Adoption of Sustainable Practices in the Construction Phase: A Review of Ten Representative Case Studies

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Abstract— **The construction sector significantly contributes to the global environmental impact, with the construction phase being a critical moment for the sustainable management of resources and emissions. This article presents an analysis of ten national and international case studies where sustainability practices were adopted during the construction phase. The study is conducted alongside an analysis of ten environmental certification protocols and the Minimum Environmental Criteria (CAM) to evaluate the effectiveness of the practices applied in the case studies. The strategies analyzed include water resource management, emission reduction, material use optimization, and the adoption of digital solutions for monitoring construction activities. The results highlight the strengths and challenges of the projects examined, contributing to the definition of useful criteria for developing a future sustainability protocol specific to the construction phase. This integrated approach provides a concrete vision to guide the sector towards more responsible and environmentally-friendly construction practices.**

Keywords— **Building Sustainability; Green Construction; Sustainable Construction Site; Environmental Certification Protocols; Environmental Impact Reduction.**

I. INTRODUCTION

The construction industry, one of the most impactful sectors on the environment, is at the center of an increasing debate on the need to adopt more sustainable practices [1]. Approximately 50% of raw materials are used, consuming 71% of electricity and 16% of water, and generating 40% of the waste sent to landfills [2][3]. These figures reflect the global impact of building activities in terms of resource consumption and emissions. The construction process contributes to over 10% of the overall climate impact of a building's life cycle, highlighting the significant ecological footprint associated with construction operations [4]. This underscores the urgency of adopting more sustainable practices within the construction sector to mitigate its environmental impact [5].

This necessity is driven not only by growing awareness of climate change and the depletion of natural resources but also by the pressure from increasingly stringent international environmental regulations [6]. The concept of sustainable development, defined in the 1987 Brundtland Commission's report "Our Common Future," emphasizes the need for a balance between economic growth, environmental protection, and intergenerational responsibility [7].

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The 2030 Agenda, signed by UN member states in 2015, set 17 Sustainable Development Goals (SDGs), guiding the European Union towards the Green Deal, which aims for net-zero greenhouse gas emissions by 2050 [8]. The Next Generation EU initiative has further reinforced this vision by promoting sustainable investments and the principle of "Do No Significant Harm" (DNSH), which ensures that economic activities and investments do not harm one or more environmental objectives, ensuring that recovery measures meet environmental standards and contribute to a more resilient and sustainable development model [9]. In Italy, the National Recovery and Resilience Plan (PNRR) aligns with these policies, focusing on ecological and digital transitions and overcoming inequalities, representing an opportunity to implement sustainable infrastructure through sustainability methodologies and protocols [10].

The combination of high energy consumption, air and water pollution, and significant waste production has made the adoption of sustainable construction practices inevitable [11]. In response to these challenges, over 600 building sustainability assessment methods have been developed globally [12]. Among these, environmental certification systems provide an integrated assessment of building sustainability, considering energy efficiency, site impact, occupant well-being, and health impacts [13]. These tools provide a solid foundation for evaluating and improving the environmental performance of buildings [14]. However, despite the effectiveness of these systems in promoting sustainability at the building level, there remains significant room for improving sustainability practices specifically related to the construction phase, which is a critical moment for implementing sustainable strategies [3].

The construction site represents a critical phase in a building's life cycle, as it is during this phase that the main activities related to construction take place, such as the use of material and energy resources, waste production, and the emission of pollutants into the air and water. The high environmental impact of construction sites is primarily linked to energy consumption for machinery, CO_2 emissions from transportation and material use, and the production of construction waste, which is often not optimally managed [15]. The adoption of electric machinery on construction sites represents a promising solution for reducing CO_2 emissions. Recent studies show that construction sites without the use of fossil fuels offer significant potential for emission reductions, especially in historical contexts where existing electrical grids can easily support electric machinery [16]. Another critical issue on construction sites concerns dust management,

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particularly PM2.5 and PM10. The adoption of sensor-based solutions for monitoring and reducing dust has proven effective in containing emissions, contributing to improved health conditions for workers [17]. Adopting sustainable construction practices on-site not only minimizes environmental impact but also brings economic and social benefits. For example, energy and water efficiency translate into lower operational costs, and improved worker health and safety increases productivity and reduces healthcare costs [18]. Additionally, sustainable construction sites can enhance the public image and reputation of construction companies, attracting environmentally-conscious customers and investors [19]. Through the analysis of ten national and international case studies, this article explores the implementation of sustainable strategies in the construction phase, evaluating the practices applied in real-world contexts.

