energies

Article

A Risk-Based Analysis Approach to Sustainable Construction by Environmental Impacts

Nasanjargal Erdenekhuu [1], Balázs Kocsi [1] and Domicián Máté [1,2,*]

[1] Department of Engineering Management and Entrepreneurship, Faculty of Engineering, University of Debrecen, H-4028 Debrecen, Hungary
[2] DHET-NRF Sarchi Entrepreneurship Education, Department of Business Management, University of Johannesburg, Johannesburg 2006, South Africa
* Correspondence: mate.domician@eng.unideb.hu; Tel.: +36-(20)-9915258

Abstract: Sustainable construction is a comprehensive process of balancing the natural and built environment by applying sustainable development concepts. The golden triangle in the construction of time, cost, and quality should also assess risks from a sustainable perspective and investigate the environmental dimensions of the project. However, proper risk assessment for green sustainability is challenging, resulting in project management conducted under uncertain conditions. This study proposes a procedure based on Monte Carlo Simulations to improve the assessment of critical risk factors associated with construction activities. The AHP method was applied to rank environmental impact indicators, and the EMV approach was used to calculate the effects of the expected outcomes. The current study shows that air, water, and land pollution, water consumption, and solid waste are the most critical indicators. The results indicate that the equipment breakdown significantly impacted the duration of (and increase in) environmental issues. The evidence suggests that attention should be paid to sustainability risk factors during construction activities, e.g., the unavailability of materials had the most significant impact on the cost of the construction phase. The results suggest that the inadequate control of sustainability risk factors can lead to poor performance and tough decisions in a construction project.

Keywords: sustainable construction; risk assessment; environmental impacts; Monte Carlo Simulations; AHP ranking

Citation: Erdenekhuu, N.; Kocsi, B.; Máté, D. A Risk-Based Analysis Approach to Sustainable Construction by Environmental Impacts. *Energies* **2022**, *15*, 6736. https://doi.org/10.3390/en15186736

Academic Editor: Jarek Kurnitski

Received: 1 September 2022
Accepted: 10 September 2022
Published: 15 September 2022

1. Introduction

Although human development is supported by the construction industry, which creates the built environment, it is one of the main contributors to the climate crisis [1] and the depletion of natural resources [2]. Moreover, more than half of the world's population lives in cities, which occupy only 3% of the planet's land area but are responsible for 75% of energy consumption and carbon emissions. The UN projected that by 2050, nearly 70% of humanity will live in urban settlements and 90% in developing countries [3]. This will result in the construction of millions of new homes, jobs, schools, clinics, water and recycling treatment facilities, countless kilometers of highways, parking lots, and related urban infrastructure. The resource demands of the built environment by the current population already exceed the long-term ecological life cycle (in all continents), and the capacity of waste production to assimilate into the ecosystem [4].

In this context, the UN's Sustainable Development Goal (SDG) 11.6 is: "By 2030, reduce the per capita negative environmental impact of cities, including an extensive focus on air quality and waste management" [5]. Moreover, improved infrastructure and modernized industries can make them more sustainable through optimal resource efficiency and more significant usage of clean and green technologies and sound building processes, acting within the capabilities of all nations [6]. Target 9.4 aims to minimize the negative environmental impacts of the construction sector and increase its positive institutional impacts [7].

Ali and Al Nsairat (2009) [8] stated that sustainable construction is a holistic process that seeks to maintain harmony between the natural and built environments by applying sustainable development concepts to the building life cycle. Several approaches have been proposed to create a responsible built environment, such as sustainable materials [9,10], sustainability in project management [11,12], and sustainability assessments [13].

One key aspect of sustainability assessment involves focusing on the current and future positive net gains of sustainability in the construction sector [14]. Integrating sustainability appraisal into the project design phase would allow monitoring and evaluation of the extent to which the project ensures sustainability throughout its life cycle [15]. Banihashemi et al. (2021) [16] assumed that the environmental impact assessment of construction projects would give project managers and designers a rational decision-making process to achieve sustainable goals. Research on this basis has established evaluation indicators to assess the environmental performance of sustainable construction projects [17,18], which have been widely adopted in the construction industry for ranking indicators [19–21]. However, although there is a growing body of research on the variety of assessment indicators that seem helpful for the sector in performance measurement, it is relatively unusual to select the most advantageous for project-level evaluation.

A major issue of research on early sustainable approaches is that, for example, green materials, advanced technologies, and regulations can make the building environment even more unpredictable and uncertain than traditional practices [8], resulting in construction projects facing multiple and complex risks. Therefore, the threats arising from new sustainability-related implementations substantially differ from traditional risk concerns. This controversy makes risk analysis one of the most complex processes in construction project management, influencing the budget, schedule, and scope of the project [22].

The primary purpose of this study was to propose a procedure to assist project decision-makers in analyzing the risks of standard and sustainable construction activities and their impacts on the duration, costs, and environmental changes of construction projects. This research seeks to address the following questions: (1) What are the key environmental impact indicators for a sustainable construction project? (2) What are the crucial risk factors for a sustainable construction project?

This study follows a case study design, using an in-depth AHP analysis of the selection of critical environmental impact indicators and the EMV approach to calculate the expected critical risk factor ranking of indicators. The study aims to better understand the interaction between environmental risk factors associated with construction activities from a sustainable perspective. Using 2017–2019 data and Monte Carlo simulation (MCS) tools, the effects of conventional and sustainability construction risk factors on environmental impact indicators were analyzed. The research contributes to the emerging literature on sustainable construction risk determinants.

The study is structured as follows. This paper will review the literature on sustainable development and the risk assessment of sustainable construction projects. The materials and methods used to answer the research questions are described in the next section. The proposed analyses were implemented in a construction project case study. Finally, the results are discussed and conclusions are drawn.

2. Review of Sustainability Concepts

The basic principle of sustainability is based on a future-oriented balance between the environment, economy, and society. Therefore, it would be a misguided approach to define sustainability as the sum of these three factors; rather it is the interaction and interplay of the three pillars, i.e., the environment, economy, and society [23,24].

The concept of sustainability—not consuming more resources than can be replaced in the same period—was first developed in the 18th century and applied to the issue of forest management. Environmental protection was later used to initiate the incorporation of economic and social dimensions and ensure the proper functioning of the ecosystem. In this context, Vogt and Weber (2019) [1] defined sustainability as the ecological cycle of exchange, which, in addition to planning and forecasting the economy, takes into account the conditions and consequences of human actions for current and future generations. Others defined sustainability as a future mindset that achieves a state of equilibrium between environmental, social, and economic aspects in pursuing a higher quality of human life [25]. Moreover, sustainability is an ideal balance between economic growth, environmental management, and social equity, as clean manufacturing, pollution prevention, control of systems, and design of architecture and structures that consider ecological characteristics can be essential elements of sustainability [26].

According to Kuhlman and Farrington (2010) [23], humanity has transformed natural renewable and non-renewable resources into manufactured capital, consisting of reproducible physical capital, including, for instance, infrastructure, buildings, machinery, and intangible assets, e.g., health, knowledge, skills, relationships, and trust. The extent to which manufactured resources can substitute for natural resources determines whether sustainability is weak or strong. Strong or weak sustainability is primarily concerned with natural resources rather than socioeconomic impacts [27]. From this perspective, a growing global awareness of the interconnectedness of environmental crises, and social and economic challenges, such as poverty and inequality, and concerns about current and future prosperity, has shaped the concept of sustainable development [23]. Poor sustainability can be understood as the need for the next generation to provide man-made assets and environmental capital which are no less than the stock of wealth inherited by the previous generation. In contrast, under the more substantial paradigm of non-substitution of ecosystem functioning, the next generation should inherit a stock of natural capital equal to (or greater than) the stock inherited by previous generations [28].

2.1. Sustainable Development

Haller (2018) [29] defined sustainable development as the process of achieving sustainability for society. In the same vein, it is a set of different processes and pathways to achieve sustainability (i.e., sustainable agriculture and forestry, green production, efficient use, good governance, science and innovation, education, and training) [30]. In comparison, others have defined it as the active and creative exploration, understanding, and shaping of the present and future of human activities on our planet [1].

According to the ideas by Hopwood et al. (2015) [31], there are three primary strategies for sustainable development: (1) Proponents of the *status quo* recognize that current political and economic structures can address sustainable development issues without significant changes; (2) sustainable development *reformists* accept significant changes in policy and lifestyle to address the ever-growing critical global problems; (3) *transformation* is the most extreme of the three concepts. Its proponents have claimed that the world's crises are caused by underlying social, political, and economic structures. Stock et al. (2017) [32] argued that sustainability is strongly linked to social and environmental protection and is mainly seen as reversible. However, the Brundtland Report focused on the needs of the present without compromising the ability of future generations to meet their needs [33].

Nowadays, development strategies are primarily focused on transformation, shifting from a growth focus to the importance of the non-substitutability of ecosystem services [6]. This trend is reflected in the recently adopted UN 2030 SDGs, which emphasize the importance of the linkage between society and natural capital, increasing the responsibility of less empowered groups and transforming economic patterns [34].

