New Millenium Construction Sites

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New millennium construction sites: an integrated methodology for the sustainability assessment

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Abstract: According to the Global Status report for Buildings and Construction, the building and construction sector accounts for 36% of global energy consumption and 39% of energy-related carbon dioxide (CO2) emissions. Specifically, the construction site represents one of the most significant sources of environmental impact, making it a pivotal element in achieving sustainability within the construction industry. The construction process and maintenance activities on buildings are, therefore, critical phases in which the construction industry is tasked with finding a balance between economic development, social well-being, and environmental protection to ensure a sustainable future for both current and future generations. To promote a construction model focused on environmental, economic, and social sustainability, this paper introduces a Performance Protocol. This protocol serves as an operational tool that allows both the construction company and the contracting authority to manage these aspects throughout the entire construction process. Digital technologies such as BIM and Digital Twin can take advantage of such model to integrate and develop sustainability analysis and simulation during the entire life cycle of a building. The use of digital tools is one of the challenges for the future of the built environment that needs to address not only the issues related to costs and management but also considering the social and environmental aspects of sustainable development.

Keywords: Sustainability; Construction sites; Environmental protection; Digitalization; Ecological and digital transition.

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1. Introduction

It is well known that construction industry traditionally consumes vast amounts of resources, contribute significantly to greenhouse gas emissions, and generate copious amounts of waste (Hussin, Abdul Rahman and Memon, 2013). Recognizing these challenges, the scientific community as well as governments are increasingly focusing on integrating sustainability principles into construction processes. In Europe, this is well underlined by the wide regulatory body that is progressively upgrading to consider sustainability issues as evidenced by the efforts made by the European Union for the regulation 2018/2026 (European Union, 2018) which is aimed at the voluntary participation of organizations in a community eco-management and audit scheme (EMAS). The EMAS system is an important tool oriented at «Sustainable production and consumption» and «Sustainable industrial policy». It endorses for a continuous improvement of environmental performance of organizations through the establishment and application of an environmental management systems that can be obtained only by an open dialogue between the public and other interested parties. Also, the International Organization for Standardization (ISO) have promoted its recommendation for environmental management systems as evidenced in ISO 14005:2019 (International Organization for Standardization, 2019) that is aimed at the development of improve an environmental management system (EMS). The same topics are included and evidenced by the Sustainable Development Goals (SDG) that are also focused at increasing environmental protection by means of the development of digital technologies that would be one of the key-elements able to reduce the environmental impact of human activities (Leal Filho et al., 2022). For the construction industry, the scope of sustainability extends beyond the simple application of green building materials. To reach such a complex goal, BIM and Digital Twin can be important tools that can be used to address challenges of sustainability for construction sites and that can be extended through whole life cycle of a building (Mohammed, 2022; Moradi and Sormunen, 2023). This must involve an overall effort to apply the principles of the circular economy to construction while improving the social and economic aspects of a sector that designs and builds the places of our daily life. The present work is aimed at the development of a holistic and integrated certification system that suits the needs of both business companies and contractual entities in terms of sustainable construction sites, including all the main players involved in the process, from designers up to users. Due to the different regulation of every country, this work is aimed at the Italian context, where the methodology proposes an innovative evaluation tool able to include specific sustainability indices inside the Common Data Environment (CDE) for the evaluation of construction site. The approach summarises the impact of the three main environmental sustainability area (carbon, water, and energy footprints) giving as outcome a list that is able to give an integrated and real-time state of the sustainability of the construction site.

2. The environmental issue

In recent years the growing interaction between the scientific community and the society has increased the attention to the term “environment”. It does not designate a precise location but refers at the same time to “what surrounds” and “what is surrounded”. As example, the directive no. 2011/92/EU defines the main environmental components as “population, fauna and flora, soil, water, air, climatic factors, material assets, including architectural and archaeological heritage, landscape and the interaction between these factors” (Europea, 2012). The relationship between environment and economic development was born in the seventies, leading to the birth of the theory of “ecological modernization”. The term defines the current conflict between social and environmental systems that can be overcome by a sustainable development as proposed in the Brundtland Report. (Hueting, 1990).

As showed in (Figure 1), during the last century the three concepts have been brought at the same level of importance rising the global attention not on only to environmental sustainability but also to social and economic (Colantonio, 2009).

2.1 Environmental sustainability

In Italy, the construction sector is responsible for the consumption of about 30% of total energy and 30% of raw materials, in addition it produces of about 57 million tons of waste every year (SPNA, 2020). Moreover, the construction process is also a great source of pollution: a medium-sized construction site during a single working day can release up to 300 kg of equivalent CO_2, as reference it is equal to three machines that travel 1,000 km (Seo et al., 2016). Therefore, it is evident the necessity to develop new strategies to increase the sustainability of construction, starting from the building processes.

