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Environmental Management of the Recovery Site in Accordance with the DNSH Principle: The Case of Palazzo Lazzaro in Fossa (AQ)

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Abstract: The construction sector, by its very nature complex and multifaceted, is constantly looking for new methods capable of improving the management system of a project, increasing the efficiency and productivity of some operational phases related to careful planning of the works. To date, the aspects related to sustainability are attributable to the materials used and energy consumption of buildings, but the construction phase of a building is the most harmful moment for the environment. This research has as its primary objective the in-depth study of one of the salient aspects of Facility Management: the guarantee of and compliance with environmental standards, in particular during the construction phase. In more detail, the aspect of the acquisition of methodologies for the environmental management of the recovery site will be explored through compliance with the so-called DNSH (Do Not Significant Harm) Principle, introduced by the Recovery and Resilience Facility (RRF), an economic instrument that supports the national recovery and resilience plans (PNRR). Environmental management will be explored through the creation of an environmental sustainability protocol applied to the construction phase and drawn up on the basis of current environmental legislation. The protocol was validated with the application of the ACS (Sustainable Construction Site Certificate) in a case study located in Italy, Palazzo Lazzaro, which is located in the post-earthquake reconstruction areas, in particular, in Fossa (AQ).

Keywords: DNSH; sustainability protocol; sustainable construction site certificate

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1. Introduction

Environmental sustainability is now one of the cornerstones for every sector; in fact the concepts of maintaining resources and environmental balance are of fundamental importance for the development of a process capable of combining the various economic activities in respect of the environment, thanks to the implementation of measures and production processes compatible with the biosphere's ability to renew itself and absorb the effects of human activities [1–3].

In September 2015, the UN member states approved the 2030 Agenda for sustainable development and, within the framework of the United Nations Framework Convention on Climate Change, the "Paris Agreement" was approved, which focuses its attention on the impact that economic activities have on climate change [4,5].

In December 2019, the European Commission presented the "European Green Deal" [6,7] as a programme of reforms and measures aimed at avoiding a disastrous future characterised by global warming, climate change and pollution, within which the principles of the 2030 Agenda and those of the Paris Agreement systematically converge [8]. The cornerstone of the Green Deal is the proposed law on climate change, which appears to be a very broad and ambitious plan that aims to achieve "climate neutrality", by reducing emissions by 55% by 2050 [9]. The economic sectors and activities affected by the reforms of the international Green Deal agreement are many; they include any economic activity capable of producing an impact on the environment and climate. In light of the objectives set by the European Green Deal [10], it has become of fundamental importance to direct the measures of economic activities towards projects and activities to support the ecological transition and the circular economy. In this regard, the EU Regulation on Taxonomy 2020/852 of the European Parliament and of the Council of 18 June 2020 and entered into force on 12 July 2020, is a reference regulatory framework consisting of documents of various kinds to encourage sustainable investments. The basic principle of the Taxonomy is called the DNSH principle "Do Not Significant Harm", which aims to assess whether a measure could have a negative impact on the six environmental objectives defined by the EU Taxonomy Regulation. The criteria on which the DNSH principle is based are aimed at climate change mitigation, a principle according to which an economic activity must not lead to significant greenhouse gas emissions (GHG); at climate change adaptation, for which it must not cause a major negative impact on the current and future climate, on the activity itself or on people or on nature or property; at the sustainable use and protection of water and marine resources, whereby an economic activity must not damage the good state of water bodies (surface, underground or marine) and cause qualitative deterioration or reduction of ecological potential. Particular attention is paid to the circular economy [11], avoiding the consequences of significant inefficiencies in the use of recovered or recycled materials, increases in the direct or indirect use of natural resources and a significant increase in waste, their incineration or disposal, causing significant environmental damage in the long term. Each activity must be aimed at preventing and reducing pollution, not leading to an increase in emissions of pollutants into the air, water or soil and each activity must protect and restore biodiversity without harming the good status and resilience of ecosystems or the conservation status of habitats and species, including those of Union interest.

The importance of the DNSH Principle is in the context of the interventions of the National Recovery and Resilience Plan (PNRR) [5] which specifically identifies the measures in line with the principles of the "NextGeneration EU" program [6] and stipulates that the interventions are aimed at achieving the objectives of the European Green Deal. The DNSH Principle represents a turning point to avoid damage to the environment caused by economic activities; however, from a more accurate study of the current regulations [8,9], it is clear that the introduction of more restrictive environmental regulations is still very difficult to apply and even more evident is the lack of a systematised method to certify compliance with the principle [10]. Focusing on the topic of the construction site, it is clear that both the legislation and the DNSH principle itself focus little on the pollution produced by the work carried out within it, even less if the recovery and/or renovation sites of historic buildings come into play, with these buildings often protected and located in sites that are difficult to manage. Much research has been conducted on the sources of pollution in construction activities: Preuilh J. et Al. argues that one of the major sources of pollution in construction activities is acoustic pollution [12]. Owolabi T. conducted a study monitoring the gases emitted by the work and highlighting how the level of pollution increases in dry seasons [13]; Thi Truong An P. et al. conducted a study on the digital twin capable of collecting and monitoring in real time, based on BIM modelling, the data relating to pollution in the construction site [14]; Tariq Bashir M. et al. highlighted how pollution from construction activities affects worker productivity in Pakistan [15]. Also based in Pakistan, Mubeen M. et al.'s research was conducted, which identified noise, dust, air and land pollution as the most frequent pollutions in construction sites [16]; Fauzany Z.A. et al. underline the critical need for greater awareness and action among government agencies, contractors and the public to safeguard the environment from the deleterious effects of construction waste pollution, thus preserving natural ecosystems and respecting environmental standards [17]. In this last study, it is highlighted how the most critical aspect is a method based on self-assessment forms provided by current legislation and written justifications, which leave complete autonomy to the company for how to certify that the construction process does not cause damage to the environment.

From this perspective, some building interventions have been taken into consideration, two of which are reported as examples, highlighting the shortcomings that they report despite being considered consistent with the DNSH principle. The first intervention studied is the redevelopment of the park and Villa Rucellai in Campi di Bisenzio (Florence, Italy). The project includes redevelopment interventions that concern a part of Villa Rucellai, a building of notable historical and architectural interest, which will host part of the "Cittadella della Cultura", a cultural centre with spaces dedicated to study and a library. The second intervention concerns the expansion and redevelopment of the Riccione Swimming Stadium. The technical sheets used in the cases under examination as a guideline for compliance with the DNSH principle are Sheet 02: Renovations and redevelopments of residential and non-residential buildings and Sheet 12: Production of electricity from solar panels. With regard to the climate change mitigation objective, a congruence with the principles is highlighted only for the design and not the construction site executive part; no studies or applications have been carried out in terms of adaptation to climate change, nor have solutions been adopted on site for the sustainable use and protection of marine waters. For objective 4 of circularity, a waste management plan has not been drawn up, nor mitigation strategies, but only the use of CAM materials. These two examples, although they can be considered compatible with the DNSH principles from a design point of view, from an operational point of view, lack strategies that make them sustainable from an executive point of view.

The so-called emission contribution deriving from construction activities comes from the engines of work vehicles, from processes that include earth moving (raising of dust) and the movement of the means of work. Also, in this case, the construction sector is one of the most impactful: it is estimated that before the pandemic, according to the sources of the World Green Building Council, buildings and the construction sector were responsible for 39% of all global carbon dioxide emissions, of which 11% were associated with the construction process [18]. With regard to the latter, carbon dioxide emissions deriving from the engine and movement of the means used for waste management are a difficult problem to manage when aiming to provide a positive contribution to the reduction of air pollution and at the same time to the mitigation of climate change [9]. Construction sites are responsible also for 14.5% of PM 2.5 emissions and 8% of PM10 emissions. The research aims to fill some gaps in environmental sustainability protocols that concern the construction site, as the most polluting moment in the life cycle of the building. In light of this, research has focused precisely on the construction process, through the development of a certification protocol in order to concentrate all the analysis of the existing literature and the aspects to be monitored during the construction site into a single protocol. The aim of the protocol is to certify the compliance of the construction process with the DNSH principle with a series of prerequisites and requirements to which a weighted score has been assigned. The fundamental criticality that this protocol aims to resolve is the absolute lack of a systematized process to refer to in order to verify compliance with the DNSH principle, which is currently entrusted to checklists drawn up at the discretion of the designer or construction company.

The protocol was then validated in the post-earthquake renovation site of Palazzo Lazzaro in Fossa (AQ), Italy, a post-earthquake recovery site located in the historic centre.

Following the application of the protocol, the critical issues of the site emerged, which led to the definition of improvement design strategies, examining the topic of CO_2 emissions and monitoring of environmental parameters via sensors.

2. Materials and Methods

The drafting of the certification protocol required a systematic and well-defined approach. The drafting process included the analysis of the relevant literature, the definition of the objectives and the selection of the necessary resources. In particular, the following steps were envisaged:

STEP 1. Study of the structure of the certification system protocols (LEED, BREEAM, DNGB, CASBEE, HQE, ITACA PROTOCOL);

STEP 2. Study of the current legislation on the DNSH Principle (in particular analysis of Regulation 2020/852);

STEP 3. Definition of the structure of the certification protocol;

STEP 4. Assignment of scores.