2.2. Sustainable Construction

The shift towards a transformational approach has led to the development of sustainability committees and national organizations worldwide and the expansion of economic evaluations, indicator measurements, and assessments linked to society in all sectors [35]. Throughout this paper, the term sustainable construction will refer to 'responsible construction and management of a healthy building environment, while considering environmental principles and resource efficiency' [36]. The following principles are introduced for the sustainable construction industry: minimizing resource consumption, maximizing resource reuse, using renewable and recyclable resources, protecting the natural environment, creating a healthy and non-toxic environment, and pursuing quality in the built environment.

From this environment- and resource-centered perspective, Yılmaz and Bakış (2015) [37] described how sustainable construction (SC) should focus on environmentally conscious production with optimal usage of resources from the beginning of the design process throughout the design life cycle. Du Plessis and Cole (2011) [38] stated that SC is a comprehensive process that seeks to maintain harmony between the natural and built environment by applying the principles of sustainable development to the life cycle of a building, starting with the extraction of raw materials for manufacturing and continuing through design, construction, and operation. Mavi et al. (2021) [39] acknowledged that SC creates and manages a safe and healthy built environment while utilizing resource efficiency.

Ali and Al Nsairat (2009) [8] believed that SC generally refers to green constructions that are energy-, water-, and space-efficient, non-toxic, and durable, with high recycled content, and that address a significant number of resource challenges. Nair and Nayar (2020) [40] also aligned sustainable construction with the wise use of resources to meet the needs of current and future generations. SC often emphasizes the reduction of environmental harm and can include features, such as conservation, recycling, and waste management, with direct social equity and less focus on profit. There is a solid drive to reduce industry's negative impacts on the natural environment, such as global warming, ecological degradation, and the depletion of natural resources [39]. As a result, the growing interest in SC worldwide has stimulated the development of different approaches to help the construction industry develop sustainably. In this context, Lima et al. (2021) [41] found that management, materials, and sustainability assessments have received the most attention in synthesizing sustainability in the construction sector.

Sustainable construction project management (SCPM), defined as the methods by which projects are monitored to ensure that their sustainable objectives are met [42], has become one of the common areas of sustainability practice in the construction industry. SCPM promotes the success of projects at all levels and helps processes ensure that the project is up-to-date and prepared to address sustainability issues [43,44]. De la Cruz López et al. (2021) [12] stated that sustainability should be an essential function of project management rather than added to existing processes in the construction industry.

Song and Zhang (2018) [45] noted that the selection of the materials is critical in creating a more sustainable built environment, as the materials used have a direct impact on quality, lifetime, cost, energy consumption, and greenhouse gas emissions (GHGs) over the entire life cycle of buildings. Factors such as availability, less processing, toxicity, recyclability, cultural acceptability, self-construction, natural origin, low energy consumption, and low maintenance costs can be considered when selecting the 'right' material for sustainable use [45,46]. Recent research emphasizes the importance of environmentally friendly building materials in implementing sustainable projects [9,46]. For example, recycled construction and demolition waste (CDW) has excellent performance and intense physical and technical properties and is vital for environmental and economic accessibility [2]. Zea-Escamilla and Habert (2014) [10] investigated bamboo-based building materials with environmental and mechanical advantages over conventional materials. Tutu and Tuffour (2016) [47] discovered that warm-mix asphalt has significant sustainability benefits, such as lower energy consumption, decarbonization, and increased potential for recycling recovered asphalt pavement. The results showed that warm-mix asphalt is equivalent to, or in some cases, perhaps an improvement on conventional types.

Sustainability appraisal in the construction sector is another approach to impact assessment that focuses on the current and future generation of positive net gains from sustainability; it can provide reliable information for different levels of decision-making [14]. Incorporating sustainability assessments into the project design phase allows the project team to monitor and assess the extent to which the project delivers sustainability throughout the project life cycle [41] and demonstrate quantifiable and achievable results to stakeholders as part of the project objectives [39]. Since sustainability is assessed at different stages of construction projects to achieve optimal efficiency throughout the entire process, sustainability assessment methods are considered the most effective tool for promoting a sustainable built environment [38]. Díaz López et al. (2019) [13] found that environmental considerations are present in all 101 assessment methods studied, including the internationally established LEED, BREEAM, and CASBEE, which demonstrate the most prominent and achievable impacts of sustainability and its socioeconomic consequences.

Furthermore, an environmental impact assessment of construction projects provides managers and project planners with a rational decision-making process to achieve sustainable goals [16]. Tupenaite et al. (2017) [19] invited ex-professionals to assess sustainable environmental, economic, and social dimensions. Unsurprisingly, environmental sustainability was found to be more decisive than the other economic and social dimensions in achieving the sustainability of new housing developments in the Baltic states.

It is understandable that the transformational approach to sustainable development has brought the assessment of the environmental impacts of construction projects to the attention of scholars. Maslesa et al. (2018) [17] systematically reviewed 69 articles and found that environmental impacts from non-residential buildings are vital; the operational phase of buildings has more significant environmental impacts than others. Eight categories of commonly used indicators, i.e., energy, emissions, water, waste, land and building area, building materials, indoor environmental quality, and recycling, were established as potentially suitable for assessing the environmental performance of buildings. Using questionnaires and semi-structured interviews, Agyekim et al. (2021) [18] investigated critical indicators for assessing the environmental performance of construction projects in Ghana. The research concluded that all indicators are crucial to determining the environmental sustainability of projects throughout their life cycle. However, water and air quality, energy use and conservation, environmental compliance, and management were the most important.

For the same reason, Enshassi et al. (2014) [48] assessed three categories of environmental impacts from construction projects in the Gaza Strip, including ecosystems, natural resources, and population impacts. According to their questionnaire results, construction projects' most critical environmental consequences include dust generation, noise and air pollution, and vegetation removal operations. Finally, the construction industry participants are advised to sharpen their knowledge and awareness of the environmental consequences of construction activities. Robust legislation should be implemented to reduce construction operations' adverse impacts.

An optimal set of indicators should be selected from a wide range of assessments to maximize the accuracy of sustainability analysis of construction projects and save limited resources [49,50]. The analytic hierarchy process (AHP) is one of the prominent decision-making tools for weighting and ranking criteria in sustainable construction projects and is primarily used for indicator set selection [51]. Considering the context of the Baltic states, an AHP-based sustainability assessment tool was developed for new residential construction projects [19]. Ameen and Mourshed (2019) [20] ranked urban sustainability indicators using AHP in the case of Iraq. Results showed that water (8.5%), safety (7.9%), and transport and infrastructure (7.8%) scored the highest. Khanzadi et al. (2020) [21] identified the application of BIM to construction phase performance in Iran and applied fuzzy-AHP to rank and weigh the indicators. The study revealed that the three most important indicators that can benefit the project construction phase are quality improvement, sustainable construction, and cost reduction. Kamali et al. (2018) [15] established a sustainability benchmarking approach by considering the life cycle of residential modular structures. In addition to AHP and ELECTRE, the technique for order preference by similarity to ideal solution (TOPSIS), and the multi-criteria decision-making method (MCDM) were also applied to rank 33 criteria to address sustainable dimensions.

2.3. Risk Analysis in Sustainable Construction

Prioritizing innovative sustainable practices can make the construction environment even more unpredictable and uncertain than traditional practices, resulting in construction projects facing multiple and complex risks [22]. The tight schedule of risky projects needs careful planning, feasibility analysis, and experience in management, all of which are essential to achieve the SC objectives. Therefore, the risks arising from new sustainability practices are substantially different from traditional risk concerns. For instance, the use of 'green and right' materials raises problems related to inadequate testing, lack of appropriate equipment, and skilled labor [52]. Regulatory requirements, such as selecting the right subcontractor, reusing, and recycling, are also not straightforward [53]. In addition, SC projects involve advanced construction techniques, complex designs and materials, and increased communication among project stakeholders, which requires more time than traditional project delivery practices [54].

Qazi et al. (2021) [22] have created a sustainability risk framework to support project managers in identifying and managing critical risks. A risk-matrix data approach was presented based on the Monte Carlo simulation (MCS) to prioritize risks caused by integrating sustainability into construction projects. The study identified thirty sustainability-related risks and divided them into five groups: management, technical, stakeholder, sustainable materials and technologies, and legal and economic risks. The proposed approach was applied to construction projects completed in the UAE, demonstrating that the usual system of risk prioritization does not determine the importance of subordinate risks. Hwang et al. (2017) [55] identified 42 risks in sustainable housing projects using an extensive literature review and questionnaire to compare the importance of the usual risks encountered in the same type of project. The study found that this type of project was exposed to more severe risks than ladder projects. Namely, complex permit procedures, overlooked high initial costs, unclear owner requirements, employment constraints, and lack of availability of green materials and equipment were the most crucial risks for SC residential projects. Guan et al. (2020) [56] explored the interdependencies between the risks of green building projects from life cycle and multi-project risk perspectives and identified (16) constraints, (22) risks, and (11) objectives. A MICMAC method and an ISM-based model were used to assess the degree of dependency of the interdependent elements. Nguyen and Macchion (2022) [57] conducted a thorough literature review on green buildings and provided a comprehensive list of risk factors.

Furthermore, in addition to the emerging sustainability risks in SC, the traditional risks arising from construction operations and their impacts should be analyzed in terms of sustainability dimensions, e.g., standard time, cost, and quality dimensions [57]. For instance, the number of pollutants, emissions, and energy consumption used by project activities, among many other factors, will not be reliably identified, and the project outcome will become uncertain [12]. Improper management and control of these uncertainties and risks can lead not only to time and cost overruns and poor quality [58] but also to low levels of project performance in terms of sustainability [16].

