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The environmental impact of cleaning materials and technologies in heritage buildings conservation

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ABSTRACT

Historic buildings constitute a large amount of the European building stock and their preservation is of paramount importance for cultural, economic and also environmental reasons, as their conservation is regarded as more sustainable with respect to demolition and reconstruction. However, historic buildings require frequent repair and conservation works, whose environmental impact is still to be evaluated. In the present paper the sustainability of conservation intervention is evaluated by the LCA analysis method, focusing in particular on cleaning materials and technologies, with reference to conservation sites located in Bologna, Italy. After identifying the most used cleaning materials and technologies, the time necessary for achieving an equal cleaning effectiveness was selected as functional unit and the LCA analysis was carried out, along with a quantitative evaluation of some other key aspects of the different methods (workers' health, acoustic impact and waste produced in the building site). The results highlight that the different technologies involve remarkably different environmental impacts, but that in some cases their impact could be easily reduced by substituting some secondary materials in the cleaning process, without affecting the effectiveness of cleaning. The results also show that the methods involving the lowest environmental impact are not necessarily the best ones in terms of safety and waste production in the building site.

1. Introduction

Due to the massive environmental impact of the construction sector [1], a large effort has been addressed during last decades to improve the sustainability of new buildings, by reducing their energy and resources consumption both during the use and pre-use phases [2,3]. Nevertheless, a growing attention has recently been addressed also to existing and historic buildings [4], that constitute a large portion of the building stock all over the world (in Europe more than 40% of buildings are older than 50 years [5]).

Some authors defined historic buildings as 'inherently sustainable' [6], because preserving them not only preserves our history and culture, but generally offers environmental savings over demolition and re-construction [7,8]. In particular, the benefits of reuse have been discussed in terms of embodied energy reduction, also by introducing the concept of 'avoided impact' [9]. However, historic buildings are also responsible for a significant environmental impact, due to:

- their scarce energy effectiveness;
- their need of maintenance and repair works.

Concerning the first issue, it is well known that the bad thermal insulation performance of historic buildings envelope frequently causes a high energy consumption during their use phase [10], and in fact many authors have investigated how to improve the energy performance of historic buildings (see, among the others, [11–14]). The significance and complexity of the energy retrofit of historic buildings made some authors define it as the 'new challenge' of research [15,16]. Even more challenging is the energy performance improvement of heritage buildings, where artistic and architectural constraints must be respected [11] and the interventions must not affect the historic and architectural value [13] or cause a loss of historical authenticity [17] of the buildings. Also due to the lack of specific protocols that help in finding well-balanced solutions for the energy efficiency improvement and conservation requirements of cultural heritage [15], some authors investigated decision support tools and evaluation methods for historic buildings renovation projects. These authors took into account also social, economic, environmental, and political-institutional parameters [8,9,18], calling this holistic approach 'sustainable renovation'

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[18]. A similar approach is proposed also in *GBC Historic Building*™, a rating system under development by the Green Building Council of Italy (GBC Italia), which combines the criteria of the International LEED® standards with specific knowledge on restoration and preservation, by adding a new topic called 'Historic Value' [19].

Concerning the second issue, it is noteworthy that maintenance, repair and renovation works carried out in historic buildings may involve a significant environmental impact, especially connected to the materials used [10]. However, while several studies focused on the impact of refurbishment (a term generally used for describing retrofitting, modifications of the building envelope, and major renovations) of historic buildings [4], the impact of *heritage building conservation* is basically not investigated yet.

The so called 'conservation interventions', also referred to as repair or restoration [4], are usually performed in heritage buildings according to well established sequence of operations [20,21]: cleaning, repointing, consolidation and protection. The selection of conservation materials and technologies is challenging, as they must fulfill several requirements, such as effectiveness, compatibility and durability [22–25], as well as general requirements described in the Restoration Charters, hence the environmental impact of these materials and technologies is currently totally neglected in the literature, apart from one paper dealing with the environmental impact of grouts used for the strengthening of heritage buildings [26].