However, construction sites are often characterized by different and ever-changing configurations that are related to practical needs. To apply the sustainability concept, it is mandatory to investigate numerous aspects such as scheduling and the design process (Cumo et al., 2022). A consistent definition of the impacts produced by the construction phase is essential to identify good

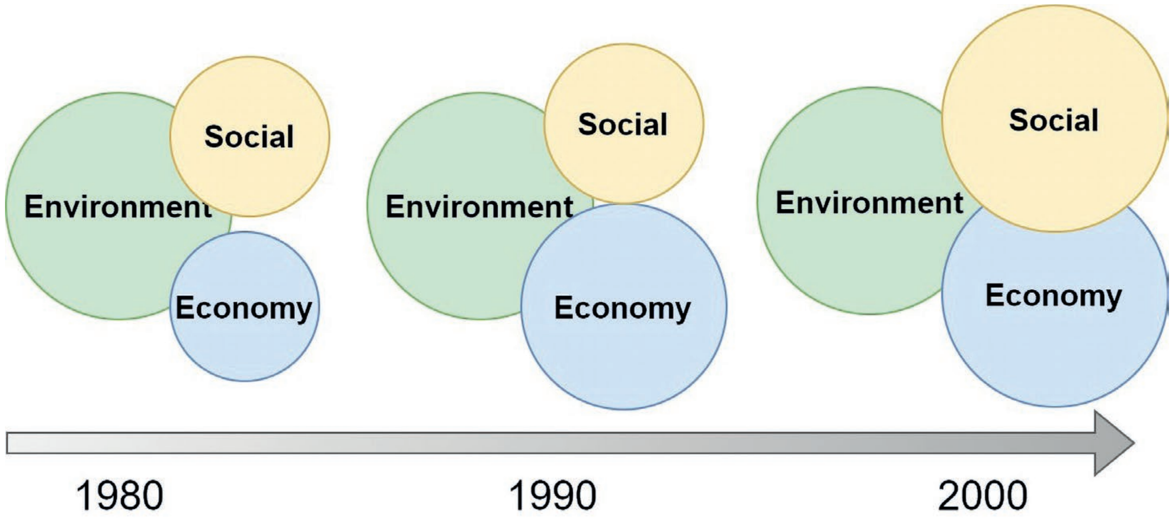

Figure 1 | Evolution of sustainable evolution topic importance during the last century (Colantonio, 2009).

practices and sustainability indicators. In the literature there are numerous studies that discusses the environmental impacts produced during the construction phase. As example, for Chen et al. (Chen, Li and Wong, 2005) construction impacts can be traced into eight categories: 1# soil type and soil contamination, 2# groundwater contamination, 3# construction and demolition waste, 4# noise and vibration, 5# dust, #6 hazardous emissions into the atmosphere and scents, 7# impacts on fauna and flora, and 8# archaeological impacts. For Cardoso (Cardoso Teixeira, 2005) the negative impacts include the wastes production, noise, dust and mud, soil and water contamination, destruction of green, the increase of traffic, parking reduction, visual impacts, and damages to the public spaces. Ametepey & Ansah (Ametepey and Ansah, 2015) based their consideration on an extensive literature study evidencing 33 different environmental impact sources typical of construction activities.

Vazquez et al. (Vazquez et al., 2011) carried out an analysis of construction sites sustainability showing not only the main environmental impacts but also presenting some solutions to mitigate their effects. In their study five sustainability parameters are defined as showed in (Table 1). To assess the quality of the impact model the construction site of a hospital was used.

2.2 Socioeconomic Sustainability

Nowadays, social sustainability remains a broad concept with no universal definition. In general, it concerns human well-being, access to basic needs, fair distribution of wealth, good working conditions and wages, equal rights, justice, access to social and health services, good education, social cohesion and inclusion, and participation in decision-making (McGuinn, 2020).

At the end of 1990s that social issues became more prominent in the global sustainability agenda (Hueting, 1990). The concept was further refined at the United Nations Conference on Environment and Development at Rio in 1992, where the 21st century sustainable development policy was framed ('Rio declaration on environment and development', 2016). The paradigm of "sustainable development" in building sector it is mainly aimed at supporting population growth, and the consequent industrialization and urbanization through the construction of infrastructures and housing, ensuring the protection of the environment, reducing the consumption of energy and natural resources, and limiting the emission of pollutants into the atmosphere, in soil and water. The related benefits can be returned in numerous ways, such as creating jobs and improving the quality of life of workers, end-users, and the surrounding community (Hussin, Abdul Rahman and Memon, 2013).

Like environmental sustainability, social sustainability is a complex phenomenon, its assessment is somehow difficult due to its subjective, qualitative, and local nature (Montalbán-Domingo et al., 2021). The lack of a standardized framework for social sustainability leads to subjective evaluation that are particularly evident for building sector (Kordi, Belayutham and Che Ibrahim, 2021).

Some studies in the literature have investigated various factors influencing social sustainability in construction projects. In particular, the following factors

Table 1 | Environmental impacts during construction phase (Ametepey and Ansah, 2015).