Goel et al. (2019) [59] agreed that the achievability of project outcomes is shaped by processes, emphasizing the need to build sustainability into the projects, including identifying and managing risks, since risk-based analysis and assessment are considered critical processes in risk management [60]. Risk analysis is the numerical estimation of the probability of occurrence and potential impact of identified individual risks under uncertainty [57]. MCS is extensively used to quantify more accurately the effects of critical risks on construction activities in an uncertain environment [61]. Aarthipriya et al. (2020) [62] analyzed the risks associated with a housing project in Bangalore and its impact on duration and budget. Estimates showed that cost overruns were caused by material price fluctuations, improper resource planning, quantity surveying, and analyzing ground conditions. Spanidis et al. (2021) [63] used fuzzy-AHP, expected value (EV) function, MCS, and PERT analysis to evaluate and predict the impact of risk on costs. Larionov et al. (2021) [64] preferred MCS to quantitatively assess the risk of pessimistic and optimistic strategies to prevent environmental damage in construction projects. Smirnova (2020) [65] investigated the problems associated with environmental risk based on MCS forecasting and used the characteristics of the natural landscape to predict the degree of interaction between the construction zones and the environment. Sobieraj and Metelski (2020) [54] explored how the appropriate technique for scheduling construction processes affects the risk of each phase and the overall project.

The literature review revealed the effectiveness of AHP in prioritizing indicators, MCS in analyzing risks affecting project duration and costs, and the importance of environmental impact indicators in assessing sustainability. However, their combinations have rarely examined how risk factors associated with construction activities affect project performance from a sustainability perspective. In order to highlight the importance of strong sustainability as a non-substitutability of ecosystem services, this study extensively addresses the environmental sustainability of construction projects. Risk factors are analyzed using environmental impact indicators and the standard time and cost constraints.

3. Materials and Methods

The proposed construction process was applied in a warehouse construction project in Tiszafüred (Hungary) to perform a more accurate risk analysis. The reinforced concrete (RC) construction started on 2 February 2017 and was completed on 1 April 2019. Although the construction project had more than 150 main phases, including architectural, structural, mechanical, and electrical, the scope of the study is limited to the analysis of only one phase consisting of 16 activities. Table 1 shows the activities listed in alphabetical order.

Table 1. Construction phase activities.

Activity ID	Description
A	Precast reinforced concrete structure planning
B	Precast reinforced concrete structure production
C	Precast reinforced concrete columns
D	Precast reinforced concrete beams
E	Reinforced concrete skirting
F	PC fire resistance wall
G	Reinforced concrete slab formwork
H	Reinforced concrete slab reinforcement
I	Reinforced concrete slab concrete
J	Masonry
K	First roof reinforcement
L	Second roof reinforcement
M	Steel trapezoidal plates
N	Skylight
O	Insulation
P	Tinning

The project team estimated the duration of activities by brainstorming and drawing on the experience of previous projects. A three-point method calculated the minimum, most likely, and maximum duration. The minimum duration was determined by analyzing the worst-case scenario of the activity. In contrast, the maximum duration was obtained by analyzing the best-case scenario of the activity. The most probable duration is estimated by analyzing the duration of the activity, considering the resources most likely to be allocated. As shown in the project data, the predecessor activity is the activity that precedes a dependent activity. Start-to-start (SS) is a logical relationship where a successor activity cannot start until the predecessor activity has begun. Finish–start (FS) is a relationship where a successor activity cannot take off until the predecessor activity has finished. Here, the successor activity is a dependent activity that follows another activity in the project schedule. The 'Lag' is the time (days) required to delay the start of the successor activity (Table 2).

Table 2. Duration and connections of phase activities.

Activity ID	Min (Day)	Most Likely (Day)	Max (Day)	Predecessor Activity	Relationship	Lag (Day)
A	76	85.5	95	-	-	-
B	62	69	76	A	SS	+45
C	27	30	33	B	SS	+10
D	39	45	51	C	SS	+10
E	59	66	73	D	SS	+10
F	49	59	69	E	SS	+10
G	3	3	3	D	FS	0
H	6	9	12	G	FS	0
I	1	1	1	H	FS	0
J	27	35.5	44	I	FS	+28
K	28	30	32	I	FS	+28
L	25	30	35	K	SS	+10
M	14	16	18	L	SS	+15
N	14	20	26	M	FS	0
O	43	60	77	N	SS	+9
P	37	40	43	O	SS	+40

Table 2 shows that the most prolonged duration belongs to activity A, with values of 76, 85.5, and 95 for the minimum, most likely, and maximum durations, respectively. However, the most extensive duration range (maximum–minimum) belongs to phase activity O (34 days). The estimated duration of all phases is uncertain since the calculated duration range is more significant than zero for all activities except G and L, for which the duration range is zero.

The potential risk factors were identified by the opinion of the project team and estimated in association with the construction operations and their impact on the project outcome in terms of time, cost, and environment. The list of risk factors is shown in Table 3, where the risk identifier is related to construction activity. For instance, activity A has two major risk factors as it stands, A1 (lack of skilled labor) and A2 (inappropriate regulation). The table also provides information on the likelihood that the risk factors and associated impacts would increase the duration and cost of the activity, as well as negative environmental impacts such as air pollution, water pollution, water consumption, and solid waste.

Risk is an essential element of the construction process. Therefore, risk analysis is an integral part of project management for all construction projects, including sustainable construction projects. It allows experts to quantify and analyze risks that could threaten a project performance's sustainability. It is critical in sustainable decision-making when uncertainty, ambiguity, or unpredictability exist [60–62]. Figure 1 shows a flowchart of the proposed methodology and analysis process.

Table 3. List and Impacts of Risk Factors.

Activity ID	Risk ID	Risk Description	Probability (%)	Relative Delay (%)	Fixed Cost Increase (USD)	Air Pollution Increase (%)	Water Pollution Increase (%)	Water Consumption Increase (%)	Solid Waste Increase (%)
A	A1	Lack of skilled workers	20	0	826	47	57	13	71
	A2	Inappropriate regulations	80	45	806	27	40	35	65
B	B1	Unavailability of materials	20	50	2348	8	25	62	29
C	C1	Lack of infrastructure	40	20	851	62	5	4	30
	C2	Equipment breakdown	30	0	980	28	48	9	8
D	D1	Lack of infrastructure	40	20	851	35	14	67	19
	D2	Equipment breakdown	30	0	980	26	75	3	16
E	E1	Unavailability of materials	30	40	5935	72	7	12	22
F	F1	Lack of skilled workers	10	30	930	75	31	17	3
G	G1	Lack of infrastructure	30	0	851	68	36	66	24
H	H1	Physical or chemical failure of materials	25	80	1755	41	35	51	68
I	I1	Unavailability of materials	10	15	930	9	76	54	28
J	J1	Unavailability of materials	30	25	2736	70	15	15	62
K	K1	Physical or chemical failure of materials	15	45	2186	38	30	59	52
	K2	Unavailability of materials	5	0	173	74	36	62	73
L	L1	Physical or chemical failure of materials	15	45	2186	54	24	19	73
	L2	Unavailability of materials	5	0	173	32	58	24	30
M	-	-							
N	-	-							
O	O1	Equipment breakdown	60	30	893	61	75	54	55
P	P1	Unavailability of materials	15	10	334	24	21	36	14

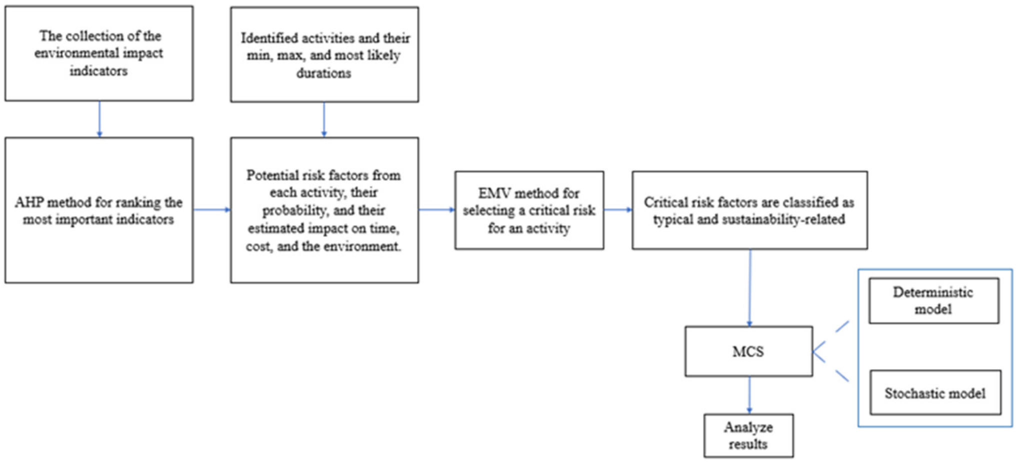

Figure 1. Flowchart of the Analysis Process.

