Life Cycle Assessment (LCA) analysis of renders and paints for the restoration of historical buildings

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Abstract. A significant percentage of the building stock in Europe was built before 1950, hence the restoration, retrofitting and renovation of historical buildings is of paramount importance not only for society, but also for the overall sustainability of the construction sector, which is known to have a huge environmental impact. In particular, the application of new paints and renders is extremely common in the restoration interventions carried out in historical buildings. In the selection of these materials, it is important to consider that they must comply with compatibility requirements, in terms of low stiffness and high water vapour permeability, not to give rise to premature defects and detachment. However, their environmental impact is basically never evaluated.

In this study, a preliminary evaluation of the environmental impact of some selected renders and paints for the restoration of historical buildings by Life Cycle Assessment (LCA) analysis was carried out. This analysis was performed using the information that are supplied by the manufacturers of the materials (as reported in the technical data sheets), so from the point of view of the designers, who must select among a range of commercial alternatives. Both ready-mix dry renders and mortars purposely prepared in the building site, with or without paint, mechanically or manually applied, were analysed.

The paint, notwithstanding its low amount with respect to the render, seems to have a very high impact. The results also suggest that an evaluation of these materials by LCA is definitely not easy, mostly because some key characteristics of materials which are needed for this analysis are currently not reported at all in the technical datasheet, thus jeopardizing a proper evaluation of their environmental impact.

1. Introduction

Historical buildings constitute a large percentage of the housing stock in the world and in particular in Europe, where more than 40% of buildings is older than 50 years [1]. For this reason, a growing effort has been addressed recently to reduce the environmental impact not only of new constructions, but also of existing buildings, both during their use phase (by reducing their energy consumption) [2] and in their maintenance and repair interventions [3]. In general, construction activities have several environmental impacts at each step of the building process: extraction of raw materials, processing, manufacturing, transportation, construction, use [4], demolition and disposal of waste at the end-of-life. Conservation and “re-manufacturing” represent a correct approach to reduce buildings’ impacts in a circular economy perspective [5].

To take into account the impact of buildings’ conservation and repair, the GBC Historic BuildingTM rating system was proposed by the Green Building Council of Italy (GBC Italia), combining the criteria
of the International LEED® standards with specific knowledge on restoration and preservation [6].

In fact, preserving historical buildings offers environmental savings over demolition and reconstruction [7], but it may also involve a significant impact, especially connected to the materials used [2]. However, while several studies focused on the impact of refurbishment (i.e., retrofitting, major renovation and modification of the building envelope) [3] of historic buildings, the studies on the impact of conservation are still very few [8][9].

In this paper, the sustainability of conservation intervention is evaluated, focusing on the finishing materials currently used in this kind of interventions, namely coarse and fine mortars and paints. To this aim, a Life Cycle Assessment (LCA) approach was employed. LCA, which was standardized in ISO 14040 [10] and ISO 14044 [11], is an objective process to evaluate the environmental impacts associated with a product, a process or an activity by identifying both energy and resources consumption and pollution and waste released to the environment, with the final aim of evaluating and implementing opportunities of environmental improvement [12]. The application of a LCA methodology can be useful also to identify the main impact spots and, therefore, to support eco-design in buildings activities [13]. The present LCA study was based on the four stages described in ISO 14040 and ISO 14044: definition of the goal and scope, inventory analysis, impact assessment and interpretation of results.

2. Materials and technologies under evaluation

The materials that were considered in this study are renders and paints which are considered suitable for the conservation and repair of historical buildings, meaning that they comply with the requirement of compatibility with historical masonry walls. For this reason, only cement-free renders (or renders with a limited amount of cement) and breathable paints were considered. In fact, the use of cement-based renders is discouraged in the field of historical buildings rehabilitation, due to their excessive stiffness, low water vapor permeability, possible content of soluble salts and low resistance to sulfate attack, which may jointly lead to a premature detachment of the newly applied renders. Also impermeable paints should be avoided, as they prevent the evaporation of the moisture possibly present in historical masonry, again causing blistering, flaking and other defects.

The following materials were considered:

- **Base 1**, a coarse mortar manufactured directly on-site for the base coat of the render, having a thickness of 15 mm. The recipe of this mortar was provided by a company working in the conservation field, and includes natural hydraulic lime (NHL), ready-to-use dry mix (air lime, cement, limestone sand <0.6mm, limestone filler, inorganic pigment, siloxane additive), limestone grit <1.2mm, river limestone sand <0.6 mm, and water in the volume proportions 1:4:4:2:2.75. This base coat, having inorganic pigments in the mixture, does not require painting;

- **Base 2**, a coarse mortar such as Base 1 manufactured directly on-site for the base coat of the render, having the same thickness 15 mm. The recipe of this mortar was provided by another company specialized in historical building conservation and includes the following ingredients: natural hydraulic lime (NHL), lime putty, river quartz sand <4mm, chemical admixture (pure acrylic resin) and water in the volume proportions 0.84:0.16:3:0.02:0.779;