The following image illustrates the methodological path used to obtain the sustainable construction site certificate (see Figure 1).

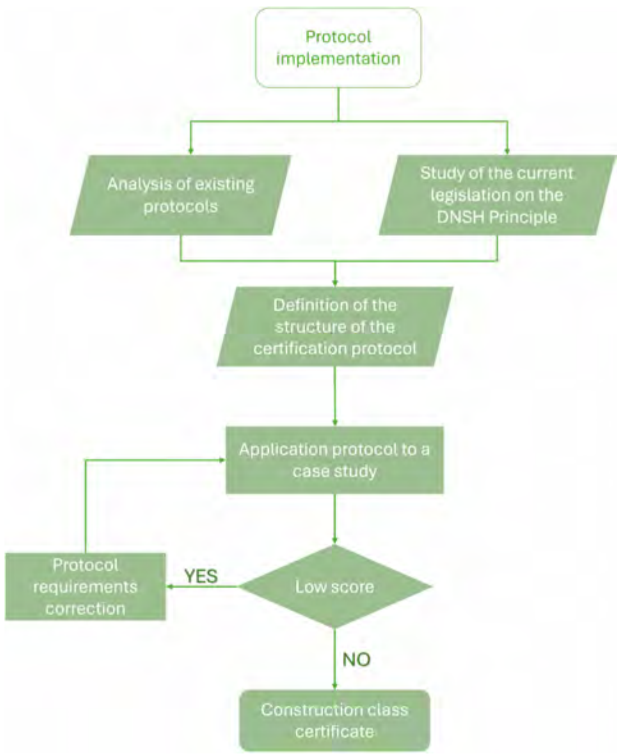

Figure 1. The methodological path illustrates how the method develops from an analysis of existing protocols and their gaps and DNSH principles, to then develop its own structure and proceed to verify the score after its application to a case study. If the score is too low, it is possible to apply prerequisites dictated by the protocol in order to increase the class achieved.

The certification protocol is structured through a series of prerequisites and requirements to which a weighted score has been assigned, deduced from the existing regulatory obligations regarding the DNSH principle and the current environmental legislation, as well as from the indications provided by the guidelines on environmental management of the construction site [19] of the rating and certification systems. The choice of the themes adopted to structure the protocol is a direct consequence of the analysis of Regulation 2020/852, which defines six environmental objectives that have been included within the method and treated as if they were macro-categories to which the requirements themselves can be traced back. The method used to assign the scores derives from the study of state-of-the-art examples and the complexity of the individual themes covered, and it assigns a higher score to the macro-categories with greater value and a lower score to the macro-categories with less importance for the specific area of the construction site. The complexity of the construction site activities did not allow for the evaluation of each individual aspect of the aforementioned environmental objectives in a meticulous and analytical manner; However, it is possible to summarise the salient aspects of the protocol:

- Prerequisites that must be met;
- Requirements;
- Guidelines and instructions on how to carry out the work that determines the requirement score;
- Limits and parameters to be met;
- Pollution control and monitoring systems on the construction site.

Each of these prerequisites are related to each of the DNSH criteria, previously mentioned and reported in Figure 2 below. The table analyses the reference legislation for each objective and the documentation necessary to obtain the coherence score.

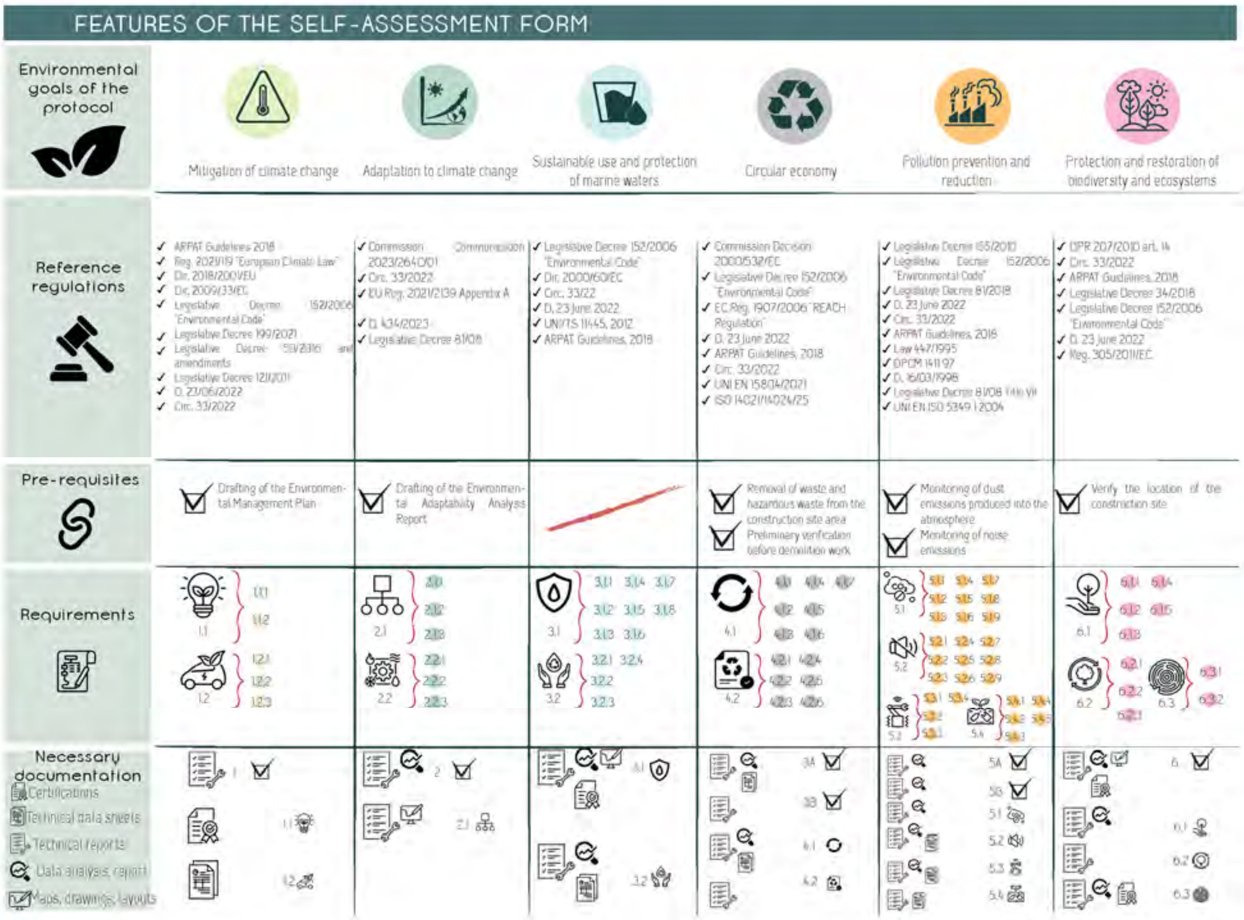

Figure 2. Main features of the certification protocol: objectives, reference legislation for prerequisites and requirements, definition of prerequisites and requirements for each environmental objective and definition of the necessary reference documentation.

The final objective of the protocol is not so much to determine how impactful the construction site activity is or the level of pollution of the work carried out within it, but rather to propose improved solutions and ways of operating that, if respected, allow not only compliance with the DNSH principle and therefore fitting into a broader discussion of incentives and tax deductions, but also to improve the relationship between the construction site and the surrounding environment, especially in cases where the latter is a historic centre or a protected natural site.

The protocol also contains references to IoT technology [20,21] for monitoring the construction site, in particular to sensors for controlling the environmental parameters of confined spaces and the oscillations of scaffolding for the safety of workers.

Application of the Protocol and Assignment of Scores

The attribution of scores represents a crucial element in the evaluation process of the certification protocol. For example, a higher score was assigned to the macro-category of "Prevention and reduction of pollution" [22–25], because all types of pollution that the construction process can cause were considered, from air pollution to noise pollution, also focusing on water and soil pollution and also introducing the issue of excessive vibrations caused by construction site vehicles and the work itself. Since it is mandatory to respect them, the choice was made to assign the same score to the prerequisites, regardless of the macro-category to which they belong (1 point for each).

The maximum score obtainable for a construction site is one hundred points.

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- Mitigation of climate change: 10 points;
- Adaptation to climate change: 10 points;
- Sustainable use and protection of marine waters: 15 points;
- Circular economy: 20 points;
- Prevention and reduction of pollution: 30 points;
- Protection and restoration of biodiversity and ecosystems: 15 points.

The maximum score obtainable for a construction site is one hundred points (see Figure 3).

Obviously, the score must be calibrated based on the type of work carried out on the construction site; the protocol was drawn up to be a valid reference for any type of construction site (demolition, renovation, recovery, conservative restoration, new construction, etc.) and for any context (urbanised area, historic centre, lake environment, natural landscape subject to constraints, etc.), so further reasoning is needed in the methodology for obtaining the final score. If a requirement is found not to be applicable to the specific construction site due to the nature of the work or the location being different from that cited by the requirement itself, the score relating to that specific requirement not applicable to the construction site being verified must be subtracted from the total score (one hundred). For example, if the construction site is not located in a place where there is local shrub vegetation, then requirement 6.1.3: "Do not use trees for driving nails, supports and for installing lighting fixtures, electrical cables, etc." for the score of 1 point, is not applicable to the construction site, and therefore the maximum score achievable by the same to be referred to will not be one hundred points, but ninety-nine points.