3.1. Analytic Hierarchy Process (AHP)

Environmental impact indicators were obtained from related articles to identify the critical factors for SC projects. The indicators were weighted and ranked by AHP to compile a list of the most critical ones. The project team also identified the most applicable risk identification methods, such as checklists, risk breakdown structures (RBS), brainstorming, and experience from previous projects. Risk has the dual nature of risks and opportunities, but this study highlighted only hazards. Therefore, the expected impact and probability of occurrence are estimated for each risk factor. Subsequently, for activities with more than one risk factor, the expected monetary value (EMV) method is applied to determine a critical risk factor for the activity. Based on the prior research on sustainability-related risks in the construction industry, the most vital risks are classified as either sustainability-related or typical risk factors. These data are fed into the MCS and run for an appropriate number of independent iterations. The results are examined to highlight the risk factors that have a considerable influence on the project's outcome; depending on the result, the team could be able to create a plan, strategy, and actions for mitigating the risk factors.

AHP allows decision-makers to quantitatively apply multiple criteria to analyze possible alternatives and select the optimal choice. Because of its built-in ability to evaluate different options, AHP is widely used in the construction industry, especially in sustainable construction [61,66,67]. AHP is implemented in four successive steps [68]: (a) structuring the decision hierarchy tree; (b) computing the vector of weights of alternatives; (c) checking consistency; (d) ranking the alternatives. Each step is described in detail below.

3.1.1. Structuring the Decision Hierarchy Tree

The first step remains at the top level, up to the decision alternatives (see Figure 2). In Figure 2, the goal at the top level of the hierarchy is to select the most suitable contractor based on experience [57]. Usually, three possible alternatives (m = 3) are listed at the second level: X, Y, and Z, e.g., environmental impact indicators.

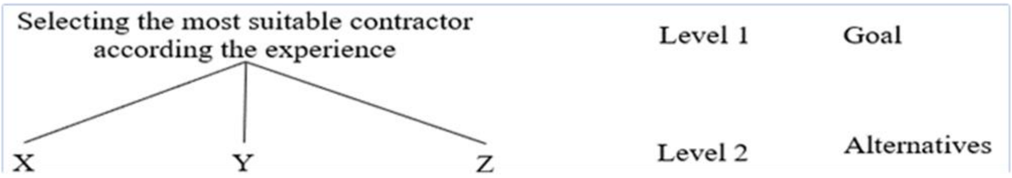

Figure 2. Selection of the Hierarchy Tree.

3.1.2. Computing the Weight Vectors

Saaty (1987) [68] suggested that a pairwise comparison matrix (B) should be created initially to estimate the weight of the different alternatives. The B matrix is the fxf matrix, where f is the number of alternatives considered. Each factor in the matrix expresses the relative importance of the factor in the row compared to the factor in the column. If two alternatives are equally significant, the factor equals 1, see (1).

$$B = \begin{bmatrix} 1 & 2 & \dots & b_{1f} \\ b_{21} & 1 & \dots & b_{2f} \\ \dots & \dots & 1 & \dots \\ b_{f1} & b_{f2} & \dots & 1 \end{bmatrix} \quad (1)$$

Table 4 shows the definition of a scale from 1 to 9 to assess the relative importance of the alternatives based on [69]. The AHP uses pairwise comparisons to simplify the judicial process with the ratio scale. At each level of the pairwise comparison matrix, items are compared pairwise in terms of their importance relative to the higher-level item.

Table 4. The scale of comparison *.

Importance	Definition	Explanation
1	Equal importance	Two activities contribute equally to the objective
3	Moderate importance	Experience and judgment slightly favor one activity over another
5	Strong importance	Experience and judgment strongly favor one activity over another
7	Very strong importance	An activity is favored very strongly over another
9	Extreme importance	Evidence favoring one activity over another is of the highest possible order
2, 4, 6, 8	-	Intermediate values

* Source: [69].

A normalized pairwise B_{norm} matrix is constructed from the B matrix by dividing each factor in the column by the sum. See Equations (2) and (3), where f is the number of alternatives.

$$\bar{b}_{ij} = \frac{b_{ij}}{\sum_{i=1}^{f} b_{ij}} \quad (2)$$

$$B_{norm} = \begin{bmatrix} 1 & 2 & \dots & \bar{b}_{1f} \\ \bar{b}_{21} & 1 & \dots & \bar{b}_{2f} \\ \dots & \dots & 1 & \dots \\ \bar{b}_{f1} & \bar{b}_{f2} & \dots & 1 \end{bmatrix} \quad (3)$$

The weight vector w is created by averaging all the factors in the row of the B_{norm} matrix. See Equation (4).

$$w_i = \frac{\sum_{i=1}^{f} \bar{b}_{ij}}{f} \quad (4)$$

3.1.3. Checking the Consistency

Once all pairwise comparisons are complete, the problem becomes a general process of calculating the largest eigenvalue corresponding to the eigenvectors v_f for evaluating the consistency index (CI). The consistency vector is calculated according to formulae Equation (5):

$$\begin{aligned} Bv_1 &= \frac{1}{w_1}\left[b_{11}w_1 + b_{12}w_2 + \dots + b_{1f}w_f\right]; \\ Bv_2 &= \frac{1}{w_2}\left[b_{21}w_1 + b_{22}w_2 + \dots + b_{2f}w_f\right]; \dots \\ Bv_f &= \frac{1}{w_f}\left[b_{f1}w_1 + b_{f2}w_2 + \dots + b_{ff}w_f\right] \end{aligned} \quad (5)$$

The largest Eigenvalue λ_{max} of the matrix is obtained by

$$\lambda_{max} = \frac{1}{f}\sum_{i=1}^{f} Bv_i \tag{6}$$

Equation (7) determines the consistency index CI, where f is the number of alternatives. The final CI divided by the random consistency index (RI) provided by different matrix orders should be less than 0.1 (10%) [68].

$$CI = \frac{\lambda_{max} - f}{f - 1} \tag{7}$$

3.1.4. Ranking the Alternatives

Finally, the weight vectors w need to be sorted in descending order to obtain the alternative ranking.

3.2. Expected Monetary Value (EMV)

EMV is a statistical approach to project risk management that calculates average outcomes when the future contains the possibilities of various events occurring, in order to quantify potential errors from construction activities [70]. Similarly, [63] et al. (2021) [34] described this method as a linear function suitable for representing cost overruns and schedule delays for different conditions and used it for pre-disaster analysis of scenarios with adverse impacts on mines. *EMV* can be calculated as:

$$EMV = P * I \tag{8}$$

where P is the probability of risk factor occurrence, and I denotes the corresponding impact of the risk factor.

3.3. Monte Carlo Simulation (MCS)

MCS is a decision-making method widely used in the construction industry to assess the level of risk exposure. It involves the statistical sampling of various stochastic integrals related to a mathematical model and the probabilities of occurrence of certain events. These events often rely on several input factors exposed to risk due to systematic changes in input parameters. The MCS determines the model's validity and selects optimal model parameters [71]. In other words, at each iteration, the project model is computed several times with different values randomly selected from the probability distribution of the input parameters to handle those that may have a negative impact on the project.

In the construction industry, program evaluation and review technique (PERT) and four-parameter beta (Beta4) distributions are suitable for representing the duration and cost of project activities [72]. Beta is a continuous probability distribution with a range [0, 1] and two positive shape factors (α, β), which are the exponents of a random variable and determine the shape of the distribution [73]. Similar to the study by Abusalem et al. (2019) [70], a symmetric distribution is adopted for Beta4 (α, β, a, b), where α = 2, β = 2, a = minimum duration, and b = maximum duration, for the activities. This distribution assigns equal importance to the risk factor at the lowest and highest values as a case of the binomial distribution called Bernoulli.

4. Results

4.1. Selecting Crucial Environmental Impact Indicators

As a first step, crucial environmental impact indicators should be identified to validate the indicators in the case study. Measuring project performance by a single indicator is not appropriate. Consequently, identifying an appropriate number of accurate indicators is critical, as the list of indicators impacts the results of quantitative performance measurement [54]. In the Swedish construction industry, Toller et al. (2013) [72] selected six indicators to monitor environmental impacts. In contrast, Maslesa et al. (2018) [17] identified eight primary indicator categories for the ecological impacts of buildings from a life cycle assessment perspective. Similarly, Alwaer and Clements-Croome (2010) [74] used sixteen key impact categories (KPIs) in their sustainability building impact study, identifying six environmental parameters. The present study selected seven indicators from related papers. Twelve peer-reviewed articles covering different building projects were selected to collect the crucial environmental sustainability indicators. The seven most frequently used indicators, including "water consumption", "noise pollution", "water pollution", "air pollution", "land pollution", "solid waste", and "energy consumption", were retained for further AHP ranking (see Table 5).

Table 5. Source and abbreviations of environmental impact indicators.

Environmental Impact Indicators	Source
Water consumption (WC)	[17,18,24,75,76]
Noise pollution (NP)	[18,24,48,76,77]
Water pollution (WP)	[17,48,76–81]
Air pollution (AP)	[17,18,48,75–78,80–82]
Land pollution (LP)	[18,48,77,79–81]
Solid waste (SW)	[17,24,48,75–78,80–82]
Energy consumption (EC)	[17,18,24,75,76,82]

Following the analysis process described in Figure 1, the AHP is used to rank the identified indicators. Table 6 shows the pairwise matrix of the corresponding indicators and their consistency vectors. The consistency ratios of the pairwise comparison matrix verify the ranking's reliability. According to Equation (6), the maximum Eigenvalue was computed: λmax = 7.593 + 7.573 + 7.567 + 7.621 + 7.604 + 7.658 + 7.403)/7 = 7.574. CI = (7.574 − 7)/(7 − 1) = 0.096 based on Equation (7). CI/RI = 0.096/1.32 = 0.073, which is consistent at <0.1 level.