II. METHODOLOGY

The methodology adopted in this research follows a structured and integrated approach based on a preliminary analysis of major environmental certification protocols, with particular attention to the construction phase (Fig. 1).

This approach responds to the need for an analysis focused on the construction phase, with the goal of examining in depth the various operational areas involved. An analysis of the state of the art was conducted, covering eight national and international environmental certification protocols—LEED, BREEAM, ITACA, HQE, DGNB, CASBEE, Green Star, and Green Globes—alongside the Minimum Environmental Criteria (CAM) currently in force in Italy. These protocols were selected for their focus, albeit to varying degrees, on the construction phase. The development process involved a careful selection of construction criteria present in the protocols and CAM, followed by an operation of reorganization and synthesis of the hundreds of practices and guidelines collected. The final result led to the identification of approximately 120 practices, subsequently divided into categories and subcategories: land and ecosystem management, water resource management, material management, waste management, air emission management, noise pollution management, contaminant management, energy management, site management, and construction process management [20]. This model provides a reference framework for understanding and organizing the sustainable practices adopted on construction sites in the selected case studies. Ten national and international projects were analyzed, chosen for their relevance and the availability of data related to the construction phase. The selection included a diverse range of projects to ensure representativeness of the various sustainable practices adopted in different contexts. The ten analyzed projects include major works both in Italy and abroad: the San Giorgio Bridge in Genoa, the Third Giovi Pass, the MOSE project in Venice, the M4 metro line in Milan, Milan-Linate Airport, Cascina Triulza in the Expo Milano area, the Hadid Tower in Milan, the World Headquarters of Jehovah's Witnesses in Warwick (USA), M&S Cheshire Oaks in the United Kingdom, and the Rudraksh Convention Center in Varanasi (India). Data collection for each project was carried out through an in-depth analysis of the project documentation and the technical and environmental reports related to construction site activities, which allowed detailed information to be gathered on the sustainability strategies implemented. The sustainable practices were then analyzed and compared with the practices extracted from the certification protocols and the CAM examined, to assess the degree of adoption and actual application in each construction

