sustainability

Article

Scientometric Analysis and AHP for Hierarchizing Criteria Affecting Construction Equipment Operators' Performance

Kleopatra Petroutsatou *, Ilias Ladopoulos and Konstantina Tsakelidou

Faculty of Engineering, Department of Civil Engineering, Aristotle University of Thessaloniki, 54124 Thessaloniki, Greece; iladopou@civil.auth.gr (I.L.); ktsakelid@civil.auth.gr (K.T.)
* Correspondence: kpetrout@civil.auth.gr

Abstract: The construction sector constitutes a significant indicator of a country's economic growth. Construction equipment is an integral part of every construction project, and its contribution during construction determines any project's completion. It also represents a significant capital investment for companies in this sector. A major strategic goal for such companies is the increase in the equipment's productivity, which is affected mostly by its operators. The aim of this research is to recognize and prioritize the criteria affecting the performance of construction equipment operators. Scientometric analysis, using VOSViewer software, was implemented for the formation of different kinds of bibliometric networks, proposing a holistic approach to this research field. Those networks delineated the field with regard to construction equipment operators and revealed the correlations between the network's items, which were formed because of previous research, and finally, conclusions were drawn. An extensive literature review in conjunction with structured interviews with experts and operators determined the factors affecting the operators' performance, with a view to creating a hybrid decision model based on the Analytical Hierarchy Process (AHP), as implemented by the Transparent Choice tool. Many experts evaluated the criteria affecting the operators' performance, leading to remarkable conclusions. Moreover, a few pointers for future research are provided.

Keywords: construction equipment; analytic hierarchy process (AHP); scientometric analysis; productivity; operator

Citation: Petroutsatou, K.; Ladopoulos, I.; Tsakelidou, K. Scientometric Analysis and AHP for Hierarchizing Criteria Affecting Construction Equipment Operators' Performance. *Sustainability* **2022**, *14*, 6836. https://doi.org/10.3390/su14116836

Academic Editors: Srinath Perera, Albert P. C. Chan, Xiaohua Jin, Dilanthi Amaratunga, Makarand Hastak, Patrizia Lombardi, Sepani Senaratne and Anil Sawhney

Received: 14 April 2022
Accepted: 27 May 2022
Published: 2 June 2022

1. Introduction

Construction projects are currently prevailing in every aspect of human life, with the goal of improving the quality of people's lives. As clearly is defined in the European Commission (2012) Road Transport Report, their standards are strictly specified so that they will eventually correspond to the demanding reality. Their successful completion relies on successful project management, which must strongly emphasize the efficient utilization of labor, material, and equipment in order to deliver a successful project on time, within the budget, and as per the defined quality standards [1]. Under this framework, the productivity of construction projects was always an issue worth examining [2,3]. Productivity is used to denote a relationship between output and its associated input used in the production system [2]. It depends on a variety of factors, such as construction equipment, which represents a significant capital investment for companies in this sector [3]. Efforts to improve productivity have been made in recent decades, focusing on the most influential factors.

A project's productivity is directly affected by fleet management, which concerns the selection of suitable construction equipment for each task according to its requirements [4]. The fleet and asset management function is responsible for strategic decisions regarding fleet composition, fleet average age, capital expenditure, finance, tax, and return on investment. It uses the data developed in other functions, interfaces with the company strategic planning process, and develops the rates, estimates, budgets, benchmarks, and standards needed to manage the whole process [4]. Nowadays, construction companies are facing multiple difficulties with how to properly and effectively manage their fleet of construction equipment. Fleet management is a feature that allows companies to avoid or minimize the risks associated with investing in equipment, efficiency, productivity, overall transportation costs, and impartial compliance in legislation [5]. On the other hand, low productivity means inefficiency of resources with the inevitable results of cost and time overruns [6,7].

Previous research on construction project productivity primarily focused on the efficiency of construction project delivery and focused on tangible input-output schema within the construction process [8]. Liberda et al. [9] managed to identify the most critical aspects in terms of human, external, and management issues that affect construction productivity. Ghoddousi and Hosseini [10] conducted a survey of the factors affecting the productivity of construction projects in Iran and concluded that the most important grounds affecting sub-contractor productivity include, in descending order: materials/tools, construction technology and method, planning, supervision system, reworks, weather, and jobsite condition. Hasan et al. [11] identified more than 46 articles from different sources concerning the factors affecting construction productivity within the last 30 years. They finally concluded that despite noticeable differences in the socio-economic conditions across both developed and developing countries, an overall reasonable consensus exists on a few of the significant factors impeding productivity.

As Hedman et al. [12] certify, the equipment operators are a crucial factor influencing the duration of the time loss, which refers to planned downtime, setup time, measurement and adjustment, equipment failure, etc. This perspective is strengthened by He et al. [13]; they studied a construction project's resilience (CPR) by measuring specific systemic indicators from the perspective of employee behavior, such as operators.

Moreover, the construction equipment operators' performance is related to their safety preconditions during earthwork, which rely upon the synergy of the work and their interactions with each other and with their supervisors [14].

The basis of this study is set on the criteria affecting the construction equipment operators' performance. Skills and aptitude are also significant factors that are considered to be critical for the performance of earthmoving equipment operators, but they co-exist with more quantitative factors, which are examined in this study. Several studies have highlighted the relationship between aptitude and employee performance. Aptitude is the potential to demonstrate the ability to perform a certain kind of work at a certain level [15]. This research contributes to the body of knowledge by combining those two abilities with other, still untapped, factors. It is agreed that the operators' performance is a mixture of tangible and intangible factors. It is described as their ability to complete their work, fulfilling certain standards, based on the goals or objectives set by their employers [12,13].

In an effort to highlight the effect of the power of equipment operators on the construction project productivity, this study dives deep into the human factors to extract the tangible (or subjective) and intangible (or objective) criteria related to the construction equipment operators' performance in the field. The definition of worker productivity is widely examined. Tangen [16] examined the ways in which the concepts of "productivity" and "performance" are dealt with in the literature, demonstrating that the terms used within these fields are often vaguely defined and poorly understood.

However, performance entails more. It includes their willingness and ability to communicate or collaborate, their promptness, and their demeanor at work. Consequently, the abovementioned factors have a significant impact on the overall performance of the construction project. The expectations and standards set by their supervisors can shape the operators' experience, can affect performance, and can certainly have an impact on their productivity and, ultimately, the project's success. In a nutshell, productivity concentrates on the output, i.e., what is produced, whereas performance is often activity-based and is quantitative or qualitative [17]. Maqsoom et al. [17] realized through their research that worker productivity is critical within construction projects as it is the measure of the rate at which work is performed, and more importantly, it helps to build knowledge on how to motivate the workers to perform at high levels. Much earlier, Navon [18] measured indirect productivity parameters and converted them into sought indicators in order to comprehensively point out the importance of the operator's performance to the project's productivity.

In order to quantify the earthmoving equipment operators' performance factors, this research focuses on identifying and hierarchizing those factors. The necessary data concerning the performance criteria were investigated through: (i) scientometric analysis, (ii) structured interviews with construction equipment experts, and (iii) structured interviews with construction equipment operators. The findings of this research will be beneficial for contractors, project managers, and equipment operators as they reveal the key issues regarding the attitudes and behaviors that play an integral role in enhancing productivity in construction projects [19].

2. Literature Review

This paper conducts a two-step literature review by adopting an interpretivist philosophical approach and inductive reasoning to generate new theories on the phenomena under investigation. In the first step, a scientometric analysis was conducted, as described in Section 2.1, to reveal the necessity of connecting the operator's performance with the construction equipment's productivity. This analysis involves the application of the "science mapping" method, which acts as both a descriptive and a diagnostic tool for research policy purposes, processing immense reservoirs of bibliometric data [20–24].

The second step justifies the criteria selection by looking into the relevant past studies that were extracted by the previous step (Section 2.2). It collects a great amount of related literature from the place where the criteria concerning operator performance are extracted and presented in a comprehensive list. Most importantly, in this section, each selected factor has been scrutinized, with a view to justifying every sub-criterion.

The above process is deemed as necessary in order to form a final criteria and sub-criteria list, as key constituents for the AHP decision tree, presented in Section 3.2.

2.1. Scientometric Analysis

This study goes deep into the published literature to reveal the void regarding the research made on the criteria that affect the construction equipment operators' performance. A scientometric analysis is used to objectively map the scientific knowledge on this specific field and to identify the research themes and the corresponding challenges based on the scientometric results, with the use of the VOSviewer application [20]. In order to create those scientometric networks, a four-step process was followed, as described in Figure 1.

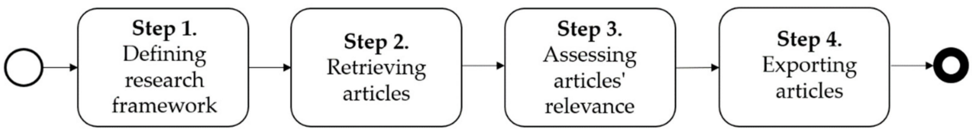

Figure 1. Flowchart of map creation in VOSViewer.

In step one, the research framework is defined, with the intention of recognizing and setting the desired goals. At this point, an initial investigation is conducted to seek the necessary research components by separating the relevant from the irrelevant.

During step two, the articles were retrieved which were closely related to the examined topic. Those articles were extracted by well-recognized bibliographic databases, such as Web of Science and Scopus, covering a period from 2001 to 2021. To identify the relevant publications, search terms were used (Table 1). Figure 2 illustrates the evolution of the research made from 2001, where an increase from 2016 and onwards has been observed. Step three includes a comprehensive relevance assessment of the extracted documents in order to finalize the publications to be inserted for scientometric mapping into VOSViewer and to comment upon the extracted maps.