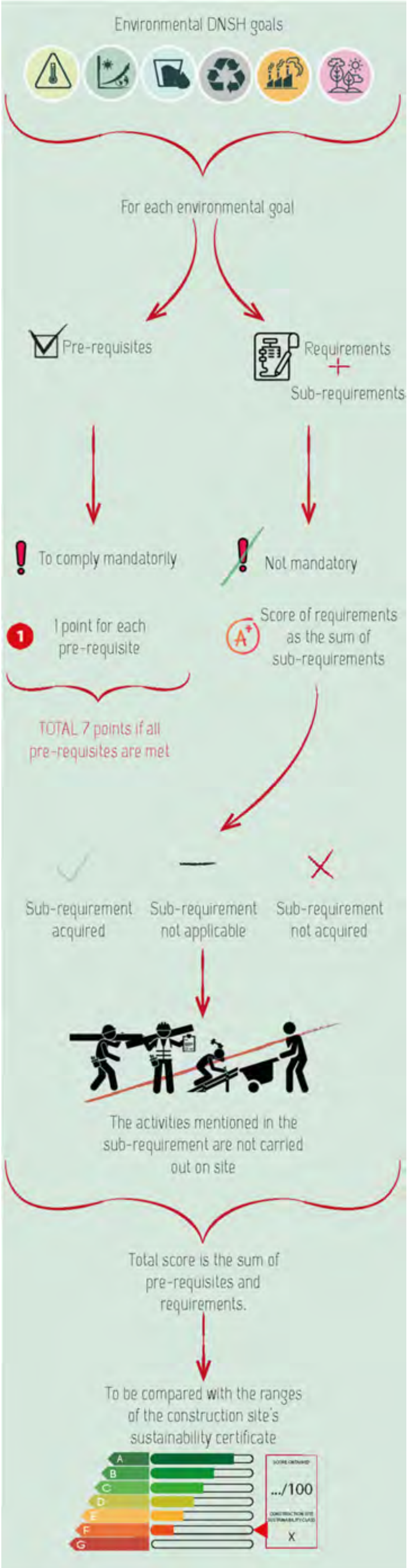


Figure 3. *Cont.*

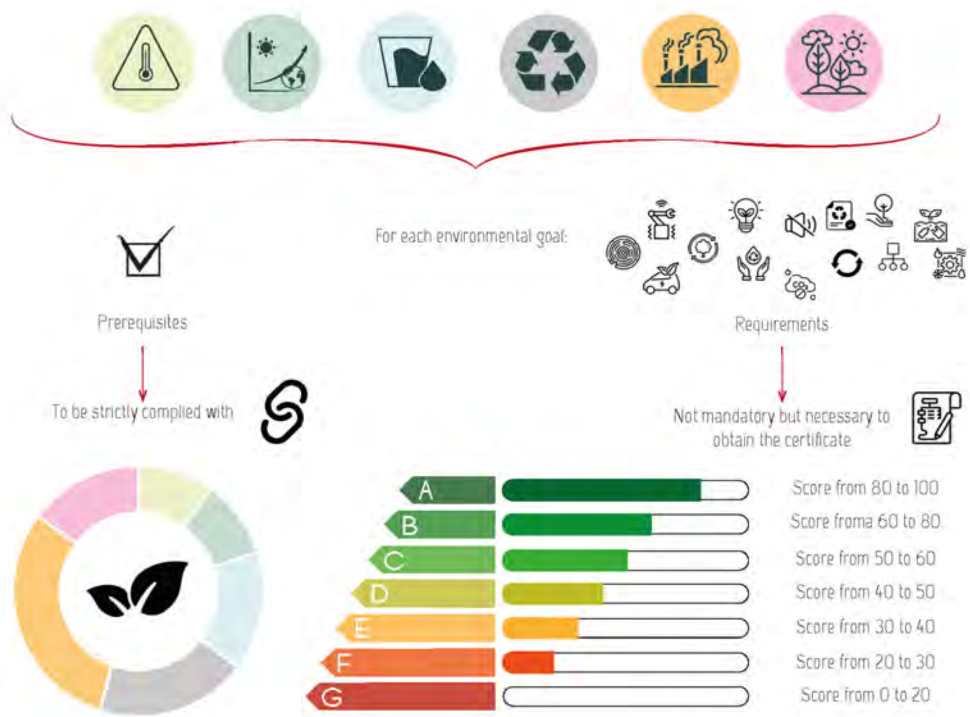


Figure 3. Definition of the score for each environmental objective and method of acquiring the score for the construction site.

To obtain the Sustainable Construction Site Certificate (ACS), it is necessary to register the construction site on the control checklists, noting down all the data relating to it and providing a brief description of its location and the salient features of its organization, highlighting its critical issues. The work carried out must also be described, attaching the timetable if necessary. Subsequently, it is essential to design the construction site based on the strategies and guidelines provided by the protocol itself, an example of which is given in the paragraph on the application to the construction site, and evaluating, through the system of requirements, the score obtained by the construction site.

Based on the score obtained, the certificate presents a division into classes, along the lines of the energy classes of an Energy Performance Certificate (EPC) of buildings:

- Class A: score from 80 to 100;
- Class B: score from 60 to 80;
- Class C: score from 50 to 60;
- Class D: score from 40 to 50;
- Class E: score from 30 to 40:
- Class F: score from 20 to 30;
- Class G: score from 0 to 20.

The DNSH principle is respected if the construction site is Class A, B or C, below the score of 50 points; it is necessary to introduce other mitigation strategies in order to increase the level of sustainability of the construction process. It is clear that, unlike the current method based on written self-certifications, the score protocol provides a valid document of clarification on whether or not the principle is respected.

The certifying body will be responsible for checking all the necessary documentation provided by the Director of the construction site, which aims to certify the acquisition of the requirements. The choice was also made to differentiate the documentation based on the macro-category, drawing up a reference guide for it, too (see Figure 4). The documentation identified for the protocol can be divided into:

- Certifications: issued by the certification bodies (e.g., GSE Energy Services Manager for 100% renewable energy supplier, FSC/PEFC for wood from certified forests);
- Technical data sheets: issued by the producers of materials and means used;
- Technical reports: drawn up by the director of the construction site in order to report the improvement strategies adopted for each macro-category, the critical issues connected to the work carried out on the construction site and the data from monitoring, (e.g., PAC Environmental Management Plan, Waste Management Plan);
- Data analysis, reports: to be attached to the technical reports to immediately explain the results of the monitoring and/or studies carried out (e.g.,: Environmental adaptability analysis report);
- Maps, drawings and layouts: to be attached to the technical reports.

