodied energy of materials is, by definition, "the energy consumed during their lifespan." (Pacheco, 2010) However there are different approaches to judge this issue. They are: the start of the extraction of raw materials to the factory gate (cradle to gate), from the beginning to the work (cradle to site) or from the start to the demolition and disposal (cradle to grave). The approach that seems more correct and will be taken into account in this subchapter shall be the third; it is this one that covers all consumption from the production phase until the end of lifespan of the material.
Thus, the embodied energy in materials is the amount of energy needed for its production, transportation, application in the construction, maintenance and demolition. This energy can vary between 6-20% of the total energy consumed during the lifespan of a building, depending, among other factors, at the building systems used, the number of users of the building, the degree of comfort demanded by the occupants and the local climate. (Mateus)

Materials	**MJ/kg**	**MJ/m^3**
Concrete 40 MPa	1,6	3890
Ceramic brick	2,5	5170
Ceramic tile	0,81	-
Cement	7,8	15210
Glass	15,9	40060
Steel	32	251200
Recycled steel	10,1	37210
Polished wood air dried	1,16	638
Polished wood dried in greenhouse	2,5	1380
PVC	70	93620

Table 1 – Embodied energy of some materials (Pacheco, 2010)

7.1.2 Potential for reutilization and recycling of materials

The choice of materials for a dwelling must be based on their potential for reutilization and recycling. When a material completes its life cycle, it has a certain potential for reutilization and recycling which is function of their ability to be used again as a resource. The knowledge of this capability is essential for rational management of resources and products of a building so it can be possible to achieve goals such as reducing the impact of buildings on the natural environment.
Thus the list of building materials is:
• Metals - are recyclable if it is possible to separate them by type. For example, steel and aluminum have a high potential for recycling and in general, the structural steel can be recycled and/or reutilized to 100% and may be again used as a structural element.
• Plastics - Most plastics can be granulated and recycled to produce new products. However, the large variety of plastics and the use of additives in their production vastly complicate recycling.
• Glass - can be recycled if properly separated and not contaminated. Recycling glass reduces its embodied energy by 20% (Mateus)
• Wood - The wood products such as windows or doors, etc., can be easily reutilized if in good conditions. The structural elements can also be reutilized if they are mechanically connected allowing an easy disassembly.
• Concrete and ceramic products - These are materials where the reutilization is extremely complicated. However, elements of concrete and ceramic products can be crushed and then recycled into aggregates for the manufacture of concrete.

7.1.3 Toxicity of Materials

The toxicity of a material represents the harmful effects this can have on humans and the ecosystem that surrounds it. Each material used in building should be fully considered, especially the specifications and the manufacturing process for the identification of chemical compounds that are toxic.

7.2 Example of a house

The home example with a typology "T2" has a ceiling height of 3 meters and consists of two bedrooms, a living room, a bathroom, a kitchen and a small hall. The construction floor area is 93 m^2.

Divisions	**Area (m^2)**
Hall and living room	26,9
Kitchen	13,7
Storage	1,7
Toilet	7,7
Room 1	11,9
Room 2	14,8

Table 2 – Areas of the divisions of the home example

7.3 Element and Building Materials Chosen

In a housing project and considering the energy costs, it must be taken into account several factors to minimize them. Indeed some have already been mentioned above. There are some examples like, to consider the climate of where the house will be built, the orientation of this, guarantee proper cooling of the housing and good natural lighting, among other important aspects.
However, in this case study, these aspects are not taken into account. So, the materials of this house will be chosen if they are non-toxic, have low embodied energy and have the potential for reutilization. That way it can be concluded the amount of embodied energy saved, if, in this case, was properly performed a selective demolition and subsequent reutilization of these materials.
The materials chosen are presented below.

7.3.1 Structure

The structure of the considered house is in LSF (light steel frame), because this is probably the best solution to guarantee that the structure material has potential of reutilization and recycling and allows a easier deconstruction too. This construction system consists, basically in a house skeleton of lightweight steel.

Figure 3 – Light Steel Frame (Engenharia Civil Wordpress, 2011)

The use of steel in the system is so significant, because the structure (walls and roof) is composed of lightweight profiles of galvanized steel. The remaining components are the fasteners (screws and connectors that join it all together), exterior finish (usually OSB - oriented strand board), interior finish (usually gypsum board) and glass wool (thermal and acoustic insulation).
Comparing this technique with conventional construction systems it can be verified many advantages such as:

• The LSF structure is much lighter weight compared to a conventional construction (concrete or masonry, for example) which allows relief for the foundation (and therefore financial savings of the same) and allows better distribution of efforts;
• In this constructive solution, the plumbing, electrical, air conditioning, gas, among others, have greater ease of access, allowing easier maintenance and economy;
• Important to sustainability and the environment, because this solution has no waste of material, leaving the work site clean and free of debris;
• The thermo acoustic result is superior in this system that in the conventional;
• Time limits are lower and installation is relatively easy because it is a simple operation that does not require heavy equipment and transport;
• It can be scheduled, monitored and controlled all steps in safety;
• Controlling costs at all stages;
• Versatile solution because it is adaptable to many architectural projects, allowing any coating and finishing;
• Resistant to moisture, corrosion and fire;

Taking into account all these advantages, this solution will be chosen for this example. However, it is impossible to calculate accurately, without making a detailed design, the entire amount of steel used in a work of this kind. It will be made a prediction of these quantities with the accounting of profiles and sheets of galvanized steel, ignoring the screws and connectors in view of the steel used are negligible for the final weight of the building. Thus, in a following subchapter will be all these weight values and embodied energy for the considered steel.