Table 1. Search Terms in Web of Science and Scopus.

Boolean Operator	Terms	Description
	construction equipment	The term that describes the main topic and the core search rule
OR OR	machinery equipment	Used for searching all machinery- and equipment-based publications, in order to exclude the irrelevant
AND	operator *	Term that specifies the distinctive topic, concerning operators
OR	product *	Term that specifies the distinctive topic, concerning productivity
AND	AHP	The applied Multi-Criteria Decision Analysis (MCDA) method
OR	Analytic * Hierarchy Process	Used to include references for AHP as Analytic or Analytical Hierarchy Process
NOT NOT NOT	medic * Health pharma *	All the terms concerning medical, health, and pharmaceutical issues

The asterisk (*) suggests that it can be replaced by any word or phrase.

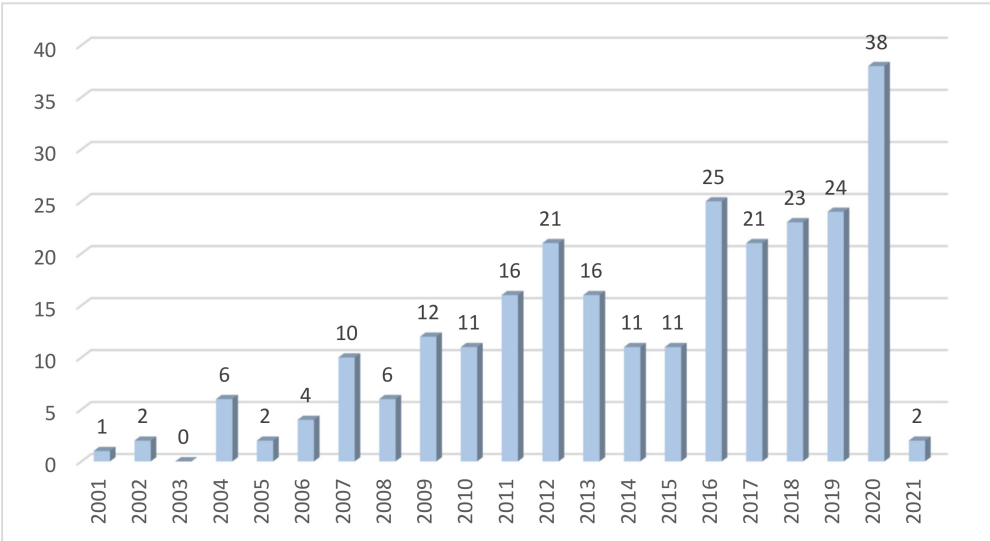

Figure 2. Total Number of Publications Related to Operator Productivity and AHP.

The fourth step of the scientometric mapping process includes the extraction of the selected literature in a recognized form for processing by the VOSViewer application.

Its final product is the production of a comprehensive network comprising the terms which coexist inside the overall publications, where their linkage strength, their appearances, and their relativity are visible, weighted, and clustered. Different clusters are represented by different automatically assigned colors and each color designates a specific research area. The terms inside each cluster are represented by circles, and their size reflects the number of publications in which they were found. The spacing between those circles indicates their relatedness, and their degree of relativity is indicated by the thickness of the curved lines connecting them. The degrees of relatedness between words are indicated by the curved lines.

This paper presents two types of visualization of terms by the VOSViewer network: (a) text data co-occurrence among the titles and their abstracts and (b) keyword co-occurrence. Their visualization networks are presented in Figures 3 and 4, and the produced clusters by subject are in Tables 2 and 3, respectively.

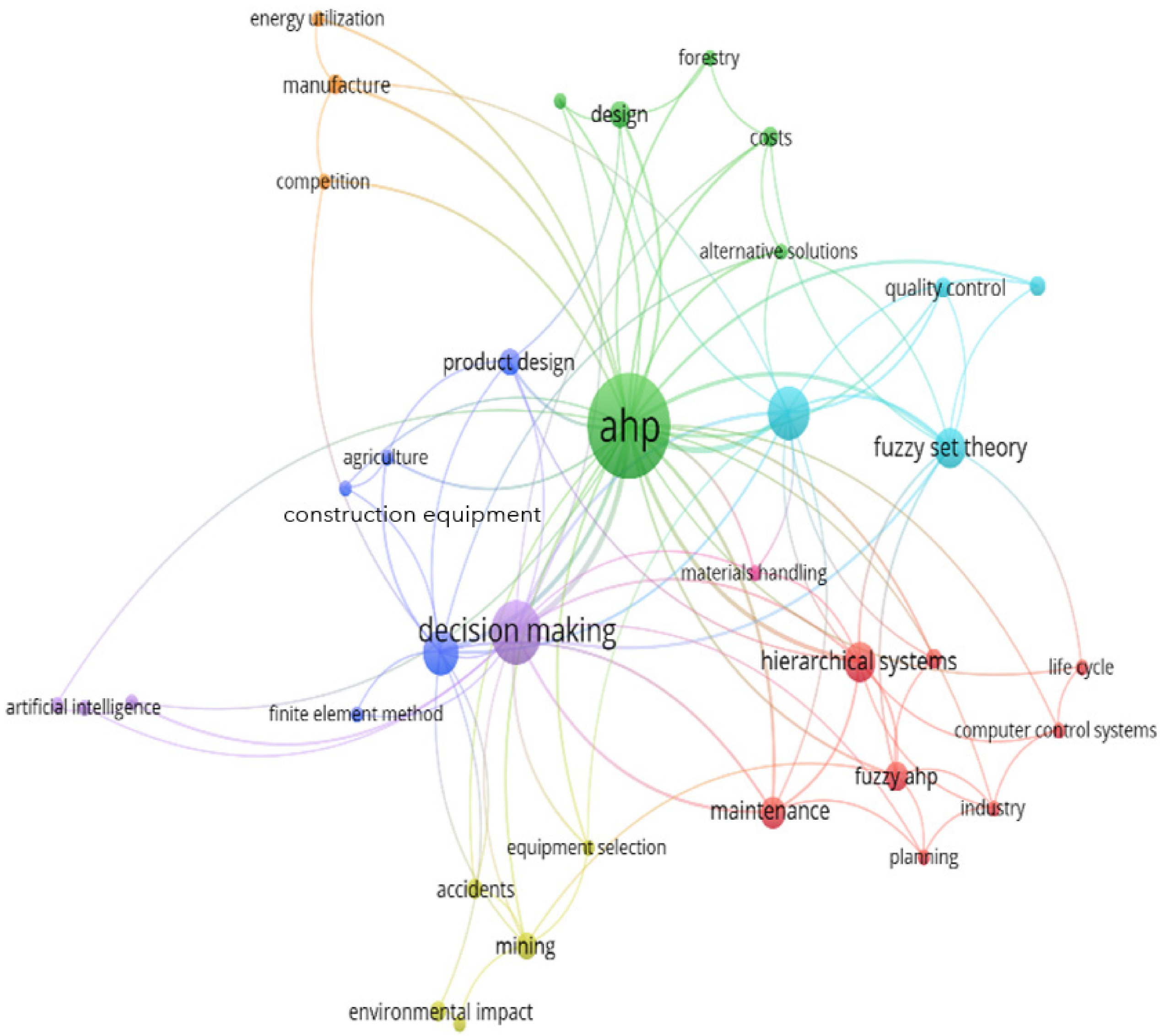

Figure 3. VOSViewer map based on title and abstract text data.

Table 2. Text Data Co-occurrence Clustering.

Cluster Number	Main Subject	Color	Terms Included
1	Hierarchization methods	Red	8
2	AHP	Green	6
3	Equipment	Dark Blue	5
4	Ore mining	Light Green	5
5	Decision Making	Purple	4
6	Construction Equipment	Sky Blue	4
7	Industry	Orange	3
8	Material Handling	Pink	1

Table 3. Keyword Co-occurrence Clustering.

Cluster Number	Main Subject	Color	Terms Included
1	Production	Red	10
2	Decision Making	Green	10
3	AHP Applications	Dark Blue	7
4	Industry	Yellow	7
5	Maintenance	Purple	6
6	Strategy and Indexes	Sky Blue	4
7	Productivity	Orange	3