Sustainability parameters	Impacts	Strategies
Sustainable Space (SS)	Erosion and Sedimentation	Protected Embankments Reduction of Dust Emission
Rational use of water (WE)	Drinking water consumption	Reduction of water consumption
Energy and Atmosphere (EA)	Energy	Reduction of Energy Consumption (Employee Awareness Courses)
Materials and resources (MR)	Solid waste generation Landfill saturation Pollution for waste transport	Optimisation of waste management Material recycling Use of recyclable and local materials
Indoor environmental quality (EQ)	Air pollution	Reducing carbon emissions and sediment production by the development of an air quality management plan

have been identified as main factors: stakeholders (Doloi, 2018; Martins and Saavedra Farias, 2019), security (Gatti et al., 2013; Toole and Carpenter, 2013), and community involvement (Kaminsky, 2019, 2018). Nasirzadeh et al. (Nasirzadeh et al., 2020) defined a wide range of factors that influence the social sustainability performance of construction projects, considering their complex interactions. Moreover, Stender e Walter (Stender and Walter, 2019) developed a framework that involves 12 indicators grouped under three main themes: social cohesion, participatory processes, and accessibility to life opportunities. Moradi & Kähkönen (Moradi and Kahkonen, 2022) analysed the sustainability indicators for the construction of buildings as tools to achieve higher level of sustainability. However, most of the studies in the literature have developed various evaluation frameworks focused on specific areas of social sustainability without providing a general analysis (Almahmoud and Doloi, 2015).

3. Materials and methods

Based on what has been discussed, it is no longer deferrable for construction companies to assess their environmental performance to enhance the interaction between themselfs and the environment. The evaluation process should follow the four phases of the Deming Cycle: (1) planning performance evaluation by selecting appropriate indicators (Plan) – (2) collecting data and information, processing indicators (Do) – (3) analysing and evaluating the collected information and communicating the results obtained (Check) – (4) reviewing the achieved performance and seeking to improve it (Act) (Isniah, Hardi Purba and Debora, 2020).

The evaluation of environmental performance must also be quantified through the determination of environmental/economic/social indicators that summarize a wide range of data about the environment into a limited number of essential information packages. These indicators should primarily address the most significant environmental impacts on which the organization can directly intervene, either at the management level, in the operational activities, or in the materials used. The organization has the freedom to choose the environmental indicators it considers most indicative, as long as they have the following characteristics:

- **Significance:** They must be able to numerically express a quantity related to the company's interaction with the environment.
- **Representativeness:** They must be scientifically valid and understandable to everyone, including non-experts.
- **Verifiability:** They must provide certainty about the information provided.
- **Reproducibility:** They must refer to certain data that are adequately documented and readily available at a low cost.

To determine a set of effective environmental performance indicators, we should refer to the technical standard ISO 14031:2021, which provides a series of guiding principles and considerations for the selection, classification, and design of these indicators. The standard categorizes environmental indicators into several categories:

- **Environmental Condition Indicators [ECI]**, which provide information about the environmental conditions that may be influenced by the organization.
- **Environmental Performance Indicators [EPI]**, which provide information related to the management of the organization's significant environmental aspects and can be further categorized into:

Table 2 | Areas of focus within the environmental performance protocol.

Area of focus	Description of the investigative analysis	Strategies
Quality and sustainability assurance	Quality and Sustainability Assurance (QSA) is a process by which construction companies, through the definition of objectives, monitoring actions, and verifications, implement a sustainability policy to achieve continuous improvement in their environmental, social, and economic performance	Protected Embankments Reduction of Dust Emission
Construction site	This dimension allows for the examination of all issues related to the management of a construction site. Sustainability criteria are explored concerning the following aspects: management of the construction site area, sustainability of energy sources, use of low-emission vehicles and equipment, minimization and mitigation of impacts from physical agents, and the use of environmentally friendly products and technologies	Reduction of water consumption
Material consumption	This dimension allows for the evaluation of actions taken in the selection of materials used in construction. Choices of materials with environmental certifications, those made from reused materials, and those sourced from areas not far from the construction site will be assessed. Another item to be evaluated is the circular waste management	Reduction of Energy Consumption (Employee Awareness Courses)
Socioeconomic area	This dimension allows for the assessment of a set of actions aimed at achieving equity in society, promoting a sustainable economy through the employment of local labour, and combating irregular work and workplace accidents through active workforce training policies.	Optimisation of waste management Material recycling Use of recyclable and local materials
Communication	This dimension allows for the evaluation of the actions implemented by the company to communicate its sustainability	Reducing carbon emissions and sediment production by the development of an air quality management plan

- Management Performance Indicators [MPI], which provide information about the organization's management efforts to influence its environmental performance.
- Operational Performance Indicators [OPI], which provide information about the environmental performance of the organization's activities.

Based on these considerations, an environmental performance protocol has been developed through an accountability model, which provides a reporting of a company's performance in terms of sustainability without using rating tools. The term "accountability" attests to the organization's ability to assume its responsibilities and transparently and seriously demonstrate the impact of its actions on the economic and social context in which it operates.