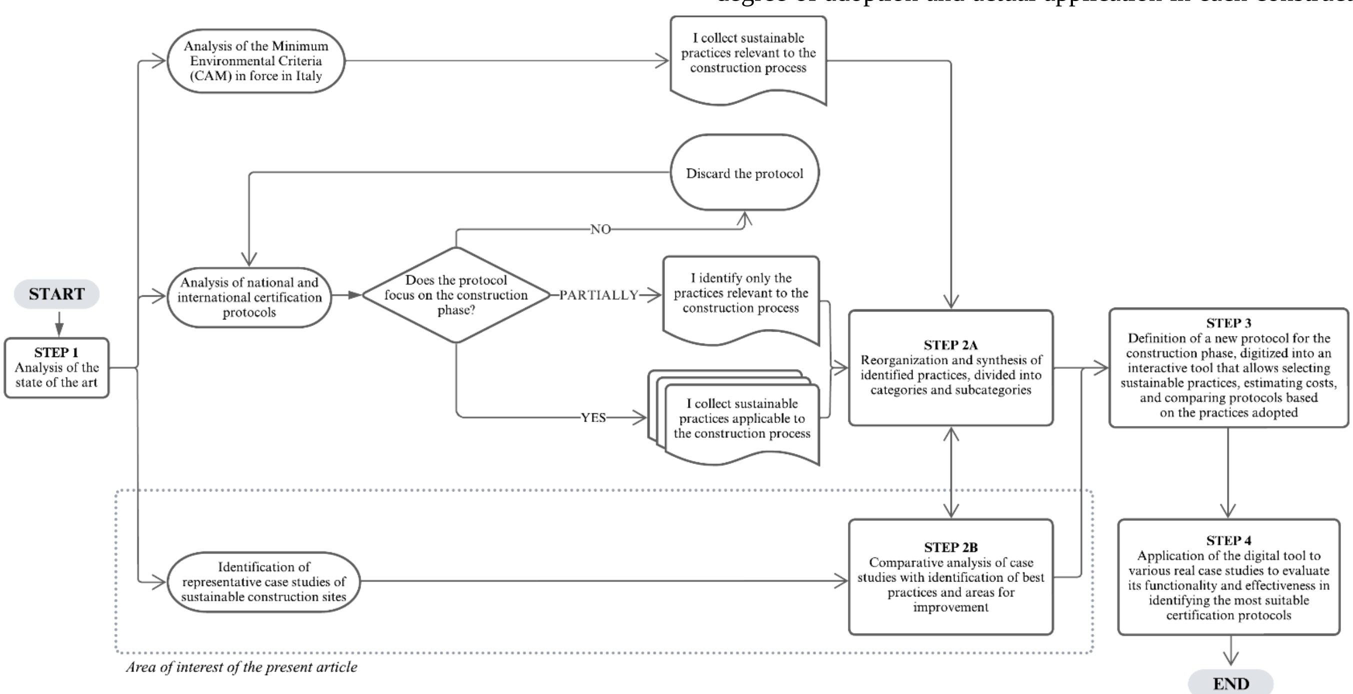

Fig. 1: Flowchart

site. The comparative analysis made it possible to identify the main areas on which construction sites focus the most in adopting sustainable practices, highlighting similarities and differences between the various projects. The observation of the case studies, combined with the analysis of eight environmental certification protocols and the Italian Minimum Environmental Criteria, contributed to outlining a set of sustainable practices that will form the basis for a future sustainability protocol, to be formalized in the next developments of the research [20].

III. CASE STUDY ANALYSIS

The case studies examined highlight the best practices for environmental monitoring and mitigation adopted in various construction projects globally. These examples, ranging from air and noise quality analysis to water and waste management, provide a detailed overview of the strategies implemented to reduce environmental impact and promote sustainability in construction site contexts that differ by type and location.

In the case of the San Giorgio Bridge in Genoa, strict air quality monitoring was conducted. Dust emissions from construction activities, including excavation, earthworks, and vehicle transit, were estimated and evaluated. PM10 emissions were categorized into areas such as storage sites and construction roads. Simulations showed that PM10 concentrations did not exceed the regulatory limit of 50 $\mu g/m^3$. NOx, CO, and CO2 emissions were monitored and found to comply with legal limits. Measures to reduce dust impact included covering vehicle loads, using misting devices, and regularly cleaning roads. Noise monitoring identified 155 receptors, and silencing equipment and sound barriers were installed. Electric machinery was prioritized to reduce noise pollution. Land and ecosystem management involved monitoring geologically risky areas and protecting water resources through washing areas and water regulation works. Recycled materials were used up to 50%, and excavated material was reused or disposed of as a by-product. Digitalization on-site, with six webcams, improved operational control and transparency [21],[22],[23].

In the Third Giovi Pass project in the provinces of Genoa and Alessandria, an Environmental Observatory was established to monitor the effectiveness of environmental measures through an Environmental Monitoring Plan (PMA). Monitoring covered soil, vegetation, fauna, noise, vibrations, and other aspects. About 180 monitoring stations were used to measure PM10, metals, and asbestos, with measures in place to ensure that PM10 did not exceed legal limits. A conveyor belt for excavated materials was installed to reduce dust emissions by avoiding the use of wheeled vehicles. Around 16 million cubic meters of excavated material were reused for environmental rehabilitation projects and naturalization of disused quarries. Noise was monitored through approximately 100 stations, with machinery and conveyor belts being soundproofed. Measures to prevent water contamination included ultrafiltration and reverse osmosis systems. Digitalization on-site included systems such as W.A.Y. for monitoring transportation and WEIGHT PORTAL for real-time management of excavated material transfers. The project also implemented waste sorting and safe disposal [24][25].