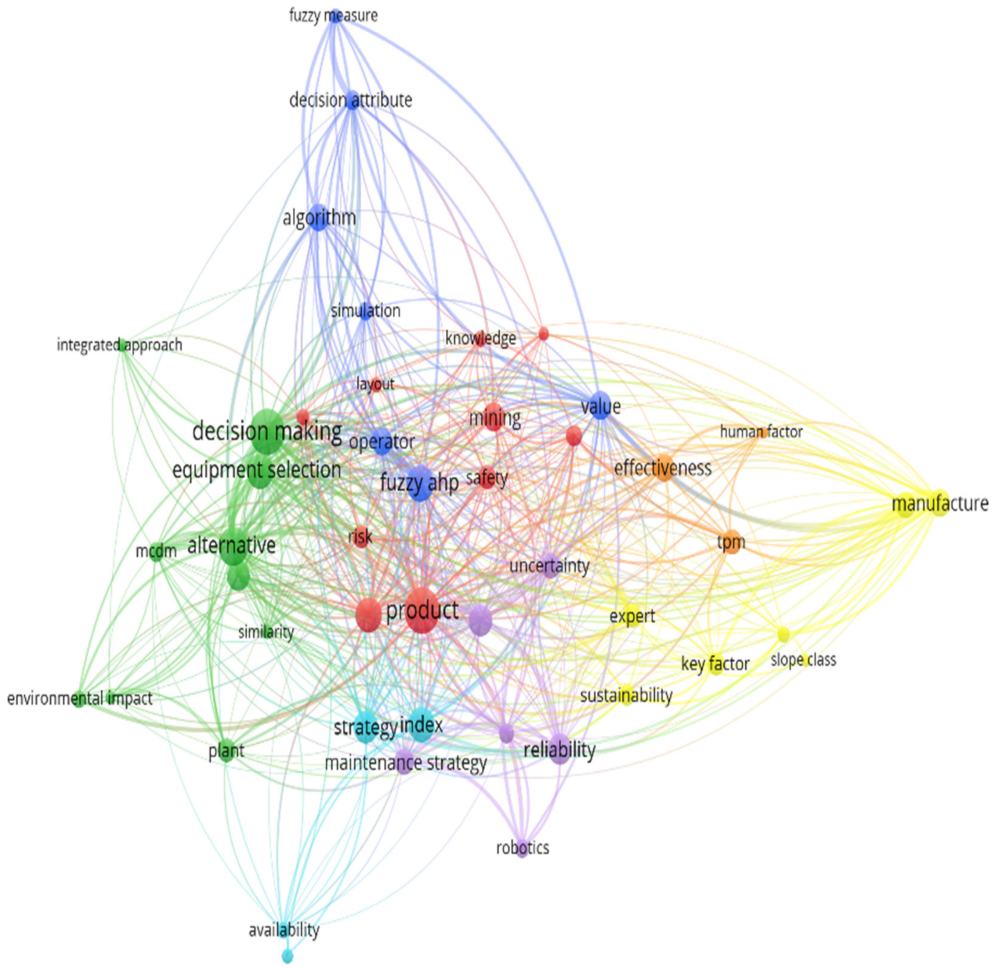

Figure 4. VOSViewer map based on keywords (network visualization).

2.1.1. Text Data Co-Occurrence among the Titles and Their Abstracts

In this scientometric network, “ahp” constitutes a heavily weighted subject in the scientific community, presenting a significant proximity with the “decision making” term, as the AHP is a specific decision-making method. A strong proximity also exists between the ”construction equipment” and the “decision making” terms, a fact that supports the application of the MCDA methods to a variety of the utilization aspects of construction equipment. Nevertheless, the “operator” or “productivity” terms are absent inside the network, while terms such as “maintenance” and “equipment selection” are orbiting and directly linked with the main reference terms of the AHP and decision making. This approach indicates a void in the literature with regard to the discussed topic.

Further scrutinization of the map leads to further implied conclusions:

- The AHP is very popular among several MCDA methods with regard to the use of equipment. The term "equipment" includes construction equipment and general equipment (in industry, agriculture, manufacturing, etc.)
- By the way that the term "decision making" is linked with the other terms, it is related to issues such as maintenance, design, equipment selection, material handling, quality control, etc.
- The absence of the terms "production", "productivity", and "operator" can be explained by the fact that these terms are not defining the titles and the abstracts of the selected publications, which does not necessarily mean that they do not exist inside the rest of these documents.
- The fact that the last four clusters have fewer terms highlights the void inside the literature when it comes to relating construction equipment productivity with decision making in the industry sector and in material handling.

2.1.2. Keyword Co-Occurrence

The analysis based on keywords indicates that the network delineates a strong link between the terms "decision making", "equipment selection", and "mcdm" by including them in the same cluster, indicating that methods such as the AHP are often used for decision making. The terms "operator", "simulation", "decision attribute", and "fuzzy ahp" belong to the same cluster, indicating a sort of correlation. There is also a noticeable proximity between the terms "decision making" and "operator", indicating their strong linkage, even though they do not belong to the same cluster. The term "operator" is also close to "safety", "reliability", "knowledge", and "experience", which are significant factors affecting factors the operator's performance.

Some further implied conclusions from the network visualization analysis are the following:

- The average linkage weight (denser network) among the keywords is much stronger than among the titles and the text data of the abstracts; this is caused by the fact that the keywords are more or less used as common "de facto" terms.
- The clustering terms (visualized by different colors), in this case, are more distinct as their amount is greater, and they are used commonly.
- The term "decision making" is located at a close distance to "equipment selection" and "operator", which clearly indicates the importance of the operator when it comes to selecting the proper equipment for certain projects. Equipment selection includes purchasing and fleet management.
- Additionally, the "operator" is related with "safety", "reliability", "knowledge", and "experience", which are crucial factors for the operator's performance and efficiency.
- The "decision making" cluster (green) lies very close to the "production" (red) and "AHP applications" (dark blue) clusters, indicating their strong relatedness.
- The "productivity" cluster (orange) also includes the "human factor", a term which refers to the operators.
- The "industry" cluster (yellow) is the most distant; however, it includes heavily weighted terms as the construction industry is an essential part of the general term.

2.2. Criteria Selection

According to Atkinson [25], human factors have a clear causal link with machine productivity rates. He also concludes that the production performance of machinery is largely reliant on the operator's skill and competence. Construction equipment operators are frequently called upon to handle difficult and demanding situations, which impacts their performance. The examined literature indicates the main criteria affecting an operator's performance, as depicted in Table 4.

Table 4. Criteria Sourcing.

Criterion	Source
Operator's Competence	
Knowledge/Experience	Holt and Edwards, 2015 [26] Yang, Edwards, and Love, 2004 [27] Dumitrescu and Delsenicu, 2018 [28] Du, Dorneich, and Steward, 2016 [29]
Training/Preparation	Langer et al., 2012 [30] Du, Dorneich, and Steward, 2016 [29] Naskoudakis and Petroutsatou, 2016 [31] Dumitrescu and Delsenicu, 2018 [28]
Motive/Earnings	Yang, Edwards, and Love, 2004 [27] Holt and Edwards, 2015 [26] Dumitrescu and Delsenicu, 2018 [28]
Stress/Fatigue	Yang, Edwards, and Love, 2004 [27] Haggag and Elnahas, 2013 [32]
Relationships and Interaction	
Between employees	Dumitrescu and Delsenicu, 2018 [28]
Between employees and employer	Dumitrescu and Delsenicu, 2018 [28]
Disagreement resolution	Dumitrescu and Delsenicu, 2018 [28]
On-site communication	Beleiu, Crisan, and Nistor, 2015 [33]
Construction Equipment	
Use complexity	Dumitrescu and Delsenicu, 2018 [28]
Maintenance adequacy	Yang, Edwards, and Love, 2004 [27] Cheuk, Leung, and Tse, 2005 [34] Naskoudakis and Petroutsatou, 2016 [31]
Fleet availability	Naskoudakis and Petroutsatou, 2016 [31] Bahnassi and Hammad, 2012 [35]
Innovation/New technologies	Lee et al., 2012 [36] Naskoudakis and Petroutsatou, 2016 [31] Barati and Shen, 2018 [37] Albrektsson and Aslund, 2019 [38]
Task	
Complexity	Dumitrescu and Delsenicu, 2018 [28]
Project demands	Dumitrescu and Delsenicu, 2018 [28]
Timetable	Naskoudakis and Petroutsatou, 2016 [31] Dumitrescu and Delsenicu, 2018 [28]
Daily workload	Yang, Edwards, and Love, 2004 [27] Haggag and Elnahas, 2013 [32]
Natural/Environmental Factors	
Exposure to dust and emissions	Langer et al., 2012 [30] Naskoudakis and Petroutsatou, 2016 [31] Dumitrescu and Delsenicu, 2018 [28] Kokot and Ogierman, 2019 [39]
Weather conditions	Du, Dorneich, and Steward, 2016 [29] Dumitrescu and Delsenicu, 2018 [28]
Soil properties	Du, Dorneich, and Steward, 2016 [29] Barati and Shen, 2018 [37]
Safety conditions	Langer et al., 2012 [30] Naskoudakis and Petroutsatou, 2016 [31] Dumitrescu and Delsenicu, 2018 [28] Kokot and Ogierman, 2019 [39] Petroutsatou and Giannoulis, 2020 [40]
Light conditions and noise levels	Bahnassi and Hammad, 2012 [35] Naskoudakis and Petroutsatou, 2016 [31] Dumitrescu and Delsenicu, 2018 [28]

2.2.1. Operator's Competence

According to Holt and Edwards [26], the operator's competence is the operator's ability to effectively and efficiently apply the machine to the work task. It depends on the knowledge/experience [26] and the preparation/training that an operator has [27]. Motives can also be an additional factor in an employee's productivity levels; this factor is usually linked to earnings and insurance type [28]. Finally, stress and fatigue have been recognized by Haggag and Elnahas [32] as common conditions for operators, drastically affecting their competence.

2.2.2. Relationships and Interactions

The risk related to the labor system may be generated by human resource errors, an inadequate job description, dangerous equipment, improper social relationships between employees, and/or physical/environmental factors [28]. Focusing mostly on the manufacturing technologies, they realized that occupational stress is being enhanced by the new constraints which employees are now obliged to cope with and has also generated the need for organizations to redesign the work environment in order to counteract both the traditional and the emergent risks. According to Beleiu et al. [33], the relationships and interactions between employees, and between employees and their employers, are critical performance factors. In addition, the way a disagreement is resolved affects their performance, but it also depends on how fast it is resolved. They also stressed the importance of on-site communication as a determinant factor in the project's success, so that its efficiency can be supportive to construction equipment operators.