3.1 Methodological Approach of the Environmental Performance Protocol

The purpose of this standard is to contribute by providing a unified and up-to-date framework for the organizational, functional, and technological conditions of a quality assurance system aimed at, on one hand, reducing the environmental risks of a construction site and, on the other hand, enhancing the social and economic context. The current study is designed to contribute to the risk assessment process, focusing on the evaluation of documentation that can serve as a guideline for identifying hazards associated with operations. This approach facilitates a more precise assessment of criticalities during the risk analysis, given that it incorporates pertinent documentation in various tables for evaluation purposes.

It encourages construction companies to implement innovative solutions to improve their performance and contribute to the environmental, social, and economic sustainability of the construction site. This standard has been developed to fully embrace the spirit of the call made in April 1987 by the United Nations World Commission on Environment and Development, as outlined in the famous document known as the Brundtland Report.

The "Sustainable Construction Site" protocol is born from the initial idea of defining a set of shared sustainability objectives to pursue, regardless of the type of infrastructure project being carried out. This defines the theoretical foundation of this new generalized model of a sustainable construction site (Figure 2). Based on the United Nations' Sustainable Development Goals (SDGs), the following sustainable development objectives have been identified to pursue "SDG-7: Affordable and clean energy", "SDG 10: Reduced inequalities", "SDG-12: Responsible consumption and production", "SDG-13: Climate action". Pursuing these objectives should be seen in the context of continuously improving process quality and the effectiveness of innovative solutions to enhance

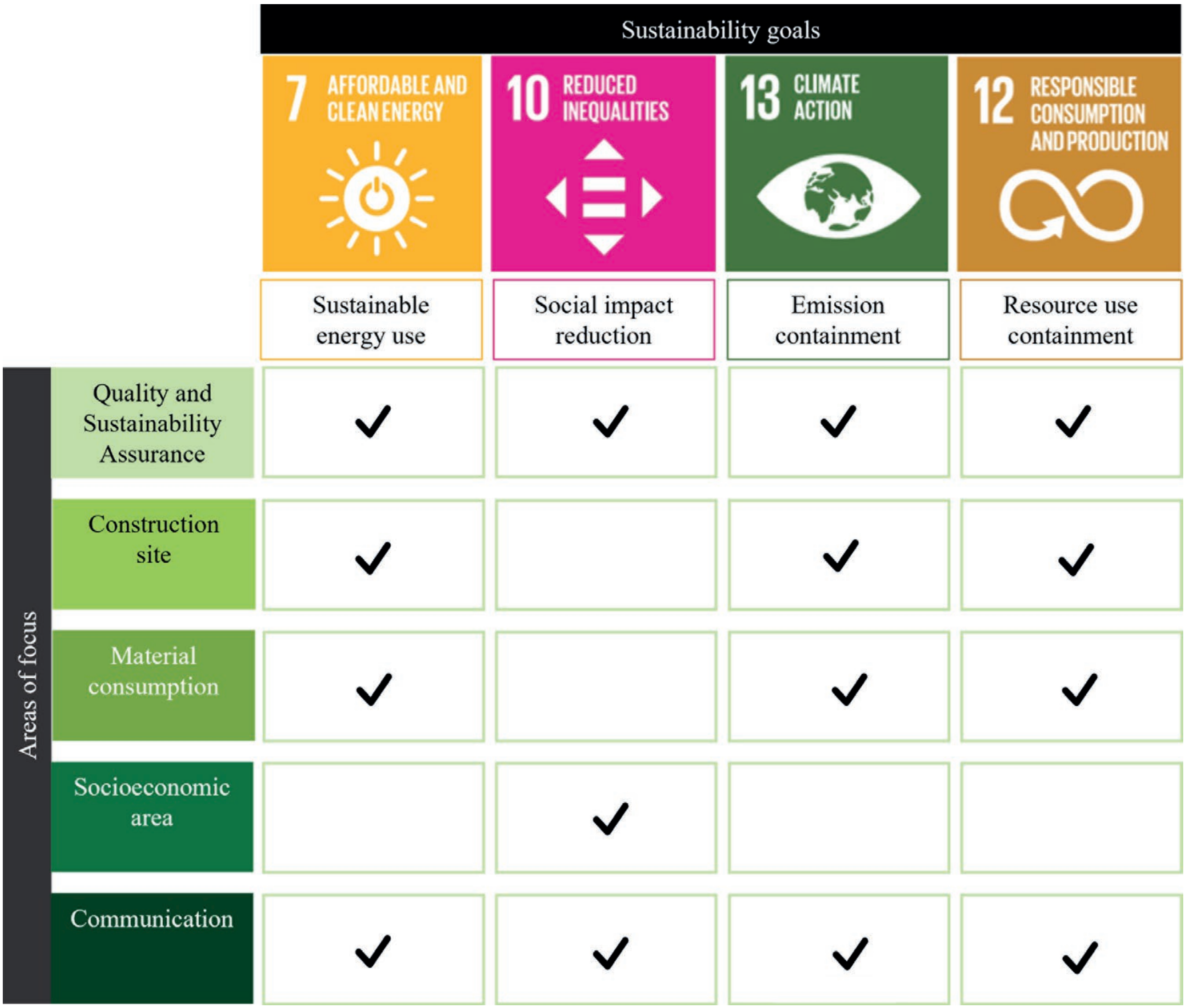

Figure 2 | Sustainable construction site model.

corporate performance and thereby contribute to the environmental, social, and economic sustainability of the construction site.