The environmental monitoring for the MOSE project in Venice included parameters for water, air, soil, and precious ecosystems. Acoustic and atmospheric pollution, including PM10, PAHs, NOx, NO2, and CO, were monitored. Mitigation measures included soil humidification and acoustic barriers, with particular attention to the impact of emissions and water turbidity. Water monitoring involved checking piezometric levels and salinity. Instruments like the Rosette-CTD measured conductivity, temperature, and pressure, while the LISST-100X laser granulometer analyzed sediments. Surveys were conducted on vegetation and fauna to monitor the effects of dredging operations and changes in plant communities. Advanced instruments allowed for the evaluation of the overall impact on biodiversity and aquatic ecosystems [26].

For the M4 Metro Line project in Milan, atmospheric monitoring was carried out with a mobile laboratory, detecting fine particulate matter (PM10 and PM25) and nitrogen dioxide (NO2). Phreatimetric and physicochemical measurements of groundwater were performed to identify any negative impacts. Noise monitoring included evaluations in construction areas and nearby residential zones. Vegetation management involved phytosanitary controls and the protection of 169 trees, along with a planting plan for new trees. Excavated material was transported underground via conveyor belts. On-site digitalization included the use of webcams to ensure public transparency [27][28].

In the Milan-Linate Airport construction project, excavated soils were reused for the development of the airport site. A vulnerability analysis of groundwater was conducted, and preventive measures were adopted to avoid contamination. Recycled materials included approximately 100,000 cubic meters of concrete and 50,000 cubic meters of cement-treated mix. To limit dust dispersion, misting devices and tarps were used for trucks. Acoustic analysis was conducted with mobile barriers, and work planning focused on daytime hours. These measures helped reduce the impact on urban traffic and airport operations [29][30].

During construction at Cascina Triulza in Milan, air pollution was monitored with a focus on PM10 and PAHs. Measures such as controlled watering of demolition areas and stabilization of access roads were adopted. Water monitoring included sampling upstream and downstream of the Guisa stream and monitoring groundwater. Noise and vibration monitoring was managed with fixed stations and mobile sensors. The project included the protection of native flora and fauna and waste management with a recycling plan. An Indoor Air Quality Plan was developed, and certified low-impact materials were selected [31],[32],[33].

In the Hadid Tower project in Milan, measures were adopted to reduce air pollution and dust dispersion on the construction site, such as using an extraction hood for welding fumes and sealing the HVAC systems to prevent internal contamination.

The site was designated as a no-smoking zone, and low-VOC chemical products were used. To protect the soil, a geotextile fabric was installed along the perimeter, while a recycling program aimed to reuse 95% of the waste. The materials chosen came from recycled and sustainable sources [34].

The World Headquarters of Jehovah's Witnesses in Warwick, USA, adopted a soil protection system to control erosion and stabilize embankments. Over 240,000 tons of stones were reused, and existing trees were preserved with the planting of new native species. To protect Blue Lake, an underwater containment barrier was installed. Waste management saw the recycling of over 70% of debris. The paints and finishes used complied with Green Building Initiative standards, reducing emissions of pollutants and minimizing health risks [35][36].

The M&S Cheshire Oaks project in the UK recovered and reused almost 55,000 tons of earth, stones, and clay. A green wall was created to promote urban biodiversity, and lime was used to reduce the need for concrete in the foundations. Over 14,000 amphibians were saved and relocated, with green spaces being created by planting 228 trees and 12,000 square meters of urban greenery. Sustainable materials such as the Hemclad® panel and FSC wood contributed to reducing the environmental impact. The project also included recycling and optimized waste management [37][38][39].