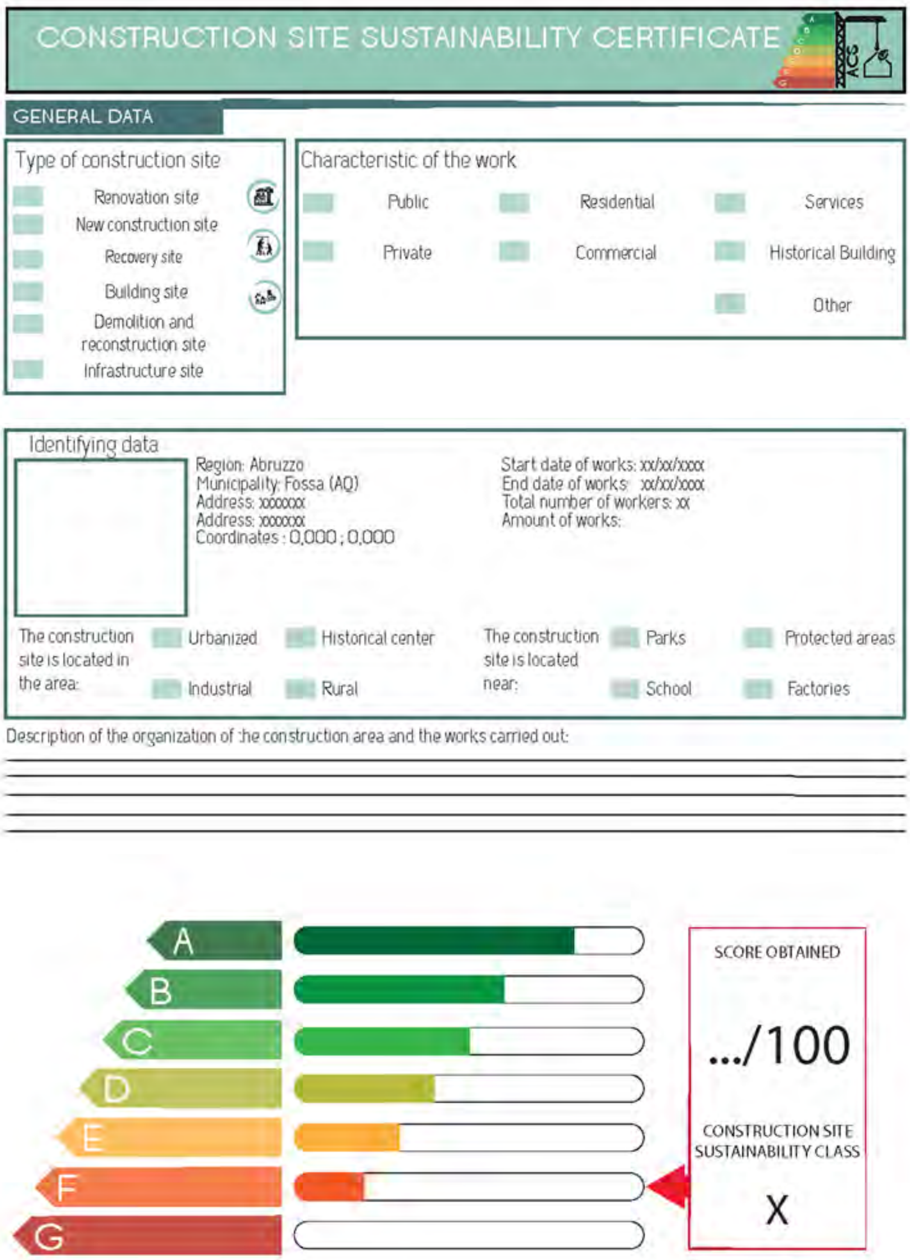


Figure 4. Layout of the Construction Site Sustainability Certificate (ACS) and subdivision of the construction site sustainability classes. The figure shows the layout for the acquisition of construction site data and the graph of the score achieved on a scale from A to G.

3. Results

3.1. Case Study: Palazzo Lazzaro in Fossa (AQ)

Among the various construction site interventions, those applied to existing buildings after the earthquake are those with the greatest impact in terms of logistics, demolitions and polluting operations for the environment. These conditions are due to the different configurations of a building complex that presents a significant diversification of interventions applied to a single large construction site. It is from this perspective that we proceeded with the validation of the protocol on the construction site under study located in the heart of the historic centre of Fossa. The Palazzo Lazzaro construction site is bordered by Largo dell'Allegria to the north, by Via Casentino to the east, by Via della Sorgente to the southwest, by Largo del Municipio and by Salita del Ponte to the east.

The location of the building itself makes it difficult to organise construction site logistics and access to transport, also considering the closure of some roads that have not yet reopened since the seismic event, therefore falling within the red zone. The crane is positioned on the road called Salita del Ponte; it has a radius of 48 m. It is necessary to take into account the presence of two other cranes located in Piazza Masci and in the nearby small street connected to Via Santo Spirito, which serve other neighbouring aggregates. Below the crane are the construction site garages, with attached construction site office and services for workers, and two tanks.

From the analysis of the construction site, it is clear that its particular position within a historic centre is responsible for many critical issues and problems related to the environmental quality of the confined spaces and the areas immediately surrounding them. One of the most noticeable critical issues is certainly linked to reaching the construction site with the heaviest vehicles. Furthermore, the presence of other construction sites located in the immediate vicinity very often causes problems related to interference from vehicles or temporary blockage of communication routes. Another element that hinders the passage of construction site vehicles is certainly the arch that marks the passage between Via Santo Spirito and Largo dell'Allegria.

From the analysis carried out on the location of the construction site, no sensitive receptors (e.g., schools, hospitals, kindergartens, etc.) were found in the immediate vicinity. However, as already mentioned, a large part of the historic centre of Fossa is currently still uninhabited, with unsafe and heavily damaged residential buildings, which could increase the risk conditions during the works. The very complex planimetric development of Palazzo Lazzaro and its position on a terrain with a strong slope makes it difficult to carry out the works, as does the positioning of the crane and the creation of the areas for the storage of materials and waste disposal. It is clear that the works are carried out in very narrow spaces and in precarious conditions, not only due to the nature of the places, but also due to the risks brought by the work related to the specific recovery site such as: the precariousness of walls and floors and the stability of load-bearing walls and collapses or demolitions. These factors also strongly influence the environmental aspect, determining the production of high concentrations of dust and polluting gases due to the nature of the work such as demolitions [23]. The narrowness of the alleys surrounding the building and the presence of other buildings which act as a shield could cause a concentration of dust and polluting gases [20] which exceeds the limits established by law and which could constitute a damaging factor for the quality of the environment surrounding Palazzo Lazzaro (Figure 5) and for that of the workers [26–28].

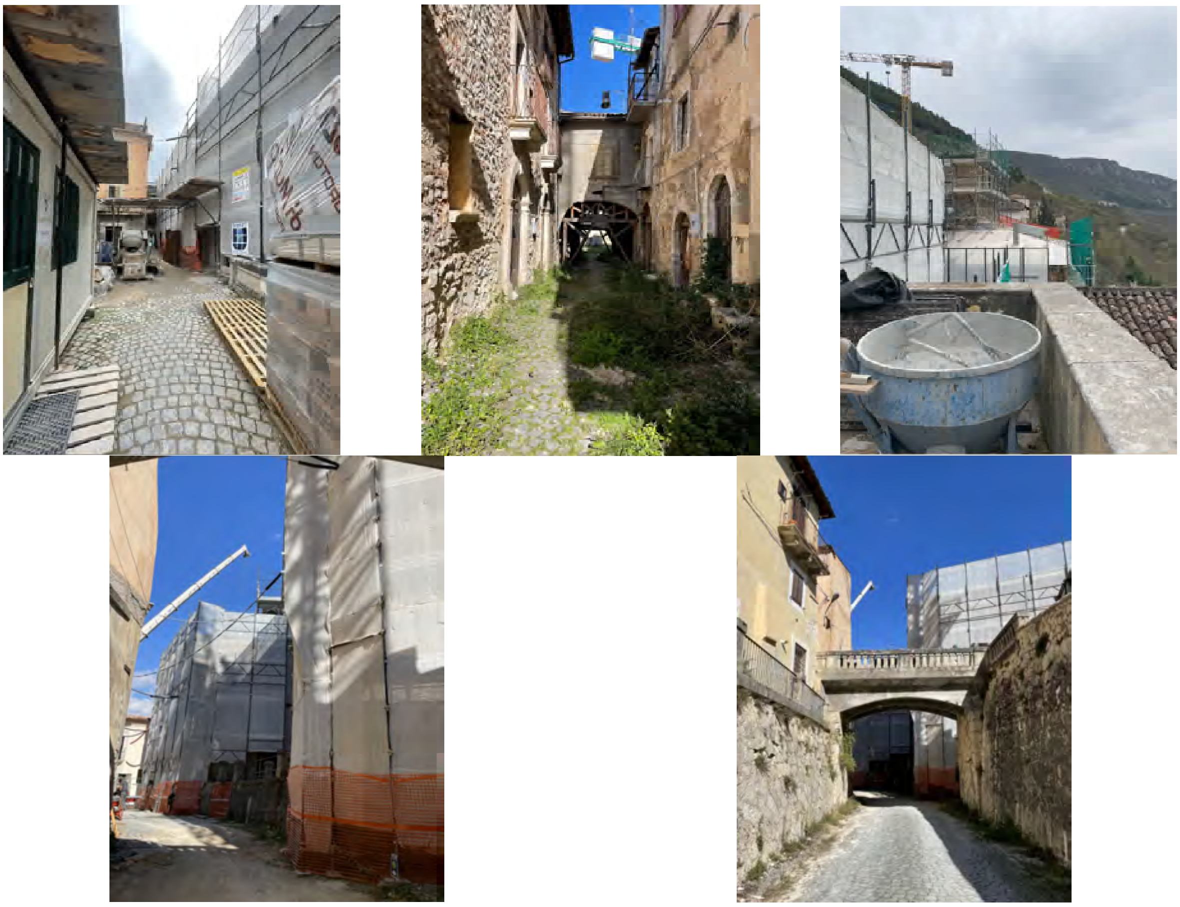


Figure 5. Construction site views of Palazzo Lazzaro.

3.2. Application of the Protocol

In order to validate the method of application of the certificate, it was necessary to perform an analysis of the traditional construction site according to the principles stated and then proceed to its evaluation by hypothesising its development according to the principles of sustainability. Following an analysis of the current state of the construction site, according to the macro-categories indicated previously, the prerequisites of the same were analysed by assigning to each element, correlated to the DNSH principles, a sustainability score of the construction site. The total acquired by the construction site, according to the traditional structure, led to obtaining a score of 24.5/78. The score obtained corresponds to the Sustainability Class "E" which does not allow certification of compliance with the DNSH principle (Figure 6).