- **Finishing 1**, a fine mortar manufactured directly on-site for the finishing coat of the render, having thickness 3 mm. The recipe of this mortar was provided by the same company described above (Base 2) and includes the following ingredients: natural hydraulic lime (NHL), brick dust, quartz sand <0.6mm and water in the volume proportions 0.75:0.25:2:0.675;

- **Finishing 2**, a commercially available ready-mix dry fine mortar for the finishing coat of the render, having thickness 3 mm. The recipe reported in the technical data sheet of the manufacturer reported only the presence of “lime mortar” with binder to sand volume ratio equal to 1:2;

- **Paint 1**, a commercially available potassium silicate-based paint, suitable for the finishing of lime-based renders and usually applied over Finishing 1;
• *Paint 2*, a commercially available lime-based paint, suitable for the finishing of lime-based renders and usually applied over Finishing 2.

3. Methods of LCA analysis

3.1. Goal and scope definition

The goal of this analysis was the comparison of alternative mortars and paints for the rendering of historical buildings during repair and retrofitting works. The final scope was a better understanding of their relative impacts, for a more sensible selection of these kinds of materials and a possible reduction of their impact, within a context (repair and conservation) where these considerations are still rather uncommon. The analysis was carried out from the point of view of the professionals involved in the restoration process, such as engineers and architects.

The functional unit selected for this analysis was one square meter (1 m²) of wall surface, i.e. 1 m² of applied materials. Of course, only mortars with the same thickness were compared, meaning that the two base coats were compared together and the two finishing mortars were compared together, as these two kinds of materials have not only different thickness, but also different functions, characteristics and formulations. The paints, besides being compared together, were also compared to the mortars, just to highlight how they contribute to the overall environmental impact of the render.

The system boundaries identify the Units of Process that must be included in the LCA model. In the present analysis a so called “from cradle to gate” LCA was applied: the system boundaries included the extraction of raw material, manufacturing, packaging and the final manual application of materials. The further steps such as transport and disposal of end of life materials were not considered, due to lack of data and information about the location of a possible working place and the waste management scenarios.

The nature of the input data used in the analysis is very important for the quality of the output results of LCA. Data may be measured directly in each process (“primary data”, e.g., energy, water, etc.), or collected from literature, statistics, projects or databases. Of course, primary data, when available, are always recommended for assuring representative results and this is the procedure currently followed in the Environmental Product Declarations, where the manufacturer provides the data for the impact evaluation.

However, in the present study, the LCA assessment was carried out from the point of view of professionals in charge of the selection of materials for the repair works. This is a very important aspect to consider, as these professionals may play a key role in the overall reduction of the environmental impact of materials in constructions, but have a limited access to primary data and information about these materials, as highlighted in a previous paper [9]. So the input data used in this study were those currently available for these professionals, namely the information reported in technical and safety data sheets of commercial materials and products and databases included in the software commonly used for LCA assessment.

3.2. Inventory

For the mortars manufactured directly on the construction site, the formulations were provided by two companies working in the conservation field. However, since the Roman age, the formulation of any mortar is always expressed in volume percent, as this allows to prepare the mix without any need of a weighing equipment. Thus, the transformation of the recipe into weight percentages is necessary to perform the LCA analysis, as all the data available in the databases are referred to the material’s unit mass. Unfortunately, this calculation requires that the bulk density of an aggregate or a binder “in stack” (i.e., the mass of a unit volume of a stack of material) is known, which is seldom the case, as this datum is never reported in any technical datasheet. For this reason, the bulk density of the aggregates and binders in this study were estimated averaging bulk density values data taken from the literature, although this necessarily leads to some approximation, as such density depends on the grain size distribution of the materials, which may vary in a large range, especially for aggregates.

For the commercial mortars, the formulations were taken from their technical and safety datasheets,
again performing the same calculation described above, as the proportions are always provided by volume. For the lacking data, the amounts of the single components were estimated on the basis of the authors’ experience. The impact data of the materials and processes were taken from the specialized life cycle inventory database Ecoinvent 3.3, included in the software used for the LCA assessment and known for its ‘integrity and usability’ [14].

For the paints, the manufacturers seldom provide any mix proportion, so the amounts of the single ingredients were both taken from the safety data sheets (which indicate the amounts of the only components with possible hazardous effects on human health) and estimated on the basis of the authors’ experience.

3.3. Impact assessment and interpretation of results

For LCA analysis, the SimaPro 8 software was used, which allows to calculate the environmental impact in the entire life cycle of the process and includes different databases with the most frequently required data about materials, manufacturing processes, etc.

In the present study, the methods employed were the Global Warming Potential (GWP 100) evaluation (midpoint), according with IPCC 2013 [15], evaluating the global warming potential expressed in kilograms of CO₂ equivalent, the Cumulative Energy Demand (CED 1.08 model as implemented in SimaPro 8, midpoint), allowing to estimate the consumption of resources (MJ), and IMPACT 2002+ (Endpoint), enabling to assess the impact on ecosystem quality, human health, climate change and resources.