However, a better understanding of the environmental impact of conservation procedures would be very useful, also in order to try to reduce this impact. As a matter of fact, in the framework of the sustainability improvement in the construction sector, it is important to underline that heritage buildings 'are not excluded because there will always be some energy efficiency measures that can be applied, even if it is not a total renovation. Minor and moderate measures may often be feasible in the case of heritage buildings' [10].

In the present paper, the sustainability of conservation intervention is evaluated, focusing on cleaning materials and technologies and employing the life cycle assessment (LCA) approach.

Cleaning is the first operation to be carried out in conservation interventions and is aimed at removing the darkening layers (black crusts and deposits or, more in general, dirt and harmful substances) from the surface of building materials [21], for both aesthetic and technical reasons [27]. Being irreversible, cleaning is a critical operation and particular care must be addressed to not damaging the sound substrate, hence the selection of compatible cleaning actions is very important for reducing the risks connected to such kind of intervention [24].

In this study, after identifying the most diffused cleaning methods, an LCA analysis was performed, in order to evaluate and compare the main environmental issues of the different cleaning technologies and to spot critical issues in terms of impact. As well known, LCA is an objective process to evaluate the environmental burdens associated whit a product, process or 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 [28]. LCA was standardized in ISO 14040 [29] and ISO 14044 [30] and has been widely applied in several fields since 2006, including the building sector, which is characterized by a high environmental impact [31]. The importance of LCA lies mainly on its innovative approach which considers all the stages of a production process to be correlated and interdependent. LCA is an excellent tool for analyzing the environmental impact of buildings and building materials [32], as it allows to quantify and compare the environmental impacts of anthropic activities, selecting among several options and for different kinds of building materials [33]. As a consequence, LCA is at the basis of certification schemes and environmental labels [34], such as the Environmental Product Declaration (EPD), and was used in an impressive amount of literature researches during last year's [31]. However, a number of review papers (e.g., [3,4,31,35]) highlighted some current limitations, barriers and open challenges of this methodology, so the application of the LCA approach can be still considered under constant improvement.

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 [29,30].

In addition to the LCA analysis of cleaning techniques, a qualitative evaluation of their impact in terms of workers' health and safety, acoustic emissions and waste produced was carried out.

2. Methods

2.1. Analysis of cleaning materials and technologies

An analysis of the most used cleaning methods in the conservation field was firstly carried out, on the basis of the available literature and the direct experience of the authors in conservation. The materials and technologies currently used for on-site cleaning of façades materials in heritage buildings (stone, mortars, masonry, etc.) were considered, excluding those that are too aggressive and/or hardly controllable by the operator. The most recently developed cleaning methods (e.g., new hydrogel [36], plasma [37], biocleaning [38], etc.), being presently under testing but having not entered into conservation practice yet, were disregarded at this stage of the research.

2.2. LCA analysis

2.2.1. Goal and scope definition

The definition of the goal and scope of an LCA depends on the analyzed system and the intended use of the study. The depth and the breadth of LCA can differ considerably depending on its goal. In defining such goal, the following items shall be unambiguously stated: the intended application, the reasons for carrying out the study, the intended audience, whether the results are intended to be used in comparative assertions to be disclosed to the public. According to ISO 14040, the scope of the study must clearly describe the analyzed system (product, process, service), its function, the functional unit, the system boundaries, the allocation procedure, the data quality, the methodology applied, and finally the necessary assumptions and limitations.

In this study, a comparative LCA analysis among different cleaning procedures in heritage buildings conservation was carried out. As this evaluation was not done before for any kind of cleaning procedure, the scope of the LCA application was here to assess the relative impact of the different procedures and also to detect the main sources of impact, for understanding if mitigation measures are possible in this field and, more in general, for increasing the awareness of the environmental aspects connected to conservation works.

The *functional unit* defines what is studied and plays a reference role to which the input and output data must be normalized in a mathematical sense. The choice is arbitrary, but must be consistent with the objectives of the study and with the function to which the product system was designed for.

For comparing different cleaning procedures by LCA analysis, the definition of a Functional Unit (FU) is absolutely necessary. For this purpose, the removal of *one square meter of a 'normal black crust'* on a plain vertical surface was taken as functional unit for this analysis. In this way, for manual techniques, the amounts of materials necessary for cleaning such surface unit of black crust