Through the application of the protocol, the most critical issues characterising the study site emerged. The critical issues identified and highlighted by the protocol are listed below:—Construction site electricity supply: the supplier does not guarantee 100% renewable energy;—Construction site mobility: The road and non-road work vehicles are diesel or petrol-powered;—Location: Location in the historic centre;—Water saving: lack of devices and strategies necessary for the reuse of uncontaminated rainwater and lack of construction site water monitoring;—Waste recovery and recycling: lack of devices and strategies for the recovery and recycling of construction and demolition waste;—Building materials: use of "classic" construction materials for the renovation of the building;—Air pollution: lack of devices and strategies necessary for monitoring PM10 and PM2.5 dust emissions into the atmosphere [21];—Removal of invasive vegetation: presence of invasive vegetation that hinders the progress of construction operations.

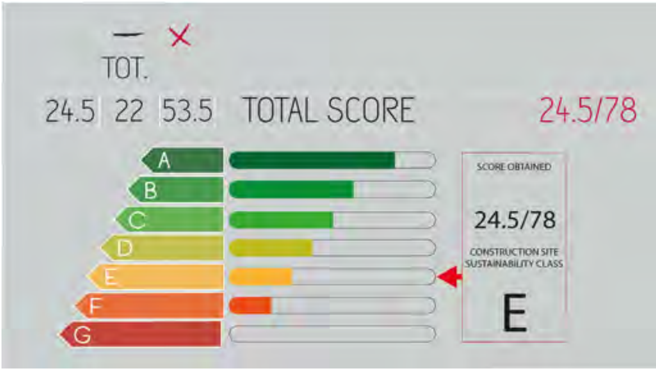


Figure 6. Score of the current state and sustainability class achieved by the construction site.

The scores were assigned by applying the same considerations of the existing protocols analysed, thus assigning a score based on the ranges of the analyses performed. In this sense, it was necessary to analyse the site reports together with the site manager, referring to the work performed in quantitative terms. The score obtained and the individual scores achieved are re-evaluated at the end of the site through a quantitative analysis of all the elements analysed (Figure 7).

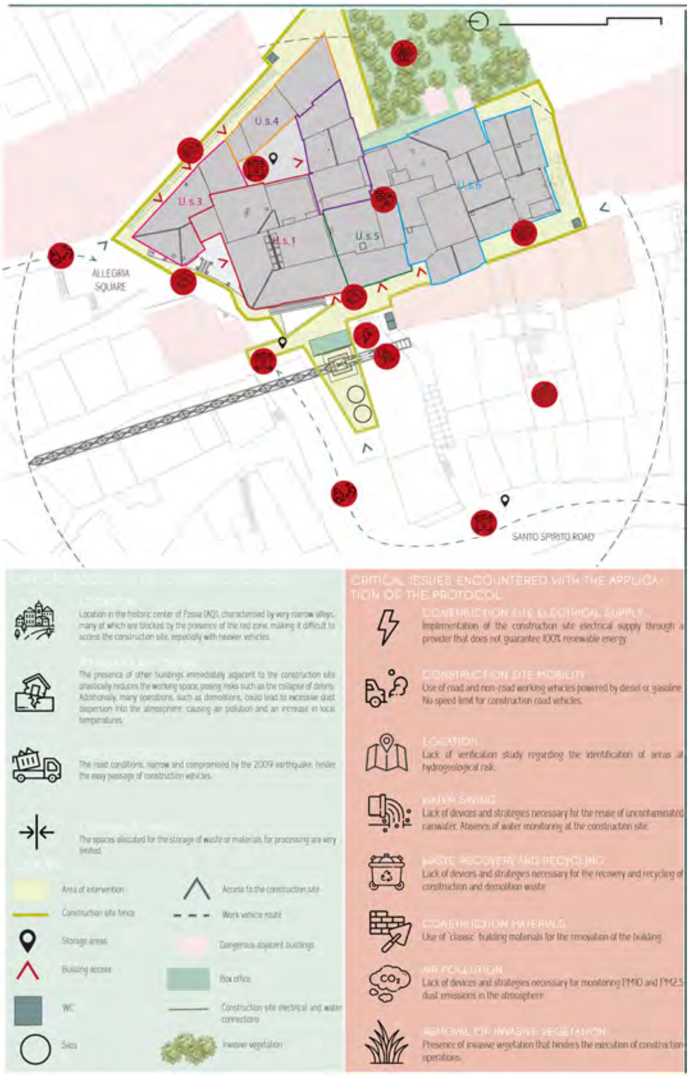


Figure 7. Mapping of construction site criticalities. The figure shows a construction site layout with the mapping of the critical elements detected.

4. Discussion

4.1. Improvement Design Strategies

Following the application of the protocol and the analysis of the critical issues found, the research focused on the definition of improvement design strategies, in order to increase the level of sustainability of the construction process of the building site [29,30] and finally respect the DNSH principle. These strategies were formulated based on the analysis of the current state and the nature of the work carried out on the building site, as well as on the basis of the objectives that could actually be pursued by the building site itself. Ultimately, an attempt was made to introduce strategies that would allow the building site to contribute substantially to the improvement of each environmental objective, both through strategies that include the introduction of devices that assist the construction process itself, and through actual actions to be carried out within pre-established times. Figure 8 shows the improvement strategies defined for the building site in tabular form, each of which includes the use of specific solutions relating to the six criteria of the DNSH principles mentioned.

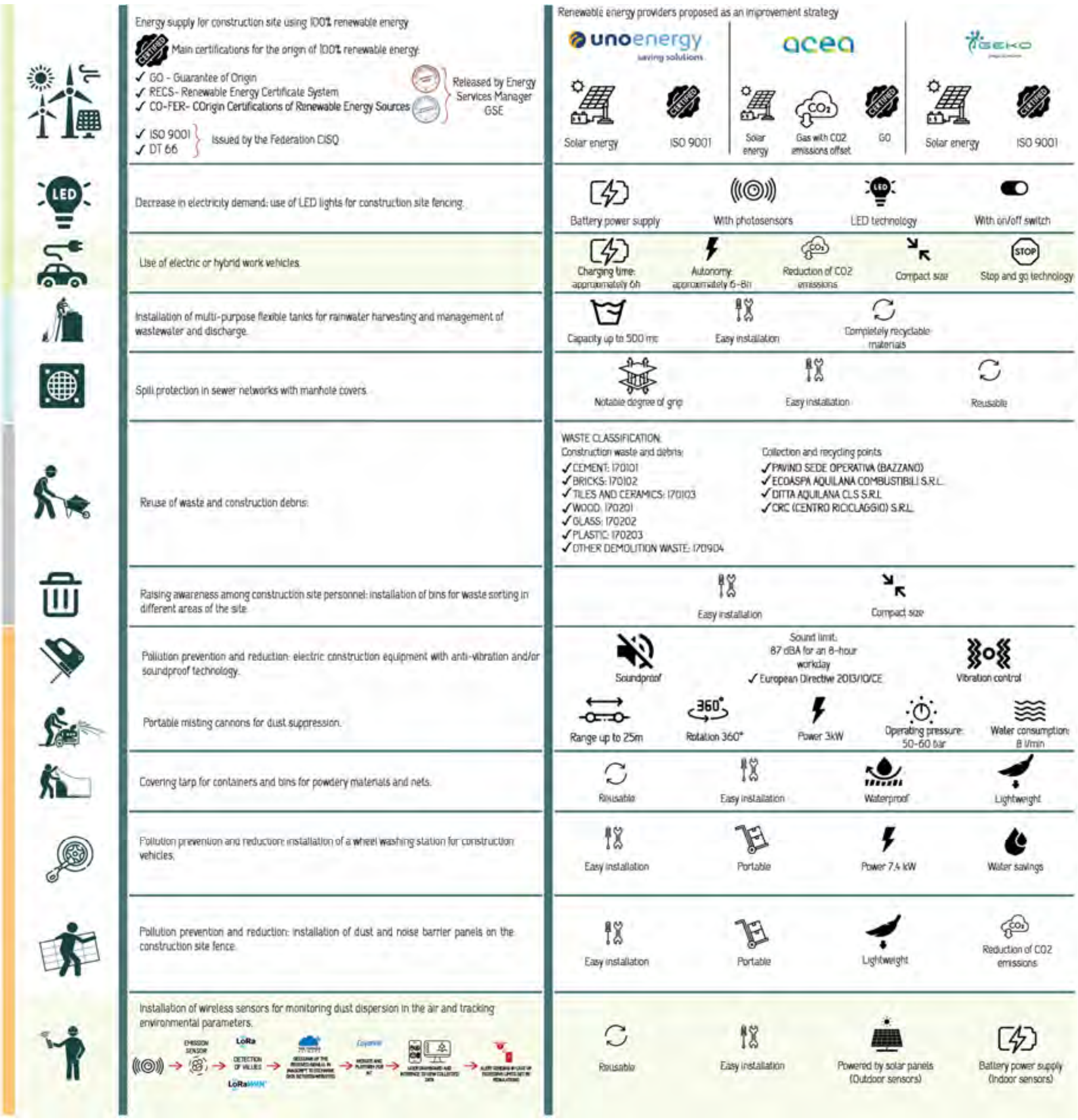


Figure 8. Improvement strategies defined for the construction site. For each requirement, solutions are suggested in order to satisfy the score and the possible achievable results.