2.2.3. Construction Equipment

The research conducted by Dumitrescu and Delsenicu [28] identified that the equipment's complexity and maintenance adequacy can affect an operator's performance. Naskoudakis and Petroutsatou [31] emphasized the fact that, with regard to equipment development, new methods and designs are implemented to enhance reliability, machine control, comfort, and safety and to reduce the costs derived from failures and breakdowns, signifying the importance of the equipment's innovation as an influential factor. Their literature review also highlighted the importance of fleet management and construction equipment deployment. According to Vorster [4], fleet management should fulfill three overriding and critically important goals directly linked to human factors: (i) the equipment must be in the right place at the right time, (ii) the equipment must achieve the stated levels of reliability and uptime, and (iii) the total owning and operating costs must be kept to a competitive minimum.

2.2.4. Task

Dumitrescu and Delsenicu [28] define the task as the complexity of activities which are undertaken by an individual as part of a working process, the timeframe for activity completion, the job requirements, etc. Thus, each task can affect the operator's performance levels. They acknowledged that natural and environmental issues appearing in the field directly affect the operator's performance. Machines operate in an abrasive environment, where the operators' security is one of the most crucial issues in the construction sector [27,32]. Designing a work environment to meet the needs of the employees and the job requirements is a fundamental factor for enhancing productivity. Moreover, lighting conditions and noise levels, exposure to dust and emissions, soil properties, and weather conditions, especially in earthmoving work and road construction projects, are the main environmental factors, with a significant impact on their productivity levels.

3. Materials and Methods

3.1. Research Process

This research adopts a seven-step approach for identifying and hierarchizing the criteria that have the most effect on the construction equipment operator's performance.

The first step is to identify the relevant literature concerning the equipment operator's performance during a construction project. The review also focuses on investigating any criteria referred to by previous authors. The second step is to supplement those criteria with others mentioned by construction equipment experts and operators, through structured on-site interviews. Several oral interviews with construction management experts and construction equipment operators highlighted the importance of the criteria affecting the performance of the operators. In addition, construction sites were visited, and many interviews were gathered, leading to the consolidation of a final criteria list, as shown in Table 4. The third step is to classify those criteria into two main categories in order to distinguish between those which are based on personal experience and those which are verifiable facts. The formed opinion or viewpoint helps to distinguish the objective from the subjective criteria. Most commonly, subjective means something based on the personal perspective or preferences of an operator, meaning the subject who is observing, and this often implies that it comes with personal biases. In contrast, objective is the attempt to be unbiased, and this means that it is not influenced by an individual's personal viewpoint.

The fourth step of the process introduces the final development of the decision tree, as shown in Figure 5. This hierarchy model is vital when it comes to utilizing the AHP for weighting those influential criteria. It also constitutes the basis for forming a specialized questionnaire (fifth step), which is applicable for weighting the criteria through Saaty's scale [41] (as described in Section 3.2). The application of the AHP (sixth step) in the current research is reviewed in the following sections. The results coming from the AHP method formulate the final scoring of the criteria weighting, leading to the seventh and last step of the process. The overall process is visualized in Figure 5.

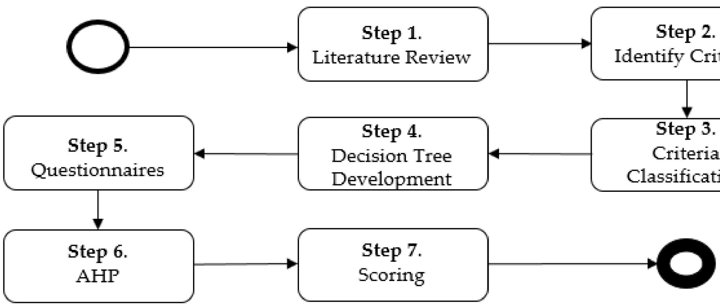

Figure 5. Methodology milestones.

3.2. Application of AHP

The AHP was presented by Thomas L. Saaty as a new approach to dealing with complex economic, technological, and sociopolitical problems, which often involve a great deal of uncertainty [42]. It is a structured technique for analyzing Multi-Criteria Decision Analysis (MCDM) problems according to a pairwise comparison scale [41]. To deal with complexity, our mind must model it by creating a structure and providing observations, measurements, and judgements and hopefully, of course, rigorous analysis to study the influences of the various factors included in the model [43,44].

The AHP is an MCDA method, used by Nassar et al. [45] to measure the relative importance among a set of criteria, and it is suitable for this research due to its ability to compare tangible (subjective) and intangible (objective) factors.

In this study, the Transparent Choice tool for the AHP [46] was employed as it concentrates all the procedure into one tool. It also incorporates a function to produce and disseminate the questionnaires, according to the imported criteria. The operators' performance criteria were classified into levels and sublevels, forming the hierarchy model in Figure 6. Even though the main function of the AHP is to guide the final decision to a certain alternative option, this research takes advantage of the AHP's criteria-weighting function to hierarchize them based on their final weighting score. Based on the same procedure utilized by Petroutsatou et al. [47], this process leads to one alternative, which is the best scoring criterion.

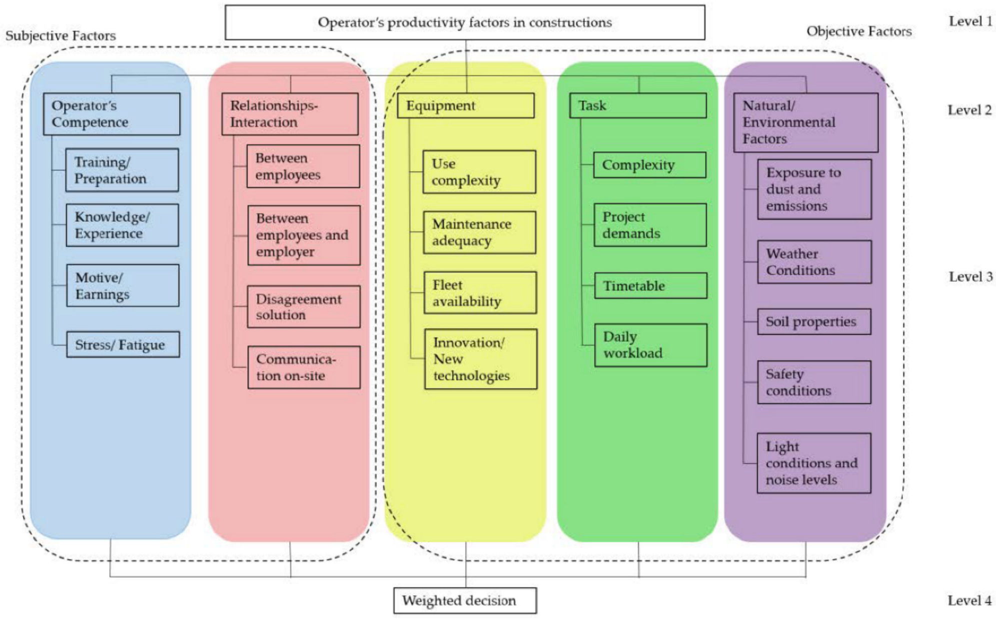

Figure 6. AHP decision tree model.

The model was imported to the Transparent Choice AHP platform; the questionnaires were created and distributed among the experts, who evaluated each criterion according to the AHP's fundamental evaluation scale. The number of evaluators who participated was 13, with different kinds of expertise in the construction sector, as allocated in Table 5. Special emphasis was given to the quality of the evaluators; this was based mostly on their expertise and not on their quantity. This fact does not affect the quality of the results as the AHP is a method with no specific statistical sample but is one that relies explicitly on the Consistency Ratio (CR), because in making paired comparisons, just as in thinking, people do not have the intrinsic logical ability to always be consistent [48]. Furthermore, this study does not constitute a polling exercise, as conducted by Tsafarakis et al. [49], where they exploited the capabilities of the AHP to investigate the preferences of individuals on public transport innovations using the Maximum Difference Scaling method.

Table 5. Evaluators' profile.

	Expertise	Quantity
1	Academia	6
2	Project Managers	2
3	Construction Equipment Operators	3
4	Construction Equipment Owners	2
	Total	13

The academia group includes professors of construction equipment disciplines with a vast experience in field engineering operations. Two experienced project managers were selected, due to their extended field work. Their perspective is based mostly on the project's performance indicators, which are directly affected by the performance of the operators they supervise. Construction equipment operators were chosen based on their experience in operating heavy earthwork machinery. Finally, representatives of OEMs, such as Caterpillar and JCB, were selected, representing the group of construction equipment owners.

The questionnaires were distributed to the above evaluators with the use of the Transparent Choice AHP Software, through its online survey application. The aggregated AHP results are presented in Table 6.

Table 6. Transparent Choice aggregated criteria weights.