Table 6. Pairwise comparison matrix of the indicators and consistency vectors.

Indicators	WC	NP	WP	AP	LP	SW	EC	Consistency Vectors
WC	0.213	0.153	0.367	0.456	0.153	0.077	0.152	7.593
NP	0.027	0.019	0.020	0.025	0.019	0.019	0.022	7.573
WP	0.107	0.172	0.184	0.114	0.172	0.307	0.304	7.567
AP	0.107	0.172	0.367	0.228	0.172	0.307	0.304	7.621
LP	0.427	0.153	0.092	0.114	0.153	0.153	0.076	7.604
SW	0.213	0.134	0.092	0.114	0.134	0.307	0.152	7.658
EC	0.053	0.077	0.046	0.046	0.077	0.051	0.051	7.403

Table 7 shows the ranking of the indicators. To achieve the objectives of the study, only the first five ranked indicators, e.g., air pollution, water consumption, 'water pollution, land pollution, and solid waste, were retained, with the other two (energy consumption and noise pollution) being excluded. However, only four indicators were used for further analysis, as data on the 'land pollution' indicator could not be collected.

Table 7. The rank of the indicators.

Environmental Impact Indicators	Weight Vector	Rank
Water consumption (WC)	0.213	2
Noise pollution (NP)	0.019	7
Water pollution (WP)	0.184	3
Air pollution (AP)	0.228	1
Land pollution (LP)	0.153	4
Solid waste (SW)	0.152	5
Energy consumption (EC)	0.050	6

4.2. Classifying the Critical Risk Factors

The EMV method was used to calculate the expected amount of money lost if the risk factor occurred. Based on the results, a critical risk factor was identified and retained for further analysis for activities with more than one risk factor. Some activities are associated with more than one risk factor, such as Activity A. Only one critical risk factor can be assigned, so risk factors with a lower EMV value have been deleted (eliminated). Once the critical risk factors for the activities were selected, the risk factors were classified based on the findings of previous studies [6,22,55]. Consequently, for example, 'F1-lack of skilled labor', 'B1, E1, I1, J1 and P1-unavailability of materials', and 'O1-equipment breakdown' were classified as sustainability-related risk factors (see Table 8).

Table 8. The classification of critical risk factors.

Activity ID	Risk ID *	Probability (%)	Fixed Cost Increase (USD)	EMV (USD)	Status
A	A1	20	826	165.2	eliminated
	A2	80	806	644.8	
B	*SB1*	20	2348	469.6	
C	C1	40	851	340.4	
	C2	30	980	294	eliminated
D	D1	40	851	340.4	
	D2	30	980	294	eliminated
E	*SE1*	30	5935	1780.5	
F	*SF1*	10	930	93	
G	G1	30	851	255.3	
H	H1	25	1755	438.75	
I	*SI1*	10	930	93	
J	*SJ1*	30	2736	820.8	
K	K1	15	2186	327.9	
	K2	5	173	8.65	eliminated
L	L1	15	2186	327.9	
	L2	5	173	8.65	eliminated
M	-				
N	-				
O	*SO1*	60	893	165.2	
P	*SP1*	15	334	644.8	

Notes: * the added first risk ID character "*S*" indicates the *sustainability risk factors* based on [6,22,55].

4.3. Risk-Based Factor Analysis

The deterministic scheduling model was created using project management (Microsoft Project) software [83]. A stochastic model was then developed using a project risk management (RiskyProject 7.2) package [84]. Due to the limited selection of environmental impacts in the software, these were replaced by the following impact types: (1) Environmental impact in the case of an increase in air pollution, (2) quality impact in the case of an increase in water pollution, (3) legal impact in the case of an increase in water consumption, and (4) performance impact in the case of an increase in solid waste. The model was repeated 500 times because, if the number of iterations was small, there was a significant difference between the results of the current iterations and the previous ones. However, after a few hundred iterations, the difference would decrease dramatically. Finally, Diamantas et al. (2007) [71]

suggested that two types of project phase durations were defined in this study. The first, called 'total duration', excluded the impact of the identified risk factors, while the second, called 'overall duration', already included them.

The earliest completion date for the project's construction phase was 9 April 2018, with a duration of 280 days. The latest completion date was 4 May 2018, with a total duration of 300 days and a 20-day deviation. The average completion date was 13 April 2018, with 284 days and 4 days variance. There was an approximately 20% chance of completion of the construction phase depending on the deterministic completion date, which was 9 April 2018 with a duration of 281 days. This meant that under the worst-case scenario of uncertainties about risk factors and the duration of activities, there was an 80% probability that the construction project phase would not have been completed on that date. The minimum fixed costs increased as the risk factors associated with the construction activities were 0 USD, while the maximum cost increase was 17,370 USD, with an average of USD 6004.

The risk factors related to fixed costs are presented in Figure 3. The current research used a sensitivity analysis to determine which risk factors were most relevant to the objectives of the project phases. The analysis resulted in a sensitivity diagram illustrating the critical risk factors' impacts and quantifying the correlations between changes in project outcomes and input elements. The sensitivity chart shows the relations as correlation coefficients or percentages. The most critical factors are at the top of the diagram, the least critical at the bottom, and the direction of the bar indicates whether the correlation is direct or inverse [65]. Thus, the sensitivity analysis facilitates focusing on the model's critical risk factors and considering them when estimating the probability of threats [71]. The sensitivity analysis in Figure 3 shows that the impact of material risk factors, namely, SE1 and SJ1 (unavailability of materials) and (K1) physical or chemical failure of materials, had the most significant impacts (0.745, 0.416, and 0.261) on the cost of the phase.

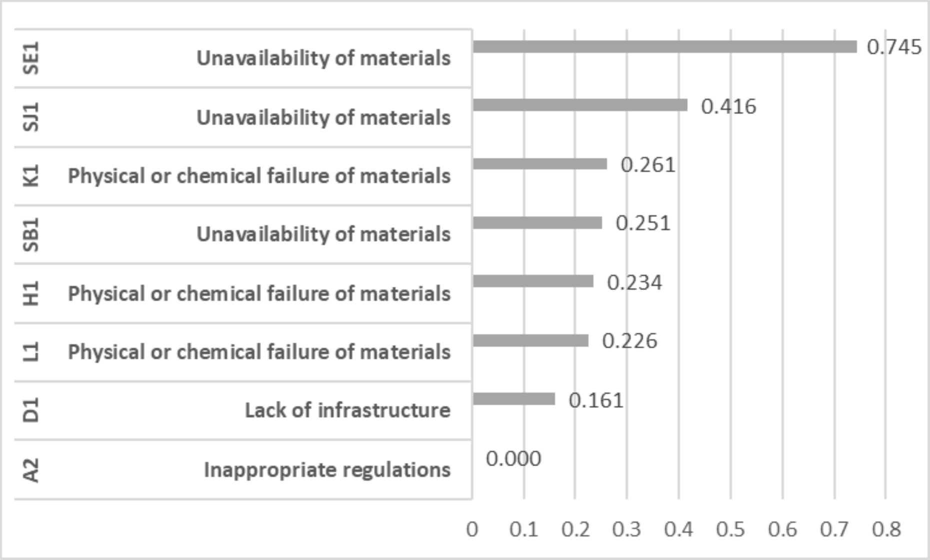

Figure 3. Sensitivity chart of costs (fixed cost increases).

Table 9 summarizes the MCS results of environmental effects. Among the typical risk factors, C1 and D1 correlated with only two adverse impacts, while H1 and K1 influenced almost all effects except duration. Six of the seven typical risk factors influenced solid waste and air pollution increased. The increase in fixed costs was correlated with the fewest factors, namely H1, K1, and L1. Table 9 shows that all correlation coefficients for the effects of the typical risk factors were less than 0.5, which may indicate that the conventional risk factors had less impact on project outcomes than the unknown risk factors arising from relatively new construction practices. The most sensitive environmental impacts from typical risk factors were an increase in water consumption with two risk factors, D1 (0.466), lack of infrastructure, and an increase in solid waste with H1 (0.427). None of the typical risk factors affected the duration of the construction phase.

Table 9. Summary results of typical risk factors.

Risk ID	Duration	Fixed Cost Increase	Air Pollution Increase	Water Pollution Increase	Water Consumption Increase	Solid Waste Increase
A2				0.255	0.180	0.318
C1			0.390			0.240
D1		0.161	0.218		0.466	
G1			0.400	0.317	0.446	0.168
H1		0.234	0.180	0.275	0.315	0.427
K1		0.261	0.199	0.211	0.262	0.243
L1		0.226	0.260			0.355

Table 10 shows the impacts of the sustainability risk factors examined. Increased water pollution correlated with the most sustainability-related risk factors. However, the risk factor with the highest impact on the five dimensions was SO1 (equipment breakdown). In addition, this factor was the most substantial for the duration, increase in air pollution, water pollution, water consumption, and solid waste, with significant coefficients of 0.596, 0.402, 0.744, 0.463, and 0.457, respectively. On the other hand, the cost overrun of the construction phase was highly correlated with the risk factor SE1 (unavailability of materials for concrete skirting), with a coefficient of 0.745.

Table 10. Summary results of sustainability-related risk factors.