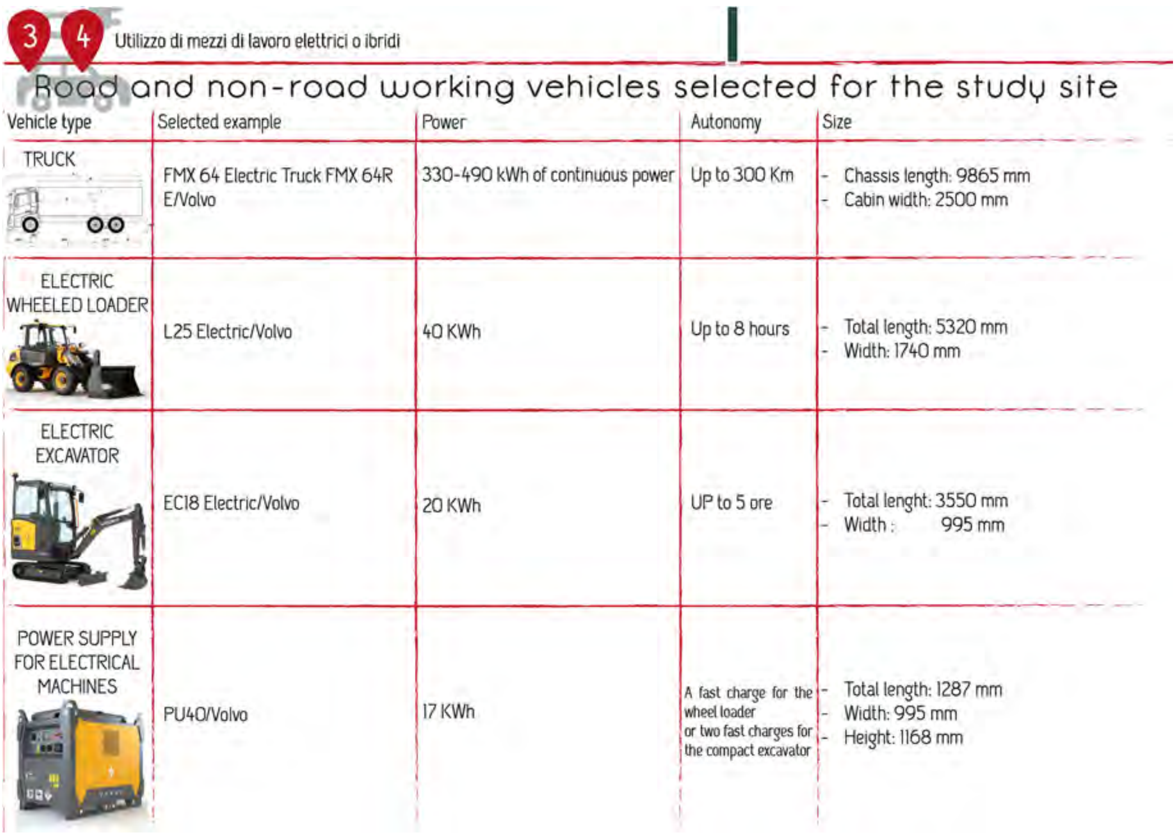
For each principle, several solutions compliant with the protocol and capable of obtaining a higher score were identified.

The solutions adopted and related to the DNSH principles reported in the introductions are reported below in detail and analysed below point by point:

(a) CLIMATE CHANGE MITIGATION

In this section, some of the sustainability scores of the construction site are analysed and related to the principle of climate change mitigation, in particular to the realisation of the construction site's energy supply through 100% renewable energy and to the reduction of electricity demand through the use of LED lights for construction site fences and to the use of hybrid or electric work vehicles [30,31]. One of the improvement strategies to reduce polluting emissions is the use of hybrid or electric work vehicles chosen based on the work carried out on the construction site. In the case in question, a power supply for electric machines is also proposed that allows the machines used when strictly necessary to be recharged directly on the construction site [32–35]; it allows for a quick recharge of the electric wheel loader or two quick recharges of the compact excavator.

In Figure 9 a summary table of construction site vehicles is provided, reporting the brand of the vehicle chosen as an example and some of its characteristics:



Vehicle type	Selected example	Power	Autonomy	Size
TRUCK	FMX 64 Electric Truck FMX 64R E/Volvo	330-490 kWh of continuous power	Up to 300 Km	- Chassis length: 9865 mm - Cabin width: 2500 mm
ELECTRIC WHEELED LOADER	L25 Electric/Volvo	40 KWh	Up to 8 hours	- Total length: 5320 mm - Width: 1740 mm
ELECTRIC EXCAVATOR	EC18 Electric/Volvo	20 KWh	UP to 5 ore	- Total lenght: 3550 mm - Width : 995 mm
POWER SUPPLY FOR ELECTRICAL MACHINES	PU40/Volvo	17 KWh	A fast charge for the wheel loader or two fast charges for the compact excavator	- Total length: 1287 mm - Width: 995 mm - Height: 1168 mm

Figure 9. Proposed working means and main features. Analysis of the machinery used in terms of power, autonomy and dimensions.

(b) SUSTAINABLE USE AND PROTECTION OF MARINE WATERS

An element compatible with the criterion of sustainable use and protection of marine waters is the installation of multipurpose flexible tanks for rainwater collection and wastewater and sewage management. A further element proposed is to install self-supporting flexible tanks as they represent an easy-to-install system that can be customised according to needs, meaning that they are therefore very effective for the limited spaces that are available in the construction site study. It was decided to install a tank in the area where there is most invasive vegetation with the aim of storing rainwater. Three other smaller tanks were planned and distributed evenly so as to serve the entire aggregate, with the aim of favoring the storage of wastewater in order to facilitate its transport to the treatment plants, facilitating the management of the process while avoiding waste and damage to the environment. The reuse of water resources on the construction site is very important for various purposes; in this case, it was decided to recover it to wet and favor the reduction of dust during demolition operations, cool the machinery and surfaces and carry out the cleaning of the construction site and to prevent the formation of harmful dust.

Even the protection from spills in sewer systems with manhole cover mats is a principle compatible with the protection of marine waters. We then proceeded with the mapping of the manholes present in the study site and in the immediate vicinity and proposed to install manhole cover mats that allow the avoidance of sudden spills into the sewer systems, allowing the passage of water but not of solid bodies and dust deriving from construction site operations.

(c) CIRCULAR ECONOMY

Elements that make the construction site compatible with the principle of circular economy are the reuse of construction waste and rubble and the awareness of construction site personnel through the installation of bins for the separate collection of waste in different areas of the construction site.

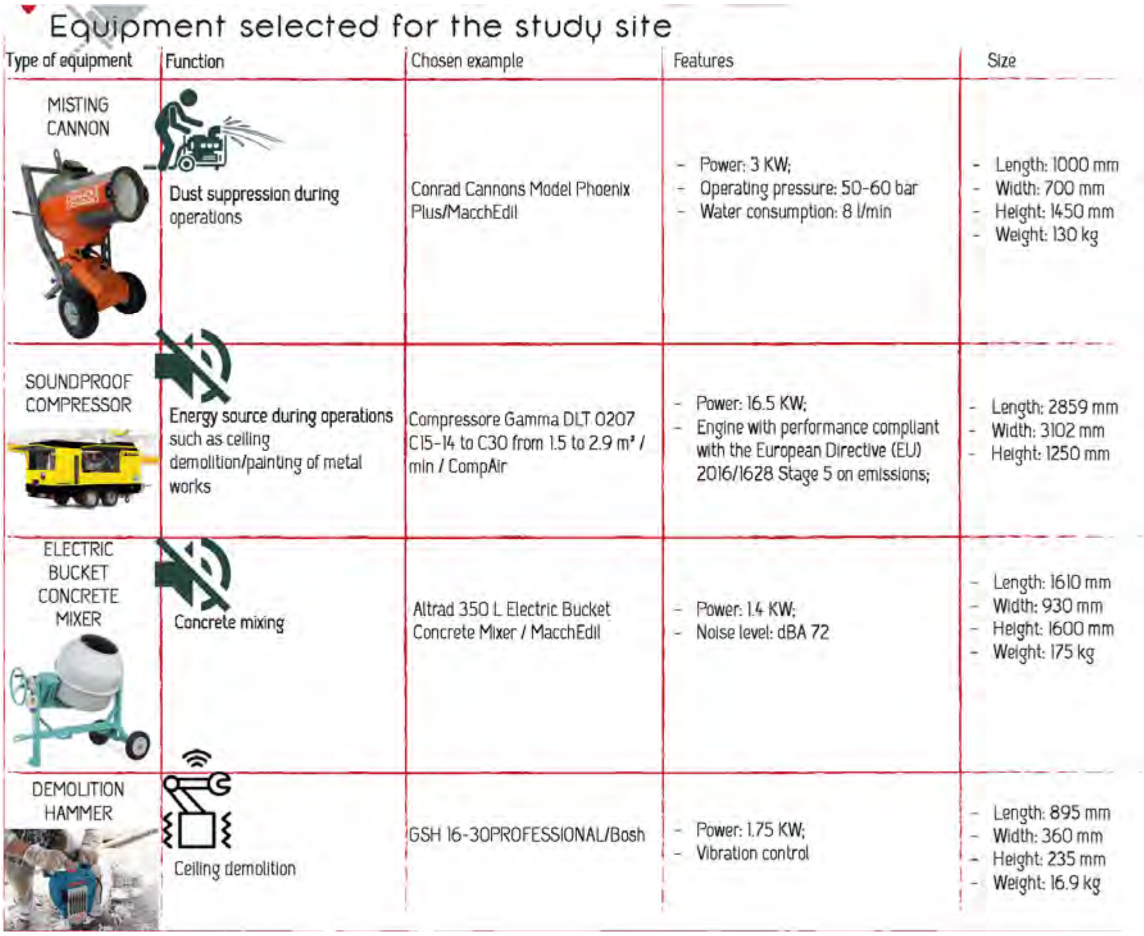
It was proposed to promote the reuse of construction waste and rubble by defining a waste management plan, which provides for separate treatment of construction waste and waste from demolition and removal. First of all, it was decided to organise the work schedule so as to have only removals and demolitions, and we proceeded with the method of selective demolition and removal. Two bins were installed to set aside the inert material, one of 12 cubic meters and the other of 8 cubic metres, and, in the same way, it was decided to designate the cloister of Palazzo Lazzaro, the terrace of U.S.1 and a suitably fenced area of Piazzale delle Fra-nine as storage or setting aside areas for the removed materials to be reused, which in the general construction site plan is indicated as a Higher Order Services Area (S.O.S.) meaning it is therefore also used for general storage and waste storage. It was also decided to provide tear-proof sheets in thick polyethylene to cover the containers on particularly windy days. For the recycling of the rubble produced, four sites were identified in the vicinity of the construction site dedicated to the recycling of inert and other materials.