The Protocol has been developed in accordance with international sustainability accountability models, which provide a reporting of corporate performance without using rating tools. The qualitative evaluation process relies on a multidimensional approach that employs a checklist of current documentation associated with national regulations concerning sustainability. Three distinct levels of importance are determined based on environmental impact. Consequently, a comparison among various construction sites could be established by automatically assessing which elements are absent from the checklist using CDE.

A particular feature of these models is the ability to make comparisons within the same company by evaluating its sustainability performance over different time periods. The purpose of these models is to guide companies towards sustainability management processes, understood as the organization's ability to continue its activities indefinitely, considering their impact on human, social, and environmental capital.

The standard is fundamentally based on two principles:

- The identification of best practices, as defined by Kahan & Goodstadt (Kahan and Goodstadt, 2001), as 'those sets of processes and activities that, in harmony with principles/values/beliefs and evidence

Table 3 | Environmental Sustainability Indicators.

Indicators	Indicator description
CO_2 Footprint	Provides a standard for the measurement, based on scientific criteria, of greenhouse gas emissions generated by construction site activities during the construction of the project.
Energy Footprint	Provides a standard for the measurement, based on scientific criteria, of primary energy consumption resulting from construction site activities during the construction of the project.
Water Footprint	Provides a standard for the measurement, based on scientific criteria, of water consumption resulting from construction site activities during the construction of the project.

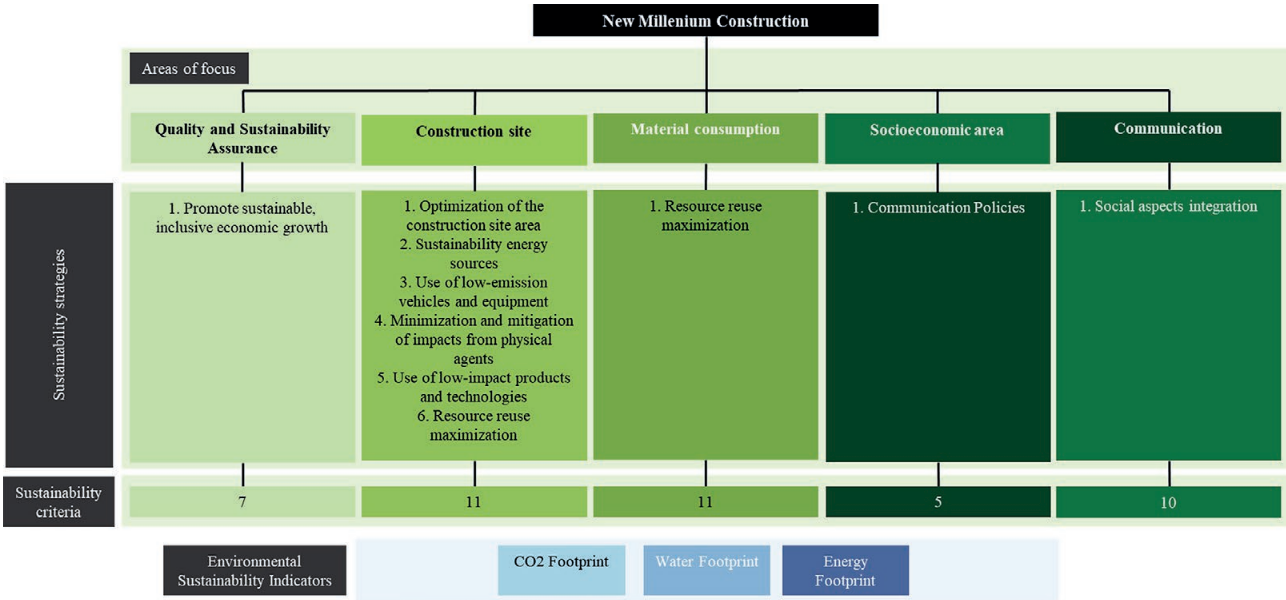

Figure 3 | Structural framework of the environmental performance protocol.

of effectiveness, and well-integrated with the environmental context, can achieve the best possible outcome in a given situation (Hill and Bowen, 1997).

- The definition of reference performances, that is, environmental sustainability indicators (ESIs) that enable the monitoring of the construction site's environmental performance for the purpose of evaluating its performance against selected benchmark references.

Finally, the environmental performance protocol includes the evaluation of three environmental sustainability indicators, which serve as internal verification parameters to monitor one's environmental performance and identify areas for improvement in environmental sustainability (Table 3).