Risk ID	Duration	Fixed Cost Increase	Air Pollution Increase	Water Pollution Increase	Water Consumption Increase	Solid Waste Increase
SB1		0.251		0.164	0.317	0.163
SE1		0.745	0.319			
SF1			0.298	0.188		
SI1				0.377	0.271	0.212
SJ1		0.416	0.353			0.392
SO1	0.596		0.402	0.744	0.463	0.457
SP1	0.404			0.161	0.198	

5. Discussion

This paper analyses the impacts of construction activities from both resource and environmental perspectives in a sustainable construction project, where appropriate resource utilization and minimal adverse environmental impacts are crucial for project implementation. The main objective of the study was to propose an efficient process for analyzing the risks of sustainable construction projects to support the project team in decision-making.

This study proposed a hybrid approach using AHP, EMC methods, and Monte Carlo simulation to estimate the delay risks of a specific construction project. Based on the results obtained, applying a comprehensive sensitivity analysis can significantly reduce the expected actual project completion time. The current approach helps managers to make informed decisions on budget allocation and the application of emerging risks (material, energy, ecological) and their impact on the project. In addition, the current framework can provide a basis for agile project management to reduce time, and related uncertainties and more efficient usage of increasingly scarce resources.

Primarily, environmental impact dimensions were considered for the risk factors of each construction activity to analyze project outcomes such as duration, costs, and environmental impacts. The analytic hierarchy process (AHP) was used to assess the weights of identified indicators and rankings. The AHP method successfully quantifies expert knowledge and experience with current risk assessment and prioritization of global challenges. The advantage of AHP is that it can consider the relative priorities of risk factors or alternatives. The current study has found that air pollution, water consumption, water pollution, land pollution, and solid waste are the most crucial indicators, and the least are energy consumption and noise pollution.

In contrast to previous approaches, we took the advantages of the MCS and EMV methods (combined to reduce the uncertainty of the results) in order to explore the relationship between environmental issues and the expected amounts of money to be spent. In addition, to highlight the importance of implementing sustainable practices in construction projects, the current research classified the risk factors of each construction activity into typical and sustainability-related risk factors that affect project success.

Another important finding was that the most sensitive environmental impacts from typical risk factors were an increase in water consumption with a lack of infrastructure and an increase in solid waste. The study's findings are consistent with those of Hwang et al. (2017) [55]. They also found that the impact of sustainable risk factors, e.g., unavailability of materials, had the most significant impact on the cost of the construction phase. The sensitivity analysis has shown that the equipment breakdown risk factor had the highest impact on the duration and crucial environmental impact dimensions, such as an increase in air pollution, water pollution, water consumption, and solid waste.

Likewise, the simulation results revealed that the riskiest activities could cause a 20-day variation in the overall phase duration of the construction. In addition, considering the risk factors of the activities in the construction phase, there is a probability of almost 80% that the project phase will not be completed.

The study suggests that construction activities should pay attention to sustainability risk factors, not only because they are strongly correlated with project duration, costs, and environmental performances but also because incorporating sustainable practices into construction projects is novel, and project team members and managers need to learn to adopt such practices continuously. Obtaining and quantifying adequate and reliable data to assess the environmental sustainability of construction projects is a challenge, which results in sustainable construction projects being managed under uncertain conditions.

Several limitations of the study must be acknowledged. Due to the use of RiskyProject software, the various environmental impacts could not be applied and evaluated. Although each environmental impact is categorized as 'Environment', the software does not calculate them simultaneously but estimates a random combination of them. As a result, different impact categories were used in the current research to obtain accurate results for each environmental impact caused by risk factors associated with construction activities. In addition, as data on 'land pollution' could not be collected, only four environmental impact indicators were used for the risk analysis. However, experts cannot correct possible irregularities because the respondents' final percentage weights are unknown. In addition, inconsistencies between human judgments may occur when several criteria must be considered simultaneously [85].

Another major limitation of the study is the time horizon of the collected data, which did not consider the pandemic's economic and social risks, energy security issues, and war conflicts. In general, the risk factors considered were assumed to be independent, which seems an acceptable simplification given the complexity of the interdependence of crucial risks. The current study examined only one case in Hungary and the results are limited by the lack of universality of the AHP analysis. Every country is affected by climate change in different ways, and construction projects adapt to the impacts very differently. One environmental consequence of global warming is an increase in the number of natural disasters, such as extreme and frequent floods, forest fires, storms, droughts, or heat waves [86]. Consequently, sustainable approaches to assessing and planning the impacts of climate change on projects require a thorough comparison.

However, the proposed process focused solely on risk-based analysis without considering possible mitigation plans and strategies. The findings have important implications for developing the most critical environmental indicators and the proposed process at the design stage. Any construction project team will be able to develop such plans and strategies to achieve the sustainable objectives of the project. The empirical assessment of sustainable project design in construction projects should also be developed from sustainability goals. These can be supported by sustainable supply chain tools, integrated green building methods, and lean processes. These strategies consider the whole life cycle of projects to ensure positive impacts on the environment, society, and the economy, which is the future trend in sustainable project management and the industrial revolution.

Future research could be extended to investigate whether social, resource, and environmental dimensions can be adequately integrated into the risk analysis of sustainable construction projects. Although the Industrial Revolution (5IR) will not radically change the traditional functions of project management, the sustainable, human-centered, and resilient aspects may differ from those used in the past [87]. More attention should be paid to decarbonization and other critical issues, e.g., green energy consumption, taxes, political risks, and environmental technologies [88].

Author Contributions: Conceptualization, N.E.; methodology, B.K.; software, N.E.; validation, N.E. and D.M.; data curation, B.K.; writing—original draft preparation, N.E.; writing—review and editing, D.M.; visualization, N.E.; supervision, B.K.; funding acquisition, D.M. All authors have read and agreed to the published version of the manuscript.

Funding: The APC was funded by the ÚNKP-22-5-DE-406 New National Excellence Program of the Ministry for Innovation and Technology from the source of the National Research, Development and Innovation Fund, Hungary.

Data Availability Statement: Not applicable.

Acknowledgments: This work was supported by the János Bolyai Research Scholarship of the Hungarian Academy of Sciences. This research was supported by the ÚNKP-22-5-DE-406 New National Excellence Program of the Ministry for Innovation and Technology from the source of the National Research, Development and Innovation Fund.

Conflicts of Interest: The authors declare no conflict of interest.

References

1. Vogt, M.; Weber, C. Current Challenges to the Concept of Sustainability. *Glob. Sustain.* **2019**, *2*, e4. [CrossRef]
2. Bonoli, A.; Zanni, S.; Serrano-Bernardo, F. Sustainability in Building and Construction within the Framework of Circular Cities and European New Green Deal. The Contribution of Concrete Recycling. *Sustainability* **2021**, *13*, 2139. [CrossRef]
3. United Nations Department of Economic and Social Affairs. *Global Population Growth and Sustainable Development*; United Nations Department of Economic and Social Affairs: New York, NY, USA; Washington, DC, USA, 2021.
4. Rees, W.E. The Built Environment and the Ecosphere: A Global Perspective. *Build. Res. Inf.* **2010**, *27*, 206–220. [CrossRef]
5. Mariño, R.; Singh Banga, R. UN Sustainable Development Goals (SDGs): A Time to Act. *J. Oral Res.* **2016**, *5*, 5–6. [CrossRef]
6. Nguyen, H.D.; Macchion, L. *Risk Management in Green Building: A Review of the Current State of Research and Future Directions*; Springer: Dordrecht, The Netherlands, 2022; ISBN 0123456789.
7. Rosati, F.; Faria, L.G.D. Addressing the SDGs in Sustainability Reports: The Relationship with Institutional Factors. *J. Clean. Prod.* **2019**, *215*, 1312–1326. [CrossRef]
8. Ali, H.H.; Al Nsairat, S.F. Developing a Green Building Assessment Tool for Developing Countries—Case of Jordan. *Build. Environ.* **2009**, *44*, 1053–1064. [CrossRef]
9. De Azevedo, A.R.G.; Alexandre, J.; Marvila, M.T.; de Xavier, G.C.; Monteiro, S.N.; Pedroti, L.G. Technological and Environmental Comparative of the Processing of Primary Sludge Waste from Paper Industry for Mortar. *J. Clean. Prod.* **2020**, *249*, 119336. [CrossRef]
10. Zea-Escamilla, E.; Habert, G. Environmental Impacts of Bamboo-Based Construction Materials Representing Global Production Diversity. *J. Clean. Prod.* **2014**, *69*, 117–127. [CrossRef]
11. Stanitsas, M.; Kirytopoulos, K.; Leopoulos, V. Integrating Sustainability Indicators into Project Management: The Case of Construction Industry. *J. Clean. Prod.* **2021**, *279*, 123774. [CrossRef]
12. De la Cruz López, M.P.; Cartelle Barros, J.J.; del Caño Gochi, A.; Lara Coira, M. New Approach for Managing Sustainability in Projects. *Sustainability* **2021**, *13*, 7037. [CrossRef]
13. Díaz López, C.; Carpio, M.; Martín-Morales, M.; Zamorano, M. A Comparative Analysis of Sustainable Building Assessment Methods. *Sustain. Cities Soc.* **2019**, *49*, 101611. [CrossRef]