During the construction of the Rudraksh Convention Center in Varanasi, India, measures were taken to reduce dust impact, including watering work areas and using tarps on vehicles to prevent dust dispersion. Careful control over water resource usage was implemented, using jute sacks to prevent erosion and septic tanks for wastewater management. Dust control measures included regular vehicle maintenance and wheel washing plants, while waste control involved implementing practices for proper disposal and recycling of materials [40][41].

IV. RESULTS

The analysis of the ten case studies highlights an increasing sensitivity within the construction sector toward adopting sustainable practices. This trend, evident in both Italy and internationally, reflects greater awareness of the environmental impact associated with construction activities and demonstrates a concrete commitment to reducing the ecological footprint, particularly concerning soil, water, energy, and waste management (Fig. 2).

Waste management stands out as a shared priority across all case studies. The most frequently implemented practices include waste sorting, recycling of scrap materials, and their reuse in new applications. Environmental impact reduction also involves mitigating air pollution, with particular attention to dust control. Commonly used measures include water misting devices, covering material piles, and wetting construction roads to combat dust dispersion. Equally important is the protection of water resources, ensured through the implementation of rainwater collection systems, prevention of groundwater contamination, and constant monitoring of surface water

	San Giorgio Bridge Genoa	Third Valico dei Giovi Genoa	Mose Venice	Line M4 Milan	Milan-Linate Airport	Hadid Tower Milan	Cascina Triulza Milan	Jehovah's Witnesses World Headquarter Warwick	M&S Store Cheshire Oaks	Rudraksh Convention Center
1. SOIL AND ECOSYSTEM MANAGEMENT	**6**	**12**	**9**	**7**	**7**	**2**	**9**	**8**	**11**	**7**
1.1 Soil conservation and habitat restoration	4	4	5	3	4	1	5	3	5	4
1.2 Contamination prevention and soil remediation	2	3	1	0	1	1	1	1	0	0
1.3 Vegetation management and biodiversity protection	0	5	3	4	2	0	3	4	6	3
2. WATER ENVIRONMENT MANAGEMENT	**9**	**13**	**5**	**4**	**9**	**1**	**4**	**4**	**2**	**6**
2.1 Protection and quality control of water resources	5	5	3	2	4	1	2	3	0	1
2.2 Management and reuse of water resources	2	5	1	0	2	0	0	1	1	4
2.3 Drainage planning and seepage prevention	2	3	1	2	3	0	2	0	1	1
3. MATERIALS MANAGEMENT	**4**	**4**	**1**	**10**	**7**	**12**	**16**	**6**	**15**	**7**
3.1 Sustainable selection of materials and resources	3	2	0	3	2	6	8	4	8	3
3.2 Reuse and recycling of construction materials	1	1	1	6	5	4	7	2	5	3
3.3 Environmental and life cycle impact assessment	0	1	0	1	0	2	1	0	2	1
4. WASTE MANAGEMENT	**7**	**7**	**0**	**6**	**6**	**9**	**10**	**6**	**9**	**6**
4.1 Organization of the waste management process	3	3	0	3	5	5	6	3	5	3
4.2 Traceability and disposal of waste	4	4	0	3	1	4	4	3	4	3
5. AIR POLLUTION MANAGEMENT	**5**	**5**	**4**	**3**	**3**	**5**	**5**	**2**	**4**	**5**
5.1 Dust control and reduction	3	3	3	3	3	3	3	1	3	3
5.2 Management of emissions and air pollution	2	2	1	0	0	2	2	1	1	2
6. NOISE POLLUTION MANAGEMENT	**3**	**4**	**3**	**5**	**5**	**0**	**2**	**0**	**0**	**2**
6.1 Planning of noisy activities	1	2	1	3	3	0	2	0	0	1
6.2 Noise mitigation through technologies and equipment	2	2	2	2	2	0	0	0	0	1
7. CONTAMINANT MANAGEMENT	**6**	**8**	**0**	**4**	**2**	**4**	**5**	**2**	**2**	**5**
7.1 Management and prevention of chemical spills	4	4	0	2	2	1	1	1	0	2
7.2 Reduction of environmental impact of contaminants	2	4	0	2	0	3	4	1	2	2
8. ENERGY MANAGEMENT	**2**	**3**	**0**	**2**	**1**	**1**	**0**	**0**	**0**	**3**
8.1 Energy management	2	3	0	2	1	1	0	0	0	3
9. SITE MANAGEMENT	**4**	**6**	**5**	**6**	**5**	**5**	**7**	**4**	**3**	**5**
9.1 Site planning and organization	4	6	5	6	5	5	7	4	3	5
0. PROCESS MANAGEMENT	**11**	**12**	**10**	**12**	**8**	**10**	**10**	**6**	**8**	**7**
10.1 Environmental planning and management	6	6	5	6	4	5	5	4	5	4
10.2 Monitoring compliance with quality standards	4	4	3	4	3	4	4	1	2	2
10.3 Sustainability training and support	1	2	2	2	1	1	1	1	1	1