To facilitate a gradual introduction of the environmental performance protocol, a phased approach has been established, allowing for the adaptation of the organization to increasingly complex sustainability requirements over time, encompassing all three pillars of sustainability. The structural framework proposed for the environmental performance evaluation is showed in (Figure 3). The protocol defines Requirements and Recommendations, which are understood as "something that is necessary, expected, or specifically requested to contribute to the environmental, social, and economic sustainability of the construction site". The full list of criteria is reported in (Figure 4). Furthermore, a certain degree of importance is associated with them, as indicated below:

- Primary Requirement (P) represents a 'fundamental' level of sustainability performance that must be mandatorily adhered to by the organization.

- Secondary Requirement (S) is a 'necessary' level of sustainability performance that must be applied in accordance with the minimum percentages defined in the PPA.

Areas of focus	Sustainability goals	Sustainability strategies	Sustainability criteria	Step
Quality and Sustainability Assurance	7 AFFORDABLE AND CLEAN ENERGY; 10 REDUCED INEQUALITIES; 12 RESPONSIBLE CONSUMPTION AND PRODUCTION; 13 CLIMATE ACTION	Promote sustainable, inclusive economic growth	1.1 Environmental Performance Protocol Management System	1
			1.2 Periodic monitoring of sustainability criteria defined by the EPP and recording the results in the digital system for the purpose of assessing improvements	1
			1.3 Supplier qualification and management policy that takes into account the sustainability requirements of the EPP	2
			1.4 Information collection regarding the adoption of sustainability requirements by suppliers	3
			1.5 Yearly sustainability requirements assessment process that highlights areas for improvement in sustainability	3
			1.6 Improvement actions, when necessary, to ensure continuous improvement across all topics specified by this standard	3
			1.7 In cases where some activities falling within the scope of the standard are outsourced to third parties, the organization ensures compliance of such operations with this standard	2
Construction site	7 AFFORDABLE AND CLEAN ENERGY; 12 RESPONSIBLE CONSUMPTION AND PRODUCTION; 13 CLIMATE ACTION	Optimization of the construction site area	2.1 Plan to enhance the efficiency of construction logistics and the supply chain	1
			2.2 Solutions to mitigate the visual impact of the construction site	1
			2.3 Construction Planning	1
			2.4 Updated Environmental Monitoring Plan	1
		Minimization and mitigation of impacts from physical agents	2.5 Use of equipment with dust suppression systems	1
			2.6 Percentage of permeable area within the construction site	1
		Use of low-emission vehicles and equipment	2.7 Use of transportation and construction activities vehicles that produce the least acoustic impact	1
			2.8 Percentage of low-emission vehicles and equipment	2
		Use of low-impact products and technologies	2.9 Support system for the use of low-impact products	1
		Resource reuse maximization	2.10 Recovery and reuse of uncontaminated rainwater for construction processes	1
		Sustainability energy sources	2.11 Percentage of renewable energy consumed on the construction site	1
Material consumption	7 AFFORDABLE AND CLEAN ENERGY; 12 RESPONSIBLE CONSUMPTION AND PRODUCTION; 13 CLIMATE ACTION	Resource reuse maximization	3.1 Material selection based on LCA methodology and product EPD regulations	1
			3.2 Control and monitoring phases in the case of hazardous product usage	1
			3.3 Percentage of virgin material used	2
			3.4 National sourcing of construction materials	3
			3.5 Percentage of materials used with EPD certification	3
			3.6 National share of materials procurement used	3
			3.7 Extra-EU share of materials procurement used	3
			3.8 Local share (within 150 km) of materials procurement used	3
			3.9 Packaging of construction materials used sent for recovery	3
			3.10 Plan to enhance the efficiency of construction logistics and the supply chain	3
			3.11 Weight percentage of economically valorized waste	2
Socioeconomic area	10 REDUCED INEQUALITIES	Social aspects integration	4.1 Fighting gender disparity	1
			4.2 Fighting gender inequality	1
			4.3 Fighting wage inequality	3
			4.4 Fighting irregular work	1
			4.5 Using local labor	1
			4.6 Wage regularity	2
			4.7 Using innovative construction safety	2
			4.8 Continuous training for the improvement of digital competencies	1
			4.9 Using of intrusion detection systems	1
			4.10 Welfare programs	2
Communication	7 AFFORDABLE AND CLEAN ENERGY; 10 REDUCED INEQUALITIES; 12 RESPONSIBLE CONSUMPTION AND PRODUCTION; 13 CLIMATE ACTION	Communication Policies	5.1 Verified and transparent communication policy on sustainability issues of the construction site	2
			5.2 Communication methodologies (including online) regarding issues with the population neighboring the construction site	2
			5.3 Archive of communications received from workers or their representatives and documentation attesting to actions taken in the case of ethical code violations	1
			5.4 Reporting policy (including online) for accidents and near-misses in the construction site area	1
			5.5 Communication policy (including online) for sanctions/observations issued by external entities and their trends over time	2

Figure 4 | Sustainability checklist criteria.