7.3.2 Doors and Windows

As mentioned earlier, the wood is an excellent material that allows recycling and reutilization in many cases. Thus, in this house, doors and windows are wooden and the areas and values embodied energy will be recorded in table 1.
In addition, also it will be accounted the existing glass in doors and windows, since glass is a material that can be recycled if properly separated and not contaminated.

7.4 List of Measurements

Before the measurements in Table 3, it should be mentioned some important considerations to achieve these values.

The LSF is a building system composed of lightweight profiles of galvanized steel with thickness from 0.95 to 1.25 mm. Panels are formed by guides and amounts structural variable width between 90, 140 and 200mm and spacing of the amounts between 40 and 60cm depending on the thickness of the plate. In this particular case it will be considered C90 profiles and U93 profiles and a spacing of 0.5 m. So in this project we have approximately 566.08 m of U93 profiles and 315 m of C90 profiles.
Thus, the results are in the following table.

Element	Materials	Unit	Amount	Embodied Energy (MJ)
Structure	Profiles C90	kg	637.6	6439.76
	Profiles U93	kg	856.5	8650.65
	OSB	m^2	118.5	-
	Gypsum board	m^2	272.8	-
Doors and windows	Wood	m^3	0.832	530.82
	Glass	m^3	0.056	2243.36
			Sum	17864.39

Table 3 – List of measurements

Note that for the results of embodied energy in Table 3, the considered wood for the doors and windows was the polished wood air dried representing 638 MJ/m^3 and the steel considered was the best case scenario, i.e. the recycled steel that represents 10.1 MJ/kg, because there is no existing data for lightweight steel.
In relation to the OSB and gypsum board, there are no data about their embodied energy. However, it is expected that these values are not high, because they are sustainable materials that allow recycling and reutilization in some cases.
So in this case a minimum of 17864.39 MJ of energy is expended in this small house. A value that can be recovered almost entirely through the reutilization of these materials.
Noteworthy is the fact that 1 MJ is approximately equal to the kinetic energy of a moving vehicle at 160 km/h. (Wikipedia, 2011) So, this way is possible to see the amount of energy wasted in a small house that, with the appropriate action taken, can be recovered, achieving major environmental, economic and social benefits.

8. Conclusions

The world is experiencing a phase of constant change and development. The construction industry is also an example, with more new materials and construction techniques, which aim to ensure comfort and security to the population. However, it cannot be dissociated the technological development from the pollution it causes. The answer to this has to be the sustainable construction.
As already mentioned, this is clearly an unsustainable industry right now. It is therefore necessary to persuade the responsible people of the area to invest in new techniques and materials and also appeal to the general population to have a greater civic participation in such matters.
It should be promoted the use of sustainable materials, focusing on recycling, reutilization and deconstruction as a way to avoid depletion of natural resources of the planet and still investigating new ways to get material that has already been used. As an example of this last fact, it´s the TPR and ISOPET, mentioned earlier.
However, for these techniques to be successful, there are certain essential measures, already mentioned, which should be highlighted once again, because it will be used in construction, being important for future workers of the area.
Thus, in order to have an efficient recycling, there are certain strategies that should be followed, such as minimizing the number of different types of materials, avoiding toxic and harmful materials and coatings whenever possible and using the maximum of mechanical connections instead of chemicals, facilitating the deconstruction of the building.
In terms of recycling, the Portuguese case is even worse than the rest of Europe. The rate of recycling of materials is too low and it should be taken measures in order to reverse this trend. For example, the case of Denmark would be interesting to be copied, because fees are charged for waste delivered to treatment plants, and, when wastes are separated or are destined for recycling, these taxes are refunded. That way the recycling rate is a lot higher in Denmark than in Portugal.
Regarding the reutilization, process environmentally better than recycling because it does not require industrial processes, the strategies to be taken may be, for example, separating the structure of the

inner walls of the coatings, facilitating access to all parts and all components of the building and use components that facilitate handling operations. It should also be highlighted a key measure that it is using an hierarchy of disassembly related to the life expectancy of components, thereby maximizing the process, as materials with lower life expectancy will be well placed in areas with easier access.
Noteworthy is the fact that deconstruction, recycling and reutilization are related. You have to ensure proper and efficient deconstruction processes to maximize recycling and reutilization. Thus, the most important thing to keep this warranty, is designing buildings providing for their future disassembly and not only its demolition. There are other important strategies, such as using modular construction, deconstruction technologies compatible with standard construction, parallel deconstruction and using lightweight materials, among others.
In this case study and taking into account only the choice of materials, there is an enormous energy expenditure that can be minimized and even completely recovered through deconstruction and reutilization. Given that small house and being considered only a few materials, there are values around 18,000 MJ of embodied energy expenditures. That way it´s possible to see the need for a careful choice of materials allowing future reutilization and recycling, but knowing that this energy can vary between 6-20% of the total energy consumed during the lifespan of a building.
In conclusion, the question that needs an answer is this: is sustainability possible? The answer is simple. Yes, it is possible, providing conditions for it, investing in education and formation, mainly of skills, not just to responsible people of the area, but also to the rest of the population.

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