Fig. 2: Number of practices divided into categories and subcategories implemented at each study site.

quality. Soil and ecosystem management is addressed through measures aimed at preventing erosion, preserving biodiversity, and promoting the planting of native plant species. Finally, digitalization emerges as a significant trend, with the implementation of environmental monitoring systems and construction site management solutions that enhance transparency and efficiency. However, all case studies revealed challenges in sustainable site management, suggesting the need for additional improvement strategies, many of which align with the criteria outlined by major environmental certification protocols.

V. DISCUSSION

The analysis of the ten case studies has highlighted the strengths and areas for improvement in each of the identified sustainability categories. Specifically, the Italian and international projects analyzed demonstrated varying applications of sustainable practices, offering significant examples of effective environmental management, ranging from waste management to the conservation of land and natural resources. In Italy, the San Giorgio Bridge in Genoa stands out for its excellent pollution management, reuse of excavated materials, and digitalization. Similarly, the Third Giovi Pass implements a comprehensive environmental monitoring system and reuses excavated material for environmental rehabilitation. The MOSE project in Venice focuses on monitoring environmental impacts, with particular attention to noise mitigation and biodiversity protection. The M4 metro line in Milan emphasizes environmental monitoring, tree preservation, and transparency. The Milan-Linate Airport project excels in reusing excavated soils, recycling materials, and managing noise pollution. Cascina Triulza implements an environmental monitoring system, waste management, and ecosystem preservation. Finally, the Hadid Tower in Milan is notable for its use of recycled materials, waste management, and attention to material sourcing. At the international level, the World Headquarters of Jehovah's Witnesses in Warwick (USA) stands out for its soil protection, tree conservation, protection of Blue Lake, and waste management. The M&S Cheshire Oaks project (United Kingdom) is distinguished by its reuse of soil and materials, promotion of biodiversity, use of sustainable materials, and waste management. The Rudraksh Convention Center in Varanasi (India) excels in reducing pollution, optimizing water resources, managing hazardous waste, and conserving greenery (Fig. 3).

The importance of sustainability in the construction sector is well recognized, given the significant environmental impact of this sector in terms of resource use, pollution, and waste production. Building sustainability assessment systems represent essential tools for promoting more sustainable construction practices. However, these systems often do not place sufficient emphasis on the construction phase, which is crucial in a building's life cycle. It is during this phase that the activities with the greatest environmental impact are realized, including intensive use of energy and materials, waste production, and pollutant emissions. The adoption of sustainable construction site practices allows for mitigating these negative impacts, with significant benefits not only from an environmental perspective—such as reducing CO_2 emissions—but also economically, thanks to energy and water savings, and improved working conditions and public health. Furthermore, sustainable construction site management helps improve the public image and reputation of construction companies, attracting environmentally-conscious clients and investors. This article highlights that sustainability in construction sites is no longer an option but an essential requirement for the future of the construction sector. Despite the progress made, the analysis points out several areas for