14. Taylor, P.; Morgan, R.K. Sustainability Assessment: The State of the Art, Impact Assessment and Project Proposal. *Impact Assess. Proj. Apprais.* **2012**, *30*, 37–41. [CrossRef]
15. Kamali, M.; Hewage, K.; Milani, A.S. Life Cycle Sustainability Performance Assessment Framework for Residential Modular Buildings: Aggregated Sustainability Indices. *Build. Environ.* **2018**, *138*, 21–41. [CrossRef]
16. Banihashemi, S.A.; Khalilzadeh, M.; Zavadskas, E.K.; Antucheviciene, J. Investigating the Environmental Impacts of Construction Projects in Time-Cost Trade-off Project Scheduling Problems with Cocoso Multi-Criteria Decision-Making Method. *Sustainability* **2021**, *13*, 10922. [CrossRef]
17. Maslesa, E.; Jensen, P.A.; Birkved, M. Indicators for Quantifying Environmental Building Performance: A Systematic Literature Review. *J. Build. Eng.* **2018**, *19*, 552–560. [CrossRef]
18. Agyekum, K.; Botchway, S.Y.; Adinyira, E.; Opoku, A. Environmental Performance Indicators for Assessing Sustainability of Projects in the Ghanaian Construction Industry. *Smart Sustain. Built Environ.* **2021**, *108*, 104388. [CrossRef]
19. Tupenaite, L.; Lill, I.; Geipele, I.; Naimaviciene, J. Ranking of Sustainability Indicators for Assessment of the New Housing Development Projects: Case of the Baltic States. *Resources* **2017**, *6*, 55. [CrossRef]
20. Ameen, R.F.M.; Mourshed, M. Urban Sustainability Assessment Framework Development: The Ranking and Weighting of Sustainability Indicators Using Analytic Hierarchy Process. *Sustain. Cities Soc.* **2019**, *44*, 356–366. [CrossRef]
21. Khanzadi, M.; Sheikhkhoshkar, M.; Banihashemi, S. BIM Applications toward Key Performance Indicators of Construction Projects in Iran. *Int. J. Constr. Manag.* **2020**, *20*, 305–320. [CrossRef]
22. Qazi, A.; Shamayleh, A.; El-Sayegh, S.; Formaneck, S. Prioritizing Risks in Sustainable Construction Projects Using a Risk Matrix-Based Monte Carlo Simulation Approach. *Sustain. Cities Soc.* **2021**, *65*, 102576. [CrossRef]
23. Kuhlman, T.; Farrington, J. What Is Sustainability? *Sustainability* **2010**, *2*, 3436–3448. [CrossRef]
24. Backes, J.G.; Traverso, M. Application of Life Cycle Sustainability Assessment in the Construction Sector: A Systematic Literature Review. *Processes* **2021**, *9*, 1248. [CrossRef]
25. Daily, B.F.; Huang, S.C. Achieving Sustainability through Attention to Human Resource Factors in Environmental Management. *Int. J. Oper. Prod. Manag.* **2001**, *21*, 1539–1552. [CrossRef]
26. Glavič, P.; Lukman, R. Review of Sustainability Terms and Their Definitions. *J. Clean. Prod.* **2007**, *15*, 1875–1885. [CrossRef]
27. Daly, H.E. Georgescu-Roegen versus Solow/Stiglitz. *Ecol. Econ.* **1997**, *22*, 261–266. [CrossRef]
28. Gervásio, H.; Simões Da Silva, L. A Probabilistic Decision-Making Approach for the Sustainable Assessment of Infrastructures. *Expert. Syst. Appl.* **2012**, *39*, 7121–7131. [CrossRef]
29. Haller, C.R. Sustainability and Sustainable Development. In *Topic-Driven Environmental Rhetoric*; Routledge: London, UK, 2018; pp. 213–233. [CrossRef]
30. Allen, C.; Metternicht, G.; Wiedmann, T. National Pathways to the Sustainable Development Goals (SDGs): A Comparative Review of Scenario Modelling Tools. *Environ. Sci. Policy* **2016**, *66*, 199–207. [CrossRef]
31. Hopwood, B.; Mellor, M.; O'Brien, G. Sustainable Development: Mapping Different Approaches. *Sustain. Dev.* **2005**, *13*, 38–52. [CrossRef]
32. Stock, T.; Obenaus, M.; Slaymaker, A.; Seliger, G. A Model for the Development of Sustainable Innovations for the Early Phase of the Innovation Process. *Procedia Manuf.* **2017**, *8*, 215–222. [CrossRef]
33. United Nations General Assembly. *Report of the World Commission on Environment and Development: Our Common Future Towards Sustainable Development*; United Nations General Assembly: Brussels, Belgium, 1987.
34. Eisenmenger, N.; Pichler, M.; Krenmayr, N.; Noll, D.; Plank, B.; Schalmann, E.; Wandl, M.-T.; Gingrich, S. The Sustainable Development Goals Prioritize Economic Growth over Sustainable Resource Use: A Critical Reflection on the SDGs from a Socio-Ecological Perspective. *Sustain. Sci.* **2020**, *15*, 1101–1110. [CrossRef]
35. Catalina Turcu Re-Thinking Sustainability Indicators: Local Perspectives of Urban Sustainability. *J. Environ. Plan. Manag.* **2013**, *56*, 695–719. [CrossRef]
36. Conte, E. The Era of Sustainability: Promises, Pitfalls and Prospects for Sustainable Buildings and the Built Environment. *Sustainability* **2018**, *10*, 2092. [CrossRef]
37. Yılmaz, M.; Bakış, A. Sustainability in Construction Sector. *Procedia Soc. Behav. Sci.* **2015**, *195*, 2253–2262. [CrossRef]
38. Du Plessis, C.; Cole, R.J. Motivating Change: Shifting the Paradigm. *Build. Res. Inf.* **2011**, *39*, 436–449. [CrossRef]
39. Mavi, R.K.; Gengatharen, D.; Mavi, N.K.; Hughes, R.; Campbell, A.; Yates, R. Sustainability in Construction Projects: A Systematic Literature Review. *Sustainability* **2021**, *13*, 1932. [CrossRef]
40. Nair, A.; Nayar, S.K. Key Performance Indicators of Sustainability. In Proceedings of the IOP Conference Series: Earth and Environmental Science, Changsha, China, 18–20 September 2020; Volume 491. [CrossRef]
41. Lima, L.; Trindade, E.; Alencar, L.; Alencar, M.; Silva, L. Sustainability in the Construction Industry: A Systematic Review of the Literature. *J. Clean. Prod.* **2021**, *289*, 125730. [CrossRef]
42. Silvius, A.J.G.; Schipper, R.P.J. Sustainability in Project Management: A Literature Review and Impact Analysis. *Soc. Bus.* **2014**, *4*, 63–96. [CrossRef]
43. Marcelino-Sádaba, S.; González-Jaen, L.F.; Pérez-Ezcurdia, A. Using Project Management as a Way to Sustainability. from a Comprehensive Review to a Framework Definition. *J. Clean. Prod.* **2015**, *99*, 1–16. [CrossRef]
44. Sfakianaki, E. Critical Success Factors for Sustainable Construction: A Literature Review. *Manag. Environ. Qual. Int. J.* **2019**, *30*, 176–196. [CrossRef]