#	Criteria	Weight	
		Local	Global
1.	**Equipment**	**24%**	**24%**
1.1	Fleet availability	37%	9%
1.2	Maintenance adequacy	42%	10%
1.3	Innovation/New technologies	12%	3%
1.4	Use complexity	9%	2%
2.	**Operator's competence**	**41%**	**41%**
2.1	Stress/Fatigue	15%	6%
2.2	Knowledge/Experience	52%	21%
2.3	Training/Preparation	19%	8%
2.4	Motive/Earnings	14%	6%
3.	**Task**	**15%**	**15%**
3.1	Project demands	34%	5%
3.2	Daily workload	18%	3%
3.3	Complexity	14%	2%
3.4	Timetable	34%	5%
4.	**Natural/Environmental Factors**	**10%**	**10%**
4.1	Exposure to dust and emissions	9%	1%
4.2	Soil properties	26%	2%
4.3	Weather conditions	21%	2%
4.4	Safety conditions	34%	3%
4.5	Light conditions and noise levels	10%	1%
5.	**Relationships—Interaction**	**11%**	**11%**
5.1	Disagreement solution	24%	3%
5.2	Between employees	19%	2%
5.3	Between employees and employer	26%	3%
5.4	On-site communication on site	32%	3%

The "local" column illustrates the sub-criteria (level 3) weighting in the context of each main (level 2) criterion. The "global" column illustrates each criterion or sub-criterion weighting in the context of the overall decision (level 1). The rankings for each group of evaluators are presented in Table 7.

Table 7. Transparent Choice evaluators weighting results comparison.

#	Criteria	Academia (6)		Project Managers (2)		Operators (3)		Owners (2)	
		Weight		Weight		Weight		Weight	
		Local	Global	Local	Global	Local	Global	Local	Global
1.	**Equipment**	**20%**	**20**	**25%**	**25%**	**28%**	**28%**	**24%**	**24**
1.1	Fleet availability	28%	6%	43%	11%	43%	12%	42%	10
1.2	Maintenance adequacy	48%	10%	42%	10%	40%	11%	25%	6
1.3	Innovation/New technologies	11%	2%	9%	2%	10%	3%	24%	6
1.4	Use complexity	12%	2%	5%	1%	6%	2%	9%	2
2.	**Operator's competence**	**41%**	**41%**	**26%**	**26%**	**51%**	**51%**	**38%**	**38**
2.1	Stress/Fatigue	20%	8%	10%	3%	10%	5%	15%	6
2.2	Knowledge/Experience	44%	18%	58%	15%	61%	31%	54%	21

Table 7. *Cont.*

#	Criteria	Academia (6)		Project Managers (2)		Operators (3)		Owners (2)	
		Weight		Weight		Weight		Weight	
		Local	Global	Local	Global	Local	Global	Local	Global
2.3	Training/Preparation	25%	10%	15%	4%	13%	7%	16%	6
2.4	Motive/Earnings	11%	5%	18%	5%	17%	8%	16%	6
3.	**Task**	**18%**	**18%**	**24%**	**24%**	**8%**	**8%**	**11%**	**11**
3.1	Project demands	26%	5%	24%	5%	44%	4%	48%	5
3.2	Daily workload	22%	4%	11%	3%	18%	1%	12%	1
3.3	Complexity	13%	2%	9%	2%	11%	1%	26%	3
3.4	Timetable	39%	7%	56%	14%	27%	2%	15%	2
4.	**Natural/ Environmental Factors**	**9%**	**9%**	**15%**	**15%**	**7%**	**7%**	**8%**	**8**
4.1	Exposure to dust and emissions	11%	1%	14%	2%	5%	0%	9%	1
4.2	Soil properties	27%	3%	10%	2%	40%	3%	21%	2
4.3	Weather conditions	20%	2%	18%	3%	21%	1%	24%	2
4.4	Safety conditions	31%	3%	47%	7%	26%	2%	37%	3
4.5	Light conditions and noise levels	11%	1%	10%	1%	9%	1%	9%	1
5.	**Relationships—Interaction**	**12%**	**12%**	**11%**	**11%**	**6%**	**6%**	**18%**	**18**
5.1	Disagreement solution	23%	3%	29%	3%	30%	2%	14%	3
5.2	Between employees	22%	3%	25%	3%	16%	1%	9%	2
5.3	Between employees and employer	21%	3%	25%	3%	30%	2%	30%	6
5.4	On-site communication	34%	4%	22%	2%	24%	1%	47%	9

An additional examination was conducted to identify each evaluator's profile with regard to the main criteria ranking coming from their perspective. Table 8 illustrates the total scores for each main criterion in order to give a comparable form and to help extract further results.

Table 8. Main criteria ranking comparison.

Evaluators	Equipment	Operator's Competence	Task	Natural/ Environmental Factors	Relationships—Interaction
Academia	20%	41%	18%	9%	12%
Project Managers	25%	26%	24%	15%	11%
Operators	28%	51%	8%	7%	6%
Owners	24%	38%	11%	8%	18%

4. Results

4.1. Cumulative Evaluation

The questionnaires were answered with a view to prioritizing the criteria affecting the construction equipment operators' performance. Figure 7 illustrates the cumulative results by percentage. The operator's competence is the most influencing factor, with an overall score of 41%, while construction equipment and task follow with a score of 24% and 15%, respectively. According to the above results, construction companies or contractors should carefully select experienced and trained personnel in order to efficiently complete any construction project. Investing in further training for their operators could also be an option to leverage the overall productivity of their construction projects.

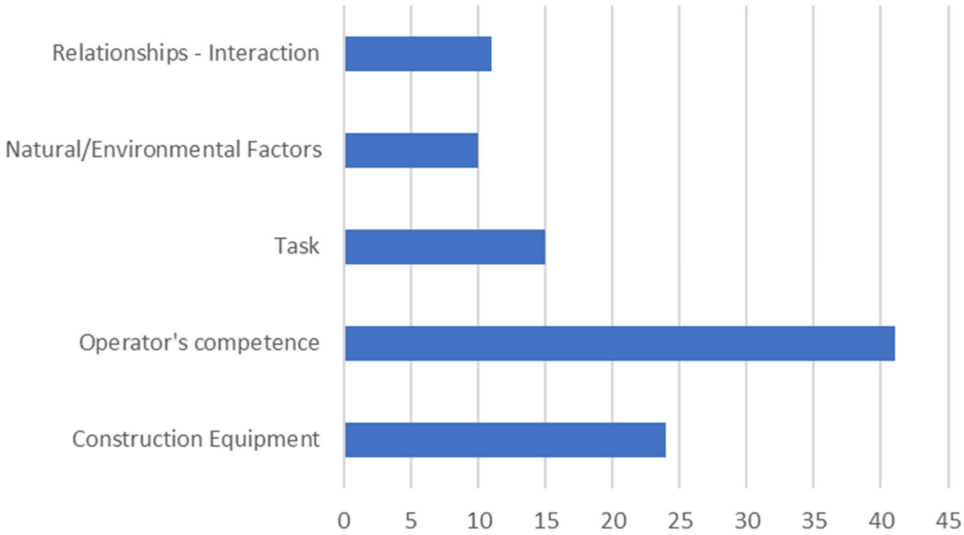

Figure 7. Cumulative results.

Each group of evaluators presented a different perspective, resulting in a different scoring for each criterion, as shown in Figure 8.

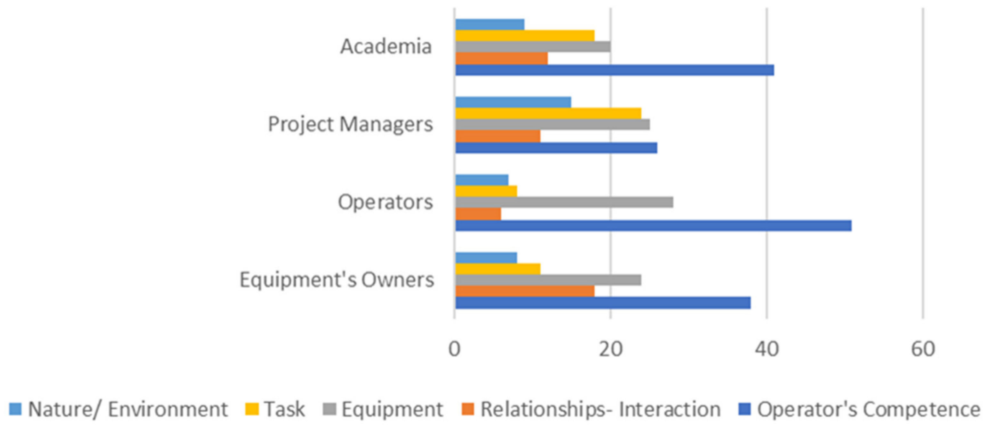

Figure 8. Criteria scoring for each group of evaluators.

The academia group presented similar results to the cumulative ones. The operator's competence was the most important criterion for all the groups of evaluators, with a different percentage in every group. The academia group and the construction equipment operators, for example, formed similar profiles, evaluating "operator's competence" as the most important criteria, with a total score of 41% and 51%, respectively. Construction equipment owners gave a total score of 38% for the operator's competence, 24% for construction equipment, and 18% for relationships—interaction. Project managers, on the other hand, evaluated the operator's competence with a total score of 26% and equipment and task with a total score of 25% and 24%, respectively.

The above analysis allows the formulation of each evaluator's different approach when dealing with earthwork operations. The operators consider the equipment as an extension of themselves, one which is totally dependent on their own skills and operating attitude. Consequently, their ability to efficiently handle the equipment improves the project's progression and the equipment's productivity. Thus, their competence is the dominant factor, with a direct effect on their performance. The academia group agrees too. The project managers score "relationships—interaction" at the lowest level among the criteria. The equipment owners rated the equipment operator's competence with the highest score.

4.2. Sub-Criteria Evaluation

According to Saaty [41], to make a decision we need to know the problem, the need and purpose of the decision, the criteria of the decision, the sub-criteria, the stakeholders and groups affected, and the alternative actions to take. In this study, where the AHP is used to hierarchize the criteria by their weighting score, the sub-criteria are used to expand the pairwise comparisons at a more in-depth level. In that way, the analysis gets to the root of the decision-making problem and becomes more precise and understandable. Based on Table 4, these sub-criteria comparisons are visualized and analyzed in the following sections.