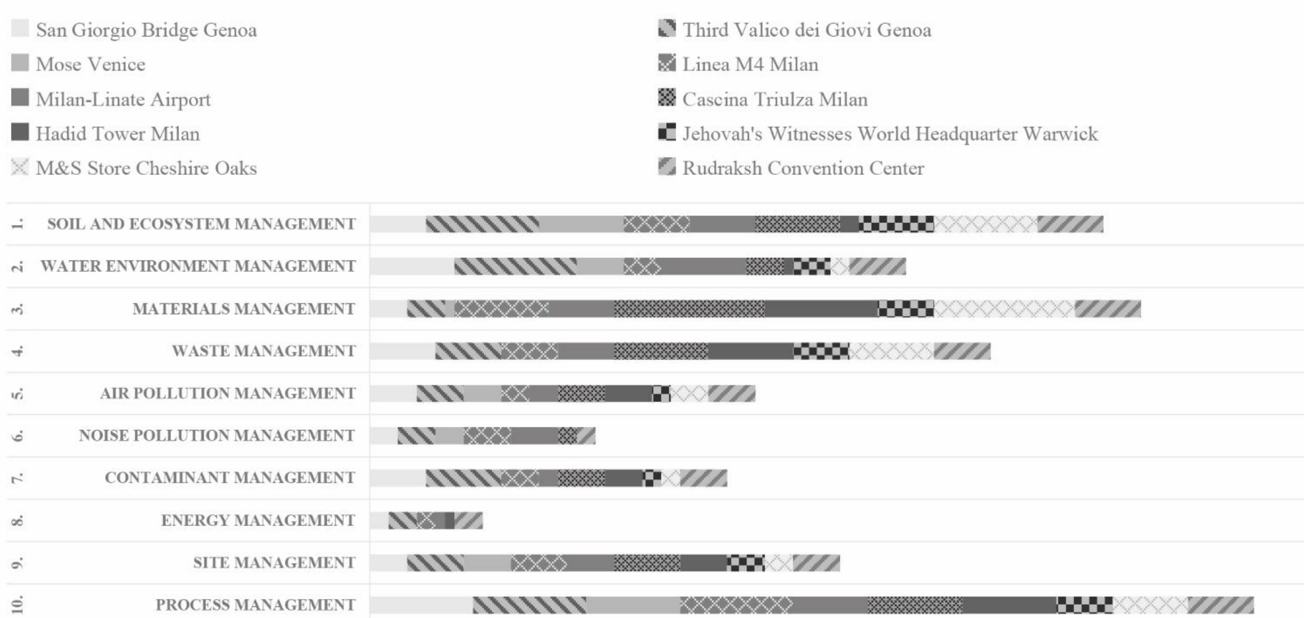

Fig. 3: Distribution of practices adopted and comparison between different areas of intervention in each case study.

improvement. In particular, there is a need for greater attention to energy resource management on construction sites. The adoption of low-impact environmental technologies and more accurate energy planning could further reduce the environmental impact of construction projects. Finally, the need to promote a more pervasive culture of sustainability within the sector through personnel training and the dissemination of good practices at all levels is emphasized. The numerous case studies analyzed demonstrate that it is possible to adopt more responsible construction practices; however, achieving these goals requires continuous and coordinated commitment from all stakeholders involved in the construction process.

VI. Conclusions

In conclusion, the future of the set of practices extracted from environmental certification protocols and the Minimum Environmental Criteria, whose definition has been supported by the analysis of the case studies, is oriented towards the development of a new protocol focused exclusively on the construction process phase. This protocol will be digitized into an interactive tool that will allow users to select the sustainable practices of interest. Each practice will be associated with a cost, and the tool will provide a final report, including the total cost of the selected practices, the percentage of practices covered by each analyzed protocol, and the respective implementation costs. This approach will enable users to compare the various protocols and, for an equal percentage of adopted practices, identify the most cost-effective protocol. This initiative not only promotes accessibility and transparency in managing sustainability on construction sites but also facilitates informed, evidence-based decisions, thereby contributing to the construction sector's evolution towards more responsible and sustainable practices.

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