45. Song, Y.; Zhang, H. Research on Sustainability of Building Materials. In *IOP Conference Series: Materials Science and Engineering*; IOP Publishing: Bristol, UK, 2018; Volume 452, p. 022169. [CrossRef]
46. Carvalho, A.; de Castro Xavier, G.; Alexandre, J.; Pedroti, L.G.; de Azevedo, A.R.G.; Vieira, C.M.F.; Monteiro, S.N. Environmental Durability of Soil-Cement Block Incorporated with Ornamental Stone Waste. *Mater. Sci. Forum* **2014**, *798–799*, 548–553. [CrossRef]
47. Tutu, K.A.; Tuffour, Y.A. Warm-Mix Asphalt and Pavement Sustainability: A Review. *Open J. Civ. Eng.* **2016**, *6*, 84–93. [CrossRef]
48. Enshassi, A.; Kochendoerfer, B.; Rizq, E. Evaluación de Los Impactos Medioambientales de Los Proyectos de Construcción. *Rev. Ing. Construcción* **2014**, *29*, 234–254. [CrossRef]
49. Wu, G.; Qiang, G.; Zuo, J.; Zhao, X.; Chang, R. What Are the Key Indicators of Mega Sustainable Construction Projects?—A Stakeholder-Network Perspective. *Sustainability* **2018**, *10*, 2939. [CrossRef]
50. Azhar, S.; Carlton, W.A.; Olsen, D.; Ahmad, I. Building Information Modeling for Sustainable Design and LEED® Rating Analysis. *Autom. Constr.* **2011**, *20*, 217–224. [CrossRef]
51. Mardani, A.; Jusoh, A.; Nor, K.M.D.; Khalifah, Z.; Zakwan, N.; Valipour, A. Multiple Criteria Decision-Making Techniques and Their Applications—A Review of the Literature from 2000 to 2014. *Econ. Res. Ekon. Istraz.* **2015**, *28*, 516–571. [CrossRef]
52. Nguyen, H.D.; Do, Q.N.; Macchion, L. Assessing Risk Factors in the Implementation of Green Building Projects: Empirical Research from Vietnam. In Proceedings of the Asia Conference on Environment and Sustainable Development, Kyoto, Japan, 4–6 November 2022; Keiji, U., Ishiwatari, M., van Hullebusch, E., Eds.; Springer: Singapore, 2022; pp. 261–271.
53. Sudmeier-Rieux, K.; Arce-Mojica, T.; Boehmer, H.J.; Doswald, N.; Emerton, L.; Friess, D.A.; Galvin, S.; Hagenlocher, M.; James, H.; Laban, P.; et al. Scientific Evidence for Ecosystem-Based Disaster Risk Reduction. *Nat. Sustain.* **2021**, *4*, 803–810. [CrossRef]
54. Sobieraj, J.; Metelski, D. Project Risk in the Context of Construction Schedules—Combined Monte Carlo Simulation and Time at Risk (TaR) Approach: Insights from the Fort Bema Housing Estate Complex. *Appl. Sci.* **2022**, *12*, 1044. [CrossRef]
55. Hwang, B.G.; Shan, M.; Phua, H.; Chi, S. An Exploratory Analysis of Risks in Green Residential Building Construction Projects: The Case of Singapore. *Sustainability* **2017**, *9*, 1116. [CrossRef]
56. Guan, L.; Abbasi, A.; Ryan, M.J. Analyzing Green Building Project Risk Interdependencies Using Interpretive Structural Modeling. *J. Clean. Prod.* **2020**, *256*, 120372. [CrossRef]
57. Eskander, R.F.A. Risk Assessment Influencing Factors for Arabian Construction Projects Using Analytic Hierarchy Process. *Alex. Eng. J.* **2018**, *57*, 4207–4218. [CrossRef]
58. Issa, U.H.; Marouf, K.G.; Faheem, H. Analysis of Risk Factors Affecting the Main Execution Activities of Roadways Construction Projects. *J. King Saud Univ. Eng. Sci.* 2021, *in press*. [CrossRef]
59. Goel, A.; Ganesh, L.S.; Kaur, A. Sustainability Integration in the Management of Construction Projects: A Morphological Analysis of over Two Decades' Research Literature. *J. Clean. Prod.* **2019**, *236*, 117676. [CrossRef]
60. Javed, N.; Thaheem, M.J.; Bakhtawar, B.; Nasir, A.R.; Khan, K.I.A.; Gabriel, H.F. Managing Risk in Green Building Projects: Toward a Dedicated Framework. *Smart Sustain. Built Environ.* **2020**, *9*, 156–173. [CrossRef]
61. Koulinas, G.K.; Xanthopoulos, A.S.; Sidas, K.A.; Koulouriotis, D.E. Risks Ranking in a Desalination Plant Construction Project with a Hybrid AHP, Risk Matrix, and Simulation-Based Approach. *Water Resour. Manag.* **2021**, *35*, 3221–3233. [CrossRef]
62. Aarthipriya, V.; Chitra, G.; Poomozhi, J.S. Risk and Its Impacts on Time and Cost in Construction Projects. *J. Proj. Manag.* **2020**, *5*, 245–254. [CrossRef]
63. Spanidis, P.M.; Roumpos, C.; Pavloudakis, F. A Fuzzy-Ahp Methodology for Planning the Risk Management of Natural Hazards in Surface Mining Projects. *Sustainability* **2021**, *13*, 2369. [CrossRef]
64. Larionov, A.; Nezhnikova, E.; Smirnova, E. Risk Assessment Models to Improve Environmental Safety in the Field of the Economy and Organization of Construction: A Case Study of Russia. *Sustainability* **2021**, *13*, 13539. [CrossRef]
65. Smirnova, E. The Use of the Monte Carlo Method for Predicting Environmental Risk in Construction Zones. *J. Phys. Conf. Ser.* **2020**, *1614*, 012083. [CrossRef]
66. Afzal, F.; Yunfei, S.; Junaid, D.; Hanif, M.S. Cost-Risk Contingency Framework for Managing Cost Overrun in Metropolitan Projects: Using Fuzzy-AHP and Simulation. *Int. J. Manag. Proj. Bus.* **2020**, *13*, 1121–1139. [CrossRef]
67. Darko, A.; Chan, A.P.C.; Ameyaw, E.E.; Owusu, E.K.; Pärn, E.; Edwards, D.J. Review of Application of Analytic Hierarchy Process (AHP) in Construction. *Int. J. Constr. Manag.* **2019**, *19*, 436–452. [CrossRef]
68. Saaty, R.W. The Analytic Hierarchy Process-What It Is and How It Is Used. *Math. Model.* **1987**, *9*, 161–176. [CrossRef]
69. Kara, Y. Measuring the Sustainability of Cities in Turkey with the Analytic Hierarchy Process. *Open J. Soc. Sci.* **2019**, *7*, 322–334. [CrossRef]
70. Abusalem, O.; Bertalan, N.; Kocsi, B. Implementing Quantitative Techniques to Improve Decision Making in Construction Projects: A Case Study. *Pollack Period.* **2019**, *14*, 223–234. [CrossRef]
71. Diamantas, V.K.; Kirytopoulos, K.A.; Leopoulos, V.N. Project's Duration Prediction: Traditional Tools or Simulation? *World Rev. Entrep. Manag. Sustain. Dev.* **2007**, *3*, 317–333. [CrossRef]
72. Golenko-Ginzburg, D. On the Distribution of Activity Time in PERT. *J. Oper. Res. Soc.* **2017**, *39*, 767–771. [CrossRef]
73. Shrestha, K.K.; Kayastha, R. Beta Distribution for Estimating Risk Associated Time Schedule of Hydropower Projects in Nepal. *Nepal. J. Stat.* **2021**, *5*, 67–78. [CrossRef]
74. ALwaer, H.; Clements-Croome, D.J. Key Performance Indicators (KPIs) and Priority Setting in Using the Multi-Attribute Approach for Assessing Sustainable Intelligent Buildings. *Build. Environ.* **2010**, *45*, 799–807. [CrossRef]

75. Carvalho, J.P.; Bragança, L.; Mateus, R. Optimising Building Sustainability Assessment Using BIM. *Autom. Constr.* **2019**, *102*, 170–182. [CrossRef]
76. Yu, W.; Cheng, S.; Ho, W.; Chang, Y. Measuring the Sustainability of Construction Projects throughout Their Lifecycle: A Taiwan Lesson. *Sustainability* **2018**, *10*, 1523. [CrossRef]
77. Banihashemi, S.A.; Khalilzadeh, M.; Shahraki, A.; Malkhalifeh, M.R.; Ahmadizadeh, S.S.R. Optimization of Environmental Impacts of Construction Projects: A Time–Cost–Quality Trade-off Approach. *Int. J. Environ. Sci. Technol.* **2021**, *18*, 631–646. [CrossRef]
78. Gangolells, M.; Casals, M.; Gassó, S.; Forcada, N.; Roca, X.; Fuertes, A. A Methodology for Predicting the Severity of Environmental Impacts Related to the Construction Process of Residential Buildings. *Build. Environ.* **2009**, *44*, 558–571. [CrossRef]
79. Dong, Y.H.; Ng, S.T. A Life Cycle Assessment Model for Evaluating the Environmental Impacts of Building Construction in Hong Kong. *Build. Environ.* **2015**, *89*, 183–191. [CrossRef]
80. Kaya, T.; Kahraman, C. An Integrated Fuzzy AHP-ELECTRE Methodology for Environmental Impact Assessment. *Expert. Syst. Appl.* **2011**, *38*, 8553–8562. [CrossRef]
81. Wibowo, A.; Alfen, H.W. Identifying Macro-Environmental Critical Success Factors and Key Areas for Improvement to Promote Public-Private Partnerships in Infrastructure: Indonesia's Perspective. *Eng. Constr. Archit. Manag.* **2014**, *21*, 383–402. [CrossRef]
82. Ijigah, E.A.; Jimoh, R.A.; Aruleba, B.O.; Ade, A.B. An Assessment of Environmental Impacts of Building Construction Projects. *Civ. Environ. Res.* **2013**, *3*, 93–105.
83. *Microsoft Project Management Software | Microsoft Project*; Microsoft: Redmond, WA, USA, 2022.
84. *Intaver Institute Risky Project Software*, Version 7.2; Intaver: Naples, FL, USA, 2022.
85. Cinelli, M.; Kadziński, M.; Gonzalez, M.; Słowiński, R. How to Support the Application of Multiple Criteria Decision Analysis? Let Us Start with a Comprehensive Taxonomy. *Omega* **2020**, *96*, 102261. [CrossRef]
86. Klingelhöfer, D.; Müller, R.; Braun, M.; Brüggmann, D.; Groneberg, D.A. Climate Change: Does International Research Fulfill Global Demands and Necessities? *Environ. Sci. Eur.* **2020**, *32*, 137. [CrossRef]
87. Török, L. Industry 4.0 from a Few Aspects, in Particular in Respect of the Decision Making of the Management: Will the New Industrial Revolution Change the Traditional Management Functions? *Int. Rev. Appl. Sci. Eng.* **2020**, *11*, 140–146. [CrossRef]
88. Peng, G.; Meng, F.; Ahmed, Z.; Oláh, J.; Harsányi, E. A Path Towards Green Revolution: How Do Environmental Technologies, Political Risk, and Environmental Taxes Influence Green Energy Consumption? *Front. Environ. Sci.* **2022**, *10*, 927333. [CrossRef]