(d) POLLUTION PREVENTION AND REDUCTION

To prevent and reduce pollution on construction sites, the measures to be adopted are electrical construction site equipment possibly with anti-vibration and/or sound-absorbing technology, nebuliser cannons for dust reduction, cover sheets for containers and bins for dusty materials and nets, the installation of a wheel washing point for construction site vehicles and the installation of dust-proof and noise-proof panels on the construction site fence.

The improvement solutions regarding the prevention and reduction of pollution constitute the most substantial part of the project since the protocol drawn up dedicates its attention to the pollution of air, water and soil and also focuses on noise pollution and vibrations generated by vehicles and construction site operations.

Below is a summary table with the main equipment chosen for the work carried out in the study site (Figure 10).



Equipment selected for the study site

Type of equipment	Function	Chosen example	Features	Size
MISTING CANNON	Dust suppression during operations	Conrad Cannons Model Phoenix Plus/MacchEdil	- Power: 3 KW; - Operating pressure: 50-60 bar - Water consumption: 8 l/min	- Length: 1000 mm - Width: 700 mm - Height: 1450 mm - Weight: 130 kg
SOUNDPROOF COMPRESSOR	Energy source during operations such as ceiling demolition/painting of metal works	Compressore Gamma DLT 0207 C15-14 to C30 from 1.5 to 2.9 m³ / min / CompAir	- Power: 16.5 KW; - Engine with performance compliant with the European Directive (EU) 2016/1628 Stage 5 on emissions;	- Length: 2859 mm - Width: 3102 mm - Height: 1250 mm
ELECTRIC BUCKET CONCRETE MIXER	Concrete mixing	Altrad 350 L Electric Bucket Concrete Mixer / MacchEdil	- Power: 1.4 KW; - Noise level: dBA 72	- Length: 1610 mm - Width: 930 mm - Height: 1600 mm - Weight: 175 kg
DEMOLITION HAMMER	Ceiling demolition	GSH 16-30PROFESSIONAL/Bosh	- Power: 1.75 KW; - Vibration control	- Length: 895 mm - Width: 360 mm - Height: 235 mm - Weight: 16.9 kg

Figure 10. Equipment proposed for the construction site and main features.

Below is an analysis of the machinery used in terms of power, autonomy and dimensions.

In addition to the construction site equipment, there are numerous devices to reduce dust and pollutants for the air and soil: we propose installing dust and noise-proof panels on the classic construction site fence, made up of a fibre mat, and lined with non-woven fabric that acts as internal insulation. The installation of this flexible sheet also acts as a visual screen so as to make the view of the construction site less impactful. To prevent soil pollution, in particular that of neighbouring roads due to road construction vehicles, we plan to install two points where the wheels of the vehicles are cleaned. The points identified to carry out this activity are the entrance to Via del Forno and the intersection between Salita del Ponte and Via Santo Spirito. Cleaning will be conducted manually with the help of a pressure washer that can be easily transported from one part of the construction site to another and with the possibility of using hot water to make cleaning more effective. The pressure washer can also be used to clean the construction site at the end of the day or the surrounding streets that will be particularly dirty after some work has been carried out. Finally, it was also decided to use a Facility Management tool for the management of the construction site which is expressed in the installation of sensors for monitoring environmental parameters [32]. Data monitoring will take place in real time as the provision of a BimKios is proposed.

(e) PROTECTION AND RESTORATION OF BIODIVERSITY AND ECOSYSTEMS

In this case, a design strategy is proposed that consists of the action of removing invasive vegetation in the construction site area, which currently hinders the normal progress of the work. It is found that there are no plant shrub species to be protected and that the construction site does not fall within a natural site of interest or belong to the Natura 2000 list.

4.2. In-Depth Analysis of CO_2 Emissions Estimates

The research was dedicated to the study of the topic of waste transportation to recycling and sorting centres, an action responsible for carbon dioxide (CO_2) emissions, an odourless and colourless gas produced by combustion. The calculation was carried out using a formula that considers a CO_2 emission factor for the type of engine used to carry out transportation, multiplied by two factors, Y and Z, where Y represents the number of trips made and Z the length in Km of each trip.

$$CO_2 \text{ emitted} = \text{g } CO_2/\text{Km} * (Y * Z)$$

In order to calculate the number of trips and the length in Km of each of them, research was carried out on the recycling and sorting centres used by the study site, and the distance in Km of each of them from the site itself was determined. A summary table is reported below (Figures 11 and 12). The site https://www.maceriesisma2009.it/ (accessed on 15 January 2025) was subsequently consulted, which is a portal where it is possible to monitor in real time the quantity and type of rubble produced by the reconstruction sites following the earthquake of 6 April 2009. The data are related to both public and private rubble. On the portal, it is also possible to observe the places where the rubble is disposed of daily and the type of vehicles used to transport it. Research was therefore carried out on Palazzo Lazzaro and it was possible to determine the Y and Z factors. An explanatory table is reported containing the quantity and type of waste produced and the number of trips made to each waste recycling and sorting point (Figures 11 and 12).

Figure 11. Collection and sorting centres in the immediate vicinity of the construction site.