Table 4 | Application phases timeline of the environmental performance protocol.

Areas of Focus	STEP 1 ▶			STEP 2 ▶▶			STEP 3 ▶▶▶		
	▼ 0	Months	6 ▼	▼ 0	Months	6 ▼	▼ 0	Months	6 ▼
	[P]	[S]	[R]	[P]	[S]	[R]	[P]	[S]	[R]
Quality and Sustainability Assurance	1.1 1.2			1.3 1.7			1.5	1.4 1.6	
Construction Site	2.1 2.3 2.4 2.5	2.8 2.9 2.11	2.2 2.6 2.10		2.7				
Material Consumption	3.2	3.1			3.11	3.3		3.10	3.4 3.5 3.6 3.7 3.8 3.9
Socioeconomic Area	4.1 4.2 4.4	4.5 4.8 4.9		4.6	4.10	4.7	4.3		
Communication	5.4	5.3	5.2	5.1 5.5					

- Recommendation (R) is an 'optional' level of sustainability performance where non-compliance does not jeopardize the satisfaction of the sustainability level. They are to be considered as improvement suggestions for the organization."

The protocol application includes three-time phases of six months each within which to make the construction site more sustainable. (Table 4) shows the temporal sequence of meeting sustainability requirements. Following is an example of an evaluation sheet for the developed protocol (Figure 5).

4. Integration of digital technologies

Digitalization is one of the main future challenges for sustainability, able to reduce the consumption of primary resources (such as energy and water), identify problems and critical issues in real time, train workers, and carry out simulations and analysis of different scenarios (Papadonikolaki, Krystallis and Morgan, 2022). The contribution of digitalization, in this perspective, represents a primary aspect in the design and implementation of a sustainable construction site (Ciribini et al., 2019). Data and information from digital site management tools, such as BIM, should be expanded and integrated across all types of construction sites and can integrate the information discussed in Performance Protocol. The integration process can be made using Dynamo and PowerBI software for BIM (Cinquepalmi *et al.*, 2023) and using visual dashboard for Digital Twin (Tagliabue et al., 2021). Through it is also possible to create an historicized database of past interventions that would provide future generations with useful information to preserve assets and systems with new technologies, evaluate the useful life of components, support safety operations and maintenance, as well as providing a common platform for data exchange. Another, hey technology is "Digital Twin" that is defined as "a digital model of an intended or actual real-world physical product, system, or process (a physical twin) that serves as the effectively indistinguishable digital counterpart of it" (Grieves, 2016). It can expand the digital logics promoted by BIM from the design and construction phase up to the building management phase, integrating real-time data and providing simulations and scenarios that can evaluate the effect of critical scenarios such as floods, acts of terrorism or fire (Shahzad et al., 2022). Currently, there is no standardized "container" for sustainability data inside both Digital Twins and BIM software (Fonseca Arenas & Shafique, 2023). Therefore, it is necessary to develop custom tools to integrate such data into digital databases. A new ontology shall be introduced in both systems that shall be able to store and manage sustainability data coming from different sources and that shall be accessed and upgradable during construction and maintenance process of a building. Moreover, such information shall also be exportable by means of open standardized formats such as Industry Foundation Class (IFC). Adding Performance Protocol classes to the fundamental ontology used could be challenging because of the lack of a standardization. The sustainability information could