4.2.1. Equipment

Wood and Gidado [50] suggested that the definition of a complex project should refer to the interaction, interdependencies, and interrelationships between the parts of a project and that a great deal of complexity lies within the organizational aspects of a project. The dynamics of innovation are based upon a wide spectrum of possibilities within the system, including incremental innovation at one extreme and breakthrough innovation at the other. Innovation is a process whereby the learning experience and the technology-adoption life cycle contribute to the creative thinking behind underlying motivational forces, whether technology- or market-driven [51]. When it comes to maintenance adequacy, the main objective is to provide maintenance capacity (resources) to meet the random maintenance workload, in order to achieve several objectives that include maximizing the system availability, safety, and the utilization of limited resources [52]. The area of asset management is gaining significance, especially in the availability contracts [53]. Maintaining a proper fleet of equipment can be of strategic importance to a company in cases where the award of a contract is also based upon the condition and availability of the equipment [54]. Furthermore, any unavailability of the proper equipment could cause its overturning, causing damage to property and personnel injury or even fatality, as Edwards [55] highlights.

According to the above literature review framework concerning equipment-related factors that affect the operator's productivity, the AHP analysis revealed the trends depicted in Figure 9.

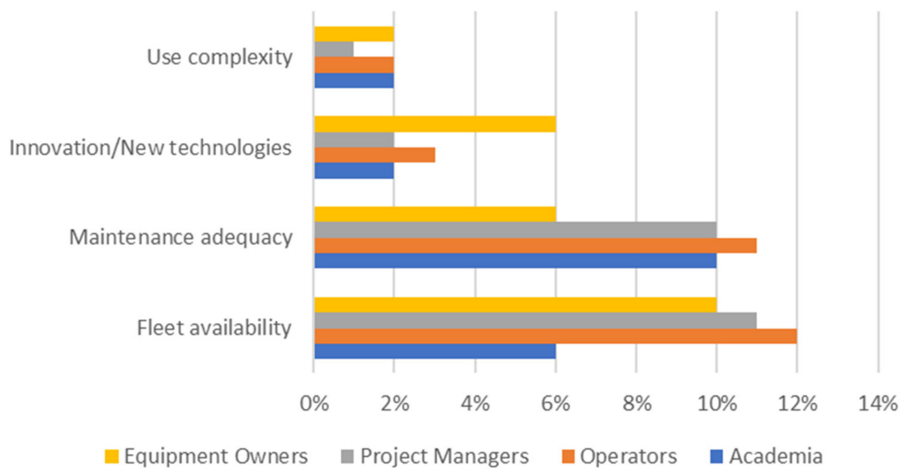

Figure 9. Equipment sub-criteria scoring.

Fleet availability and maintenance adequacy were of great interest for most of the evaluators, and they presented similar weighting results. Specifically, equipment operators granted 12% and 11% to fleet availability and maintenance adequacy, respectively, declaring those two factors as the most influential ones when it comes to construction equipment.

4.2.2. Operator's Competence

The research suggests that personal motivation is a critical internal driving force that, if harnessed, can significantly improve an operator's productivity rate when working mobile plant and machinery [56]. Edwards et al. [56] concluded that the operators' personal motivation can best be encouraged by paying attention to "personal satisfiers" and "security" aspects, with particular emphasis being given to work flexibility and variety, a safe work environment, and appropriate operator remuneration.

In terms of reducing fuel consumption, unit emissions and cost, Jukic and Carmichael [57] revealed that, compared to the baseline values, trained drivers saw a reduction in their fuel consumption by an average of 8.5 percent, reducing to 7.7 percent in the several weeks following training.

Regarding the operator's knowledge/experience, Edwards [58] indicated that the more competent (a mix of qualification and experience) an excavator operator is, the more efficiently (i.e., productively) they can employ the machine and vice versa.

Fatigue is one of the factors leading to reduction in productivity, poor quality of work, and increased risk of accidents in construction [59]. Handling heavy construction equipment is considered as a hazardous occupation and requires personnel to maintain high levels of work situational awareness (WSA). In an analysis made by Sneddon et al. [60], it was found that higher levels of stress, sleep disruption, and fatigue were significantly associated with lower levels of WSA.

The AHP results highlighted the aforementioned factors against the operator's competence among evaluators, as shown in Figure 10.

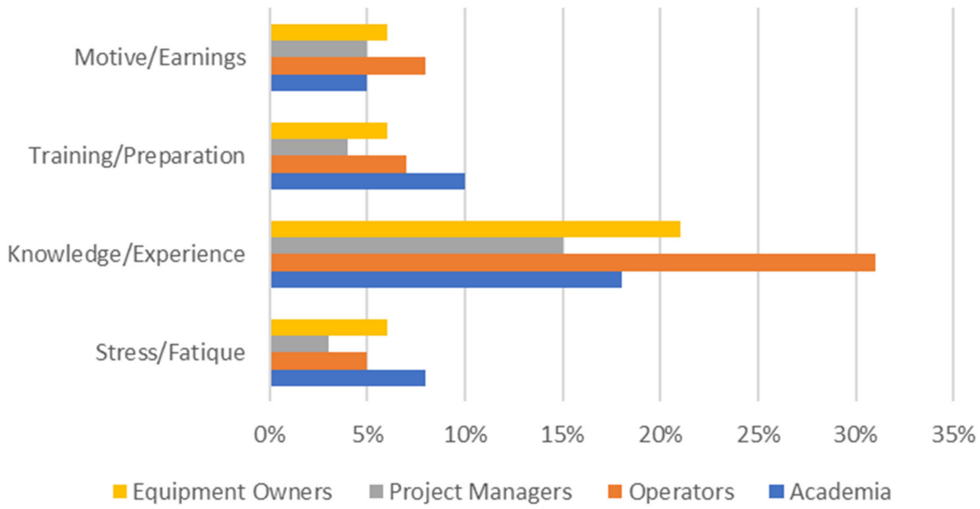

Figure 10. Operator's competence sub-criteria scoring.

The AHP weighting results point out the knowledge/experience criterion as being the most influential on the operator's competence, with total scores of 31% and 21% for the operator and the equipment owner evaluation groups, respectively.

4.2.3. Task

According to Dinakar [61], a clean and efficient planning mechanism, which clearly specifies the work and timetable to be used, can prevent delays in construction projects. Particularly in the European Union, it is a common practice to execute most of the public works through co-founded financial projects. Those projects are characterized by tight budgets and strict timetables [62]. Such timetables could be stressful for the earthwork equipment operators, causing their productivity degradation.

Wood and Gidado [50] tried to provide a greater understanding of the science of complexity in construction. Their research results suggested that the definition of a complex project should refer to the interaction, the interdependencies, and the interrelationships between parts of a project and that the largest amount of complexity lies within the organizational aspects of a project.

Izetbegović and Nahod [63] examined the relationship between the workload, the time pressure, and the work productivity of a construction project. Their findings showed a significant productivity reduction in the case of an additional workload, no matter whether the additional work was required or was a consequence of prior poor performance.

Choi et al. [64] examined the relationship between the construction worker's occupational safety and the application of wearable devices for localization. Their research was motivated by the increasingly demanding and hazardous construction environment. Additionally, Barlow [65] raised concerns about the poor performance of the construction industry, in the UK and elsewhere, caused by increasingly demanding customers and construction project complexity.

The above factors related to the project's tasks were weighted in relation to the construction equipment operator's performance, and the AHP results are presented in Figure 11.

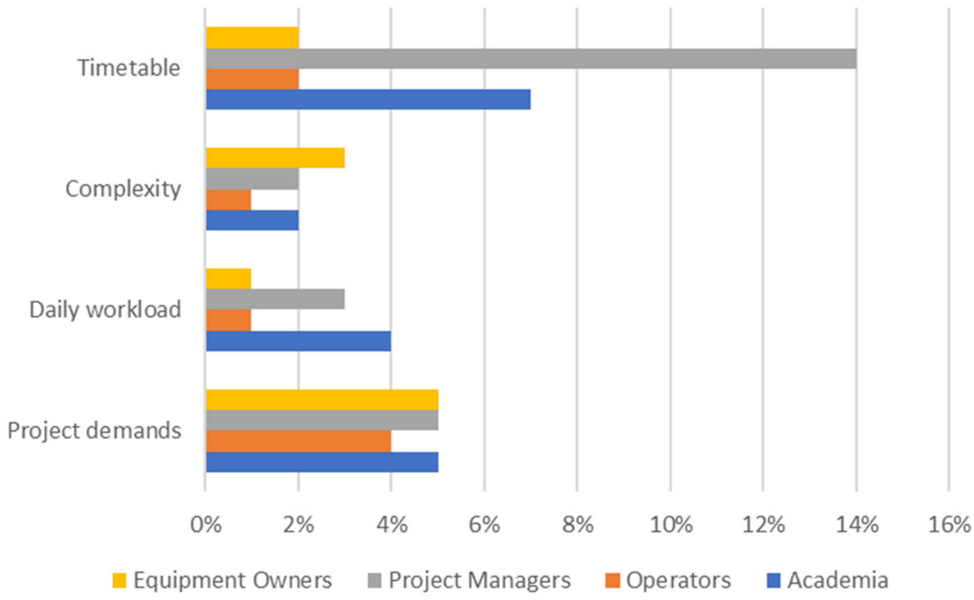

Figure 11. Task sub-criteria scoring.