Concerning the mortars, the process of NHL is not present in the database, while there is a process available for “hydraulic lime”, so this latter one was considered. In the conservation field, generic hydraulic lime and natural hydraulic lime are well distinguished, as the first one may be manufactured by simply mixing air lime and Portland cement, while the latter one is obtained by firing natural raw materials (lime with clay). In this study, the LCA was carried out for the mortars considering both the process of ‘air lime’ and ‘hydraulic lime’, to investigate the impact of a different kind of lime-based binder: the results showed that the difference in the impact of the whole mortars is extremely limited, so all the calculations (reported on the following paragraph) were carried out considering ‘hydraulic lime’.

Concerning Paint 1, potassium silicate is not among the kinds of paint available in this database, so the data for an alkyd paint were considered, although quite different in composition.

4. Results and discussion

A comparison among the two finishing mortars and their paints, in terms of global warming potential (GWP 100), cumulative energy demand (CED 1.08) and impact categories (IMPACT 2002+), is reported in Figures 1, 2 and 3. The environmental impact of the two finishing mortars, having the same thickness (3 mm), is basically comparable, although in all the evaluations a higher impact related with the Finishing 1 was observed. All the impacts of Paint 2 are always significantly lower than the mortars and Paint 1. Paint 2 shows approximately 1/3 of values of all the impact categories with respect to the finishing mortars. This result is consistent, considering that they all are manufactured with lime binder (although of different nature) and that the thickness of the paint is 1 mm, so 1/3 of the thickness of the finishing mortars. Yet, notably, Paint 1 involves a very high impact, notwithstanding its thinness.
At first sight, this high impact might be related to the fact that the LCA was carried out considering Paint 1 as an alkyd one, while it is actually composed of potassium silicate, as discussed above. However, examining the LCA results of the main impacts of the two paints (Figure 4), using the “tree graphs” representation, it is clear that the key factor of the paint is not the binder, but the white pigment, namely titanium dioxide, which is present in Paint 1, as reported in the safety data sheet, and not in the lime-based Paint 2. The use of TiO2 also involves some impact in terms of ‘carcinogens’, as shown in Figure 3, and in fact this pigment is taken into account also in the rules for the Ecolabel awarding to paints and varnishes [16]. Interestingly, for Paint 2, the polypropylene packaging seems to be responsible for most of the impact.

The comparison between the two base mortars is reported in Figures 5, 6 and 7. Base 1 is a colored mortar, containing inorganic pigments, which can be used alone, without any further finishing or paint, while Base 2 cannot be used alone, so also Paint 1 was reported in the histograms, for comparison’s sake. Also in this case, the impact of the two mortars, Base 1 and Base 2, having the same 3 cm thickness, is basically comparable. Notably, Paint 1 has a very high impact when compared to the base mortars (Figures 5-7), notwithstanding its much lower thickness (3 mm versus 30 mm), hence the use of a base and paint (Base 2 + Paint 1) involves a much higher impact with respect to a pigmented base (Base 1). About Energy Demand, non-renewable fossil fuels represent the highest impact factors, while following IMPACT 2002+ results, as shown in Figure 7, global warming, non-renewable energy and respiratory inorganics are the main impact categories, with the highest values for Base 1 and Base 2.
Figure 3. Single score evaluation of finishing mortars and paints according to impact categories (IMPACT 2002+).

Figure 4. Networks of Paint 1 (left) and Paint 2 (right).
5. Conclusions
In this study, the LCA assessment of some finishing materials currently used in conservation works of
historical buildings, namely two base mortars, two finishing mortars and two paints, was carried out. Both mortars manufactured directly on the building site and commercial mortars were investigated. The assessment was performed from the point of view of professionals, so taking into account the information that they have access to in real practice.

The study allowed to highlight some critical issues in the analysis of this kind of materials. Firstly, all the recipes are currently expressed in volume percent, while the application of the LCA methodology requires the mass percentage of the different components, hence the ‘in stack’ bulk density values of the binders and aggregates would be necessary, although they are seldom reported in technical datasheets. Secondly, very limited information are reported in the same datasheets of commercial products concerning the nature and amount of the components in the formulations, which hinders an accurate evaluation of the materials’ impact. Some useful information can be found in the safety datasheets, such in the case of the presence of chemical admixtures or titanium dioxide.

Concerning the impact of the different materials, the results allowed to make the following remarks:

- The two finishing mortars under analysis are basically comparable in terms of impact.
- The two coarse mortars, Base 1 and Base 2, show quite the same GWP impact and the same performances in the other impact categories. Base 1 shows a slightly lower Energy Demand midpoint impact, maybe because of the kind of components.
- The lime-based Paint 2 shows the lowest impacts both in midpoint and in endpoint evaluation, while the impact of Paint 1 is very high, owing to the presence of titania white pigment in the formulation. An interesting result was found concerning the impact due to the polypropylene packaging for Paint 2.

On the base of the study carried on two kind of finishing materials, LCA can be considered once again as a useful tool in environmental impact evaluation and in particular it can give interesting results in terms of comparison between several different solutions.

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