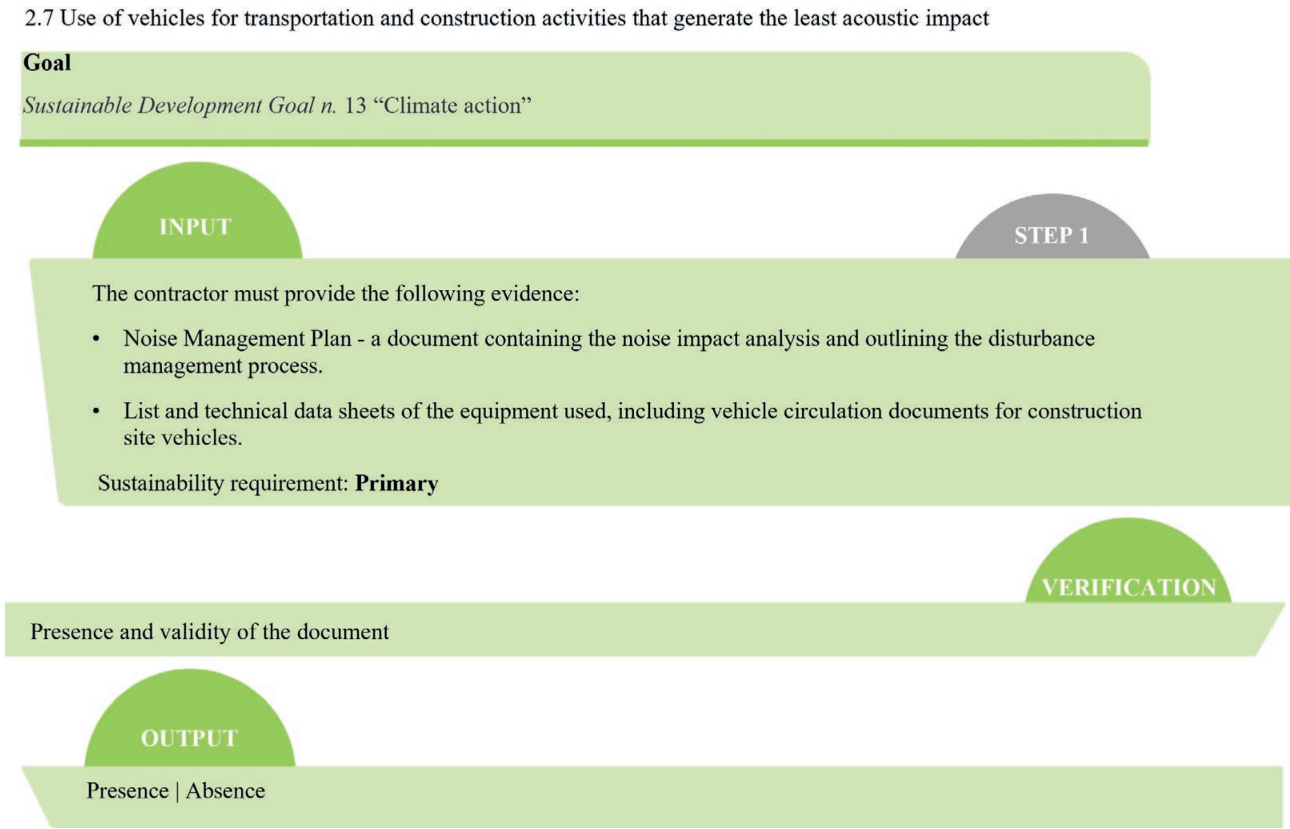

Figure 5 | Assessment sheet example of the environmental performance protocol.

be placed in a container that is not specific for their use such as for IfcProduct or IfcPropertyDefinition making difficult for an external user to understand such data. Another approach is to use external data format as JSON or XML to add another layer of information to BIM data. However, this method could lead to an increase in the number of files and the necessity of external scripts to read the information that a common BIM software does not expect. The application of the methodology could be implemented internally or externally from the BIM and Digital Twin models using custom scripts to analyse the data and to automatically obtain the main information related to what is missing. This can be improved by means of Machine Learning (ML) tools that can inspect input data assessing its quality. The process can be based on classifiers algorithms such as decision tree to analyse the data structure obtaining information about what it is missing basing on the information given or using Markov decision process (MDP) to develop simulations based on the choices made during the project phase to increase the whole sustainability of the project. Moreover, Deep Learning Neural Networks (DLNN) can be used to assess the completeness of textual data showing in almost real time if some information is missing in the various input documentation. Computer Vision (CV) models can further enhance the sustainability evaluation during the construction process evidencing from a visual feed if all the procedures prescribed in the documentation are appropriately applicated.

These are only few examples of what it can be done using ML, the choice of what use depends on the specific project its requirements in terms of sustainable processes. To integrate such models can be used open-sourced software as Python's ML specific library (OpenCV, SkLearn, PyTorch, etc.) or Data Science Tools such as Knime and Orange. There are also many private companies that offers complete environments for Data Science (IBM SPSS, Amazon SageMaker, Azure Machine Learning, etc.). To monitor the actual state of a building can be used also Internet of Things sensors to assess if sustainability parameters such as energy consumption, wastes production, wastes tracking, water usage, and the carbon footprint returns the expected values (Kamble et al., 2022; Ghansah and Lu, 2023).

At least, another key element of digitalization is the possibility to visualize data not only by tables and dashboards, but also using 3D interactive models that can benefit also from Virtual Reality (VR), Augmented Reality

(AR), and Mixed Reality (MR) to show data directly to the user with advanced techniques able to reconstruct the digital environment in its completeness (VR), to add information to the real world (AR) or to mix virtual elements and reality (MR).From a social point of view, digital tools also allow the sharing of information and data between users, decision-makers, and industries, thus allowing a common and agreed workflow between the parties.

5. Conclusions

Sustainable development is a complex concept that requires a balance between economic development, social well-being, and environmental protection.

A sustainable construction site can therefore be defined as a workplace where methods and technologies are implemented to reduce the environmental and socio-economic impact of construction. The building process is a fundamental phase in which industries must demonstrate their commitment. To promote a construction site model oriented towards sustainability, a Performance Protocol has been developed and configured as an operational tool that allows both the industries and contracting authorities to manage these aspects throughout the construction process.

The tool provides specific objective qualitative and quantitative indicators, which allow to direct and evaluate the sustainability of a construction site and to summarize in a clear and qualified way the results for each assessment area and for three environmental footprints. At least, digital technologies such as BIM and Digital Twins shall integrate the data coming from the methodology in order to develop a digital tool able to predict and assess the sustainability of a building in different scenarios.

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