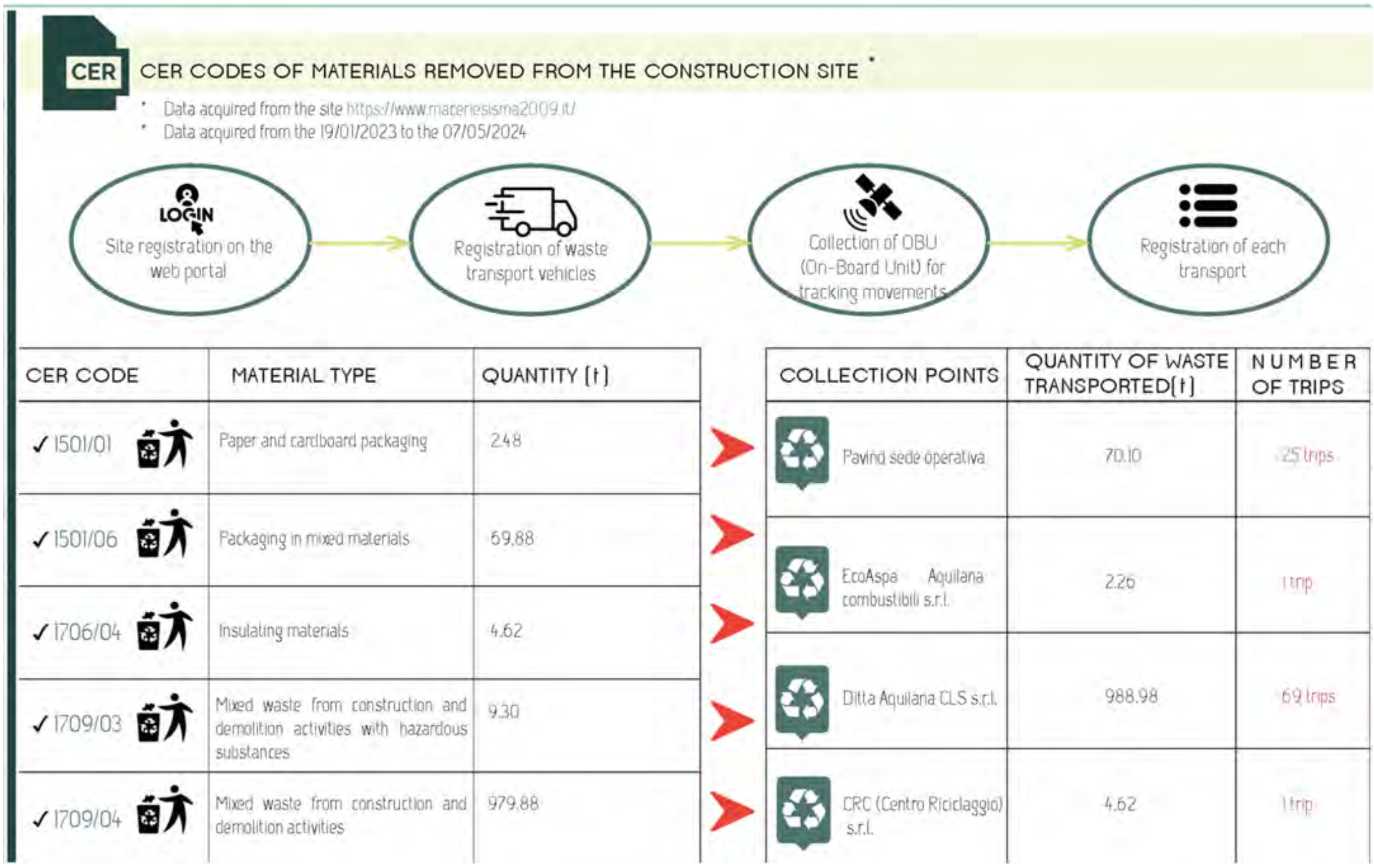


Figure 12. Data acquisition method, type and quantity of waste produced by the construction site and collection points and relative number of trips made. (Data acquired from 19 January 2023 to 7 May 2023).

Research on the emission factors of g CO_2 was also conducted and, for this purpose, the website fetransp.ispramabiente.it/ was consulted, which provides a database of the average emission factors of road transport in Italy. As a simplifying hypothesis, carbon dioxide was considered as the only greenhouse gas in the “Polluting selection” box. The emission factor for a diesel-engine “Heavy Duty Truck” is approximately 668 g CO_2/Km, while there is no material for the emission factors regarding electric or hybrid trucks. An article regarding the CO_2 emissions of electric cars was therefore consulted [36] whose results report emission factors equal to:

- 124 gCO_2/Km for diesel engines;
- 51 gCO_2/Km for electric/diesel engines;
- 0 gCO_2/Km for electric engines.

It can be seen that the emission factor of a car is significantly lower than that of a truck. This is because the calculation of an emission factor is based on the consideration of the life-cycle analysis [11].

Using the data from the cited study [34], comparative evaluations were carried out as shown in Table 1:

The balance sheet shows how, by using an electric/diesel vehicle, it is possible to have approximately 58% less emissions released into the atmosphere, which would be completely eliminated if a vehicle with a purely electric engine were used.

Table 1. Comparison of CO_2 emissions of diesel and electric/diesel vehicles.

DIESEL ENGINE	
Pavind Operational Headquarters:	124 g CO_2/Km ∗ 25 ∗ 5.4 Km = 16.7 Kg
EcoAspa Aquilana combustibili s.r.l.:	124 g CO_2/Km ∗ 1 ∗ 6.0 Km = 0.7 Kg
Aquilana CLS s.r.l.:	124 g CO_2/Km ∗ 69 ∗ 8.0 Km = 68.4 Kg
CRC Centro Riciclaggio s.r.l.	124 g CO_2/Km ∗ 1 ∗ 9.7 Km = 1.2 Kg
Tot Kg CO_2 = (16.7 + 0.7 + 68.4 + 1.2) = 87 Kg CO_2	
ELECTRIC DIESEL ENGINE	
Pavind Operational Headquarters:	51 g CO_2/Km ∗ 25 ∗ 5.4 Km = 6.9 Kg
EcoAspa Aquilana combustibili s.r.l.:	51 g CO_2/Km ∗ 1 ∗ 6.0 Km = 0.3 Kg
Aquilana CLS s.r.l.:	51 g CO_2/Km ∗ 69 ∗ 8.0 Km = 28.2 Kg
CRC Centro Riciclaggio s.r.l.	51 g CO_2/Km ∗ 1 ∗ 9.7 Km = 0.5 Kg
Tot Kg CO_2 = (6.9 + 0.3 + 28.2 + 0.5) = 36.5 Kg CO_2	

Based on the assessments carried out, the DNSH principle compliance assessment protocol was reapplied, after redesigning the construction site according to the improvement strategies defined in the previous paragraphs.

The score now obtained by the construction site is 65.5/78 points; having reached sustainability class A, it is possible to certify compliance with the DNSH principle.

The highest score is achieved thanks to the use of electric vehicles and equipment that reduce CO_2 emissions and consumption [35,36].

The comparison with the previously obtained score of 24.5/78 points (Figure 13) (before the redesign of the construction site) is highlighted, which highlights the importance of adopting improvement design strategies aimed at the environmental management of the construction site.

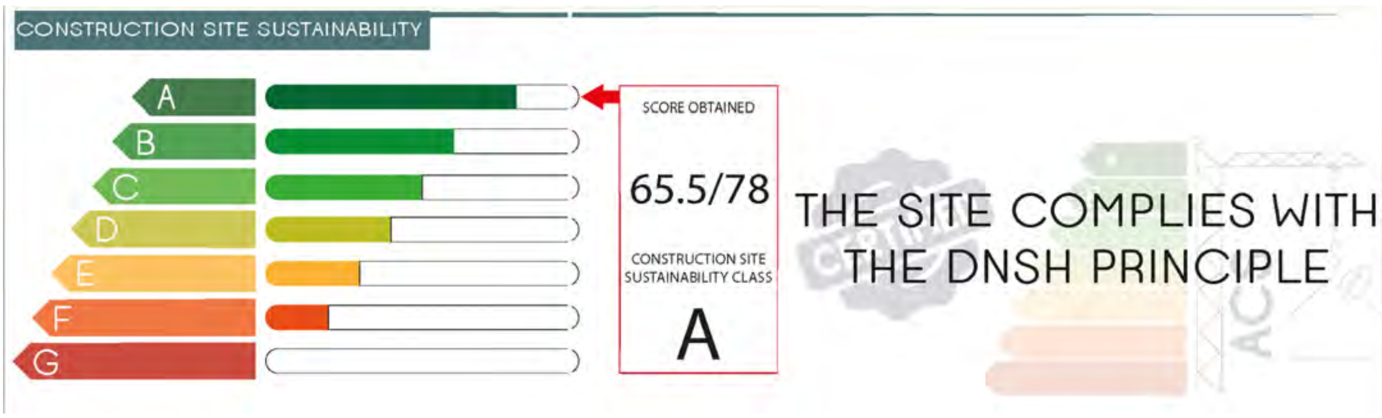


Figure 13. Project status score.

5. Conclusions

The topics addressed lead to the awareness of the importance of planning construction site processes, to avoid or reduce possible environmental impacts. With it having emerged that the issue of sustainability is still far from being a parameter to always take into consideration throughout the life cycle of the building and that the method for certifying compliance with the DNSH Principle of the construction process is still immature and disorganised, there is confirmation that the construction site has not yet been fully reworked from an environmental point of view. The protocol developed on the basis of sector legislation on environmental matters is an effective tool capable not only of "measuring" the sustainability of a construction process, but also acting as a design guide and reference.

The environmental awareness of the activities connected to the construction site, which is expressed, in this case, in the company's compliance with the DNSH Principle, is also the central theme on which the innovation and competitiveness of the company itself focuses, which is encouraged by the system of the allocation of funds of the National Recovery and Resilience Plans (PNRR). It is therefore clear that the DNSH Principle is the fundamental pillar for the success of projects under the PNRR, as its impact goes beyond compliance with current legislation.

If correctly respected, the DNSH Principle is essential not only for the success of individual projects, but also for progress towards a more resilient future and a long-term sustainable development model. This study highlights how it is possible to mitigate the impact of the construction site through certain requirements, but at the same time highlights the need not only for careful planning of the activities and methods of execution with relative training of the workers, but also for monitoring of the construction site activities during the execution of the works that allows for the verification of compliance with the requirements. The limit of the application of the research is represented by the economic quantification of the activities to be carried out for the assignment of a high sustainability class to the construction site. The aim is, in fact, to try to associate the costs for the installation of devices and equipment necessary to comply with the DNSH principles with the savings obtained in terms of consumption in order to obtain a positive balance for both aspects and to encourage the application of such sustainability practices during construction interventions. The protocol as it is structured can also be applied in large-scale contexts such as in large centres under construction due to catastrophic disasters [36]. It is possible to structure, together with a construction plan, a sustainability plan for the interventions in order to be able to certify even extensive interventions by regulating a broader system of applicability of the intervention [37]. The future development of the research will be the validation of the protocol through the analysis of the real consumption and compliance with the parameters achieved through the preliminary simulation of sustainability of the construction site that allows for the updating of the prerequisites of the parameters relating to the certification scores. Following the application of the protocol simulating the achievable score, it will be necessary to quantify the actual consumption and emissions of the construction site in order to validate also in real quantitative terms the achieved sustainability class [38–40]. Further studies will be addressed in terms of costs and benefits in applying the protocol as a future research development.

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