The AHP results highlight the importance of the projects timetable from the project managers and the academia perspective by giving a weighting score of 14% and 7%, respectively. The weighting scores of the equipment owner and the operators point out that the project's timetable is of less importance (2% each), while their attention falls onto the project's demanding conditions (5% and 4%, respectively).

4.2.4. Natural/Environmental Factors

According to the World Health Organization (WHO), hearing loss is one of the top 10 most serious health problems worldwide, and noise-induced hearing loss (NIHL) is the leading occupational disease [66,67]. Duffy et al. [68] determined the factors associated with sun exposure behaviors among Operating Engineers (heavy equipment operators), highlighting their high risk for skin cancer due to high rates of exposure to ultraviolet light and low rates of sunblock use. Additionally, Eger et al. [69] highlighted the importance of light conditions and the operator's line of sight during construction works.

The unsafe behavior that is seen everywhere on construction sites is the biggest challenge for further improvement of construction safety performance. Focusing on the "human" related issues in construction safety, Fang et al. [70] reviewed the research and practices of safety management and came up with three key elements to look at, namely safety leadership, safety culture, and safety behavior. It is also notable that the subject of construction safety in general is widely referred to in the global literature.

Elazouni and Basha [71] managed to link problems with the operating construction equipment with low productivity and noted that weather conditions are one of the main factors that are unanticipated prior to the inception of the work and adversely affect productivity.

In order to highlight the importance of soil properties during construction, Parsakho et al. [72] investigated the effects of moisture, porosity, and soil bulk density during a forest road construction. Furthermore, Devi and Palaniappan [73] presented the influence of technological, operational, and site-related parameters, such as soil properties, on the performance of earthmoving operations.

Earthwork constructions emit a large amount of dust into the environment, which causes serious health hazards to construction workers. To reveal the characteristics of the health risks to workers caused by the dust generated during the earthwork construction phase, to polish the evaluation system of health damage in construction projects, and to improve the occupational health of workers, Luo et al. [74] and Chen et al. [75] established a health-risk evaluation system, which revealed the negative effect of dust exposure to the equipment operators' performance. Additionally, Ahn and Lee [76] presented a methodology for incorporating the analysis of operational efficiency into quantifying the amount of exhaust emission from construction operations and thus pointing out the effects of those emissions on construction projects productivity.

The above factors related to natural and environmental effects were weighted in relation to the construction equipment operators' performance, and the AHP results are presented in Figure 12.

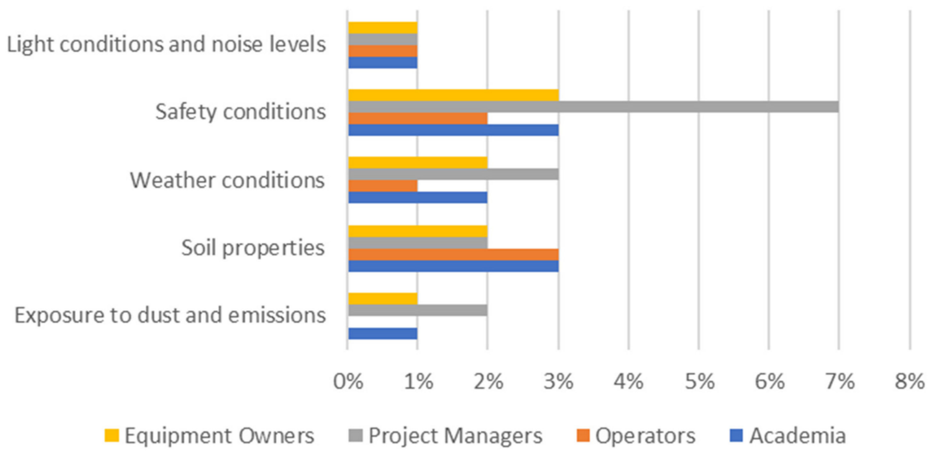

Figure 12. Natural/Environmental factor sub-criteria scoring.

All groups of evaluators agreed that safety conditions during construction and earthworks are of greater importance when it comes to the operator's performance. The highest score came from project managers (7%), as a result of it being their main obligation to ensure construction safety during construction works. Equipment owners (3%), academia (3%), and operators (2%) followed. On the other hand, the highest ranking given by the equipment operators was the soil properties (3%). The operators also considered that their exposure to dust and emissions had no effect on their performance.

4.2.5. Relationships—Interaction

The communication channels and the relationships developed between an employer and an employee are analyzed. The manager will be considered either as an agent of the employer or as an individual actor defending his or her own interests and with the ability to intervene between the three actors [77].

In order to identify the necessary factors for a safe construction site, Mohamed [78] conducted research in which he corroborates the importance of the role of management commitment, communication, workers' involvement, attitudes, and competence, as well as supportive and supervisory environments, in achieving a positive safety climate.

Additionally, investigations have been carried out which suggest that the motivation of employees in all industries is affected by the environment or culture in which they work [79]. Their research concluded that the environment of a construction site does affect demotivation levels of site personnel. Specifically, several variables were significantly linked to this result, including long hours, chaos, non-recognition for work done, and colleagues' aggressive management style.

This study incorporates the above research to investigate the influencing weight of those relationships—interaction factors on the performance of construction equipment operators and presents them in Figure 13.

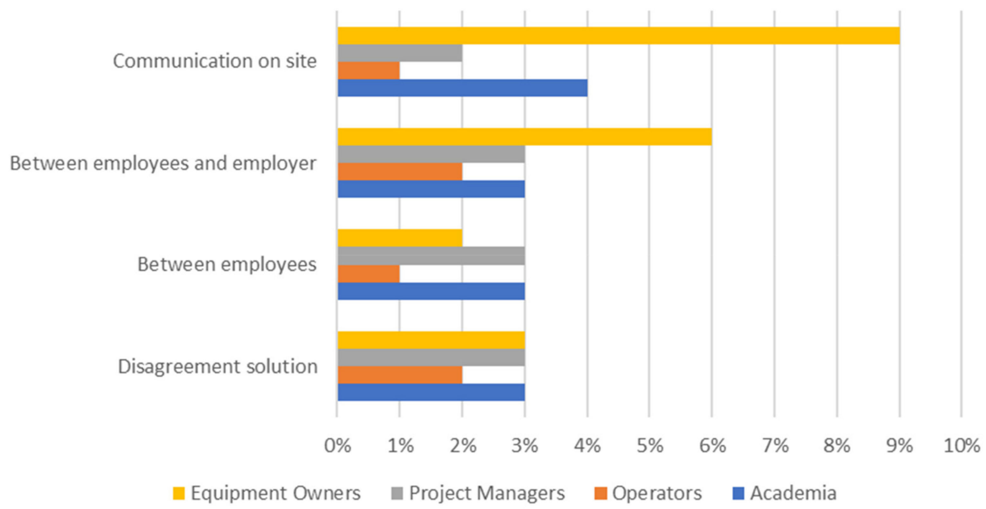

Figure 13. Relationships—Interaction.

The AHP results indicated the significance of the on-site communication, especially for the equipment owners, the academia group, and the equipment operators (9%, 4%, and 2%, respectively). On the other hand, what was more important for the equipment operators was the relationship between the employees and employers (2%), but also the ability to come to a solution to the problem when there is a disagreement in the field (2%). The importance of the relationship between employees and employers is also highlighted by the equipment owners (6%). The above diversity could be explained in terms of working mentality. Employees, such as the equipment operators, are the task receivers and those who are directly affected by the employer's decisions and management attitudes. The way they interact with superintendents and the way they reach a solution to a disagreement affects their psychological condition, their level of motivation and, of course, their will and temper for more productive work.

5. Discussion

It is generally accepted that construction equipment is an integral part of every project in the construction sector, and it represents a significant capital investment for the companies that own it. The efficient utilization of this resource makes the project successful [33]. This research started with the objective of identifying and hierarchizing the factors affecting the construction equipment operator's performance. This is a topic that is frequently and widely discussed in the construction industry sector, but not comprehensively examined and quantified, as was found through the literature review.

In previous research, many scholars have utilized different methods to exploit the results of other related publications, mostly by examining a project's productivity in general or in relation to other factors. However, no research has been found to systematically summarize those publications and provide a holistic approach on their interdependencies and, more specifically, to feature the linkage between equipment operator performance and the project's productivity. Two hundred and sixty-three topic-related publications were examined and visualized through the VOSViewer application. The statistical analysis of those articles revealed that the researchers' interest in construction equipment and operator productivity has been increasing over the past 5 years. Technological evolution seems to radically affect the construction sector, and therefore, it was examined as an influential factor on the construction equipment operators' performance.

The objective of this research was to identify the criteria and sub-criteria with a great effect on the equipment operator's performance. The structured interviews with experts in the field, combined with the conducted literature review led to the development of the decision tree model (Figure 6), with five main criteria affecting the operator's performance: (i) operator's competence, (ii) relationships—interaction, (iii) equipment (iv) task, and (v) natural/environmental factors. Furthermore, each criterion has been evaluated in relation to a total of twenty-one dependent sub-criteria.

The operators' competence was the most important criterion among all the groups of evaluators (i.e., academia, project managers, operators, and equipment's owners). This result supports that the idea that to ensure successful projects, an experienced and trained personnel is an important success factor. Furthermore, the availability of the equipment on the sites and the maintenance adequacy of the fleet are among the most prevailing factors between the equipment and the operator's productivity. Notably, prescriptive maintenance and the deployment of equipment are of the utmost importance according to our analysis. Regarding the task that should be delivered and to what extent this can affect the operator's performance, the academia group and the project managers highlight the importance of the project schedule, whereas the operators and equipment owners focus their attention on the project's demands. This stance discloses that the projects owners and academia demonstrate a holistic approach to the issue and not an activity-based concern, as the operators and equipment owners do. Regarding environmental factors, safety conditions are ranked first for ensuring the operator's enhanced productivity for the project managers, whereas, for the operators, soil properties are the determinant factor in their ensured work effectiveness. Lack of effective communication channels and conflicts among the construction teams are criteria that are ranked high as causal factors for an operator's poor productivity.

Based on the aforementioned research and our presented analysis, the practical applications of this study principally relate to helping stakeholders in plant and machinery to better understand the interrelationships between the factors investigated that affect the equipment operators' performance. More specifically, it offers practitioners valuable indicators to: (i) identify causal situations for the operators' inefficiencies, (ii) reinforce their fleet management, and (iii) thus ensure the project's success.

6. Conclusions

Enhanced productivity is an overarching goal in the construction sector as it integrates the effectiveness and efficiency of project's resources while guaranteeing the quality of the work. This paper explores, for the first time, qualitative evidence for the interdependencies between the equipment operator's performance and the construction equipment's productivity. Through an extensive literature review and interviews with experts, this paper was challenged to provide an annotative approach and pave the way for further constructive thinking on the examined topic.

This research objective was to: (i) recognize the factors affecting operators' performance levels that are closely related to a project's productivity and (ii) prioritize those factors by attributing total scores with Transparent Choice's tool for the AHP. The AHP was selected as the most suitable method for this research by utilizing its ability to weight and hierarchize the criteria, without the need to specify alternative attributes. The factors were divided into two groups, subjective and objective, and each group included two and three categories, respectively. On level three of the decision tree model twenty-one factors were investigated and shortlisted using the AHP. The decision tree model was evaluated by different types of evaluators, such as academia, equipment owners, operators, and project managers. Each group of evaluators formed a different profile by attributing different total scores to each criterion. The academia group was the group of evaluators that presented similar results to the cumulative ones and similar profiles to the operators' group. The operator's competence was considered by all groups of evaluators as the most important factor; in particular, "knowledge" and "experience" ranked first, followed by "training" and "on-site preparation" and contributed radically to the construction equipment operators' performance.

The limitations of this research relate to the fact that this was the first holistic approach to relating the equipment operators' performance with the tangible and intangible factors identified in the literature and expert interviews. More experts could surely enhance the robustness of our results. Moreover, in future research, the qualitative approach presented here could be expressed in mathematical equations in order to quantify the sensitiveness of the factors analyzed in relation to the equipment's productivity.

Author Contributions: Conceptualization, K.P.; Data curation, K.T.; Formal analysis, I.L.; Investigation, K.T.; Methodology, K.P. and I.L.; Project administration, K.P.; Software, I.L. and K.T.; Supervision, K.P.; Writing—original draft, I.L. and K.T.; Writing—review & editing, K.P. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Acknowledgments: The authors would like to acknowledge the significant contribution made by the evaluators, without whose valuable input and support the quality of this work could not be ensured.

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

References

1. Gunduz, M.; Abu-Hijleh, A. Assessment of Human Productivity Drivers for Construction Labor through Importance Rating and Risk Mapping. *Sustainability* **2020**, *12*, 8614. [CrossRef]
2. Yi, W.; Chan, A. Critical review of labor productivity research in construction journals. *J. Manag. Eng.* **2014**, *30*, 214–225. [CrossRef]
3. Petroutsatou, K.; Marinelli, M. *Construction Equipment, Operational Analysis and Economics of Civil. Engineering Projects*, 2nd ed.; KRITIKI SA: Athens, Greece, 2018.
4. Vorster, M. *Construction Equipment Economics*, 1st ed.; Pen Publications: Columbus, IN, USA, 2009.
5. Petroutsatou, K.; Ladopoulos, I.; Vlachokostas, G. Comparative Evaluation of Fleet Management Software in the Greek Construction Industry. *IOP Conf. Ser. Mater. Sci. Eng.* **2022**, 1218. [CrossRef]
6. Petroutsatou, K.; Sifniadis, A. Exploring the consequences of human multitasking in industrial automation projects: A tool to mitigate impacts-Part II. *Organ. Technol. Manag. Constr.* **2018**, *10*, 1770–1777. [CrossRef]
7. Marinelli, M.; Petroutsatou, K.; Fragkakis, N.; Lambropoulos, S. Rethinking new public infrastructure value for money in recession times: The Greek case. *Int. J. Constr. Manag.* **2018**, *18*, 331–342. [CrossRef]
8. Antunes, R.; Gonzalez, V.; Walsh, K.; Rojas, O. Dynamics of project-driven production systems in construction: Productivity function. *J. Comput. Civil. Eng.* **2017**, *31*, 4017053. [CrossRef]
9. Liberda, M.; Ruwanpura, J.; Jergeas, G. Construction Productivity Improvement: A Study of Human, Management and External Issues. In Proceedings of the Construction Research Congress, Honolulu, HI, USA, 19–21 March 2003. [CrossRef]
10. Ghoddousi, P.; Hosseini, M.R. A survey of the factors affecting the productivity of construction projects in Iran. *Technol. Econ. Dev. Econ.* **2012**, *18*, 99–116. [CrossRef]
11. Hasan, A.; Baroudi, B.; Elmualim, A.; Rammeezdeen, R. Factors affecting construction productivity: A 30 year systematic review. *Eng. Constr. Archit. Manag.* **2018**, *25*, 916–937. [CrossRef]
12. Hedman, R.; Subramaniyan, M.; Almstrom, P. Analysis of Critical Factors for Automatic Measurement of OEE. *Procedia CIRP* **2016**, *57*, 128–133. [CrossRef]
13. He, Z.; Wang, G.; Chen, H.; Zou, Z.; Yan, H.; Liu, L. Measuring the Construction Project Resilience. *Buildings* **2022**, *12*, 56. [CrossRef]
14. Zhu, Z.; Yuan, J.; Shao, Q.; Zhang, L.; Wang, G.; Li, X. Developing Key Safety Management Factors for Construction Projects in China: A Resilience Perspective. *Int. J. Environ. Res. Public Health* **2020**, *17*, 6167. [CrossRef]
15. Johari, S.; Jha, K.N. How the Aptitude of Workers Affects Construction Labor Productivity. *J. Manag. Eng.* **2020**, *36*, 04020055. [CrossRef]
16. Tangen, S. Demystifying productivity and performance. *Int. J. Product. Perform. Manag.* **2005**, *54*, 34–46. [CrossRef]

17. Maqsoom, A.; Mubbasit, H.; Alqurashi, M.; Shaheen, I.; Alaloul, W.S.; Musarat, M.A.; Salman, A.; Aslam, B.; Zerouali, B.; Hussein, E.E. Intrinsic Workforce Diversity and Construction Worker Productivity in Pakistan: Impact of Employee Age and Industry Experience. *Sustainability* **2022**, *14*, 232. [CrossRef]
18. Navon, R. Automated project performance control of construction projects. *Autom. Constr.* **2005**, *14*, 467–476. [CrossRef]
19. Ofori, G.; Zhang, Z.; Ling, F. Key barriers to increase construction productivity: The Singapore case. *Int. J. Constr. Manag.* **2020**. [CrossRef]
20. Tijssen, R.; Van Raan, T. Mapping Changes in Science and Technology: Bibliometric Co-Occurrence Analysis of the R&D Literature. *Eval. Rev.* **1994**, *18*, 98–115. [CrossRef]
21. Cobo, M.; López-Herrera, A.G.; Herrera-Viedma, E.; Herrera, F. Science Mapping Software Tools: Review, Analysis, and Cooperative Study Among Tools. *J. Am. Soc. Inf. Sci. Technol.* **2011**, *62*, 1382–1402. [CrossRef]
22. Jan van Eck, N.; Waltman, L. Software survey: VOSviewer, a computer program for bibliometric mapping. *Scientometrics* **2010**, *84*, 523–538. [CrossRef]
23. Zhong, B.; Wu, H.; Li, H.; Sepasgozar, S.; Luo, H.; He, L. A scientometric analysis and critical review of construction related ontology research. *Autom. Constr.* **2019**, *101*, 17–31. [CrossRef]
24. Van Eck, N.; Waltman, L. VOSViewer Manual 2018. Available online: https://www.vosviewer.com/documentation/Manual_VOSviewer_1.6.8.pdf (accessed on 22 December 2021).
25. Atkinson, R. Project management: Cost, time and quality, two best guesses and a phenomenon, its time to accept other success criteria. *Int. J. Proj. Manag.* **1999**, *17*, 337–342. [CrossRef]
26. Holt, G.; Edwards, D. Analysis of interrelationships among excavator productivity modifying factors. *Int. J. Product. Perform. Manag.* **2015**, *64*, 853–869. [CrossRef]
27. Yang, J.; Edwards, D.; Love, P.E.D. Measuring the impact of daily workload upon plant operator production performance using Artificial Neural Networks. *Civ. Eng. Environ. Syst.* **2004**, *21*, 279–293. [CrossRef]
28. Dumitrescu, A.; Delsenicu, D. Risk assessment in manufacturing SMEs' labor system. *Procedia Manuf.* **2018**, *22*, 912–915. [CrossRef]
29. Du, Y.; Dorneich, M.; Steward, B.L. Virtual operator modeling method for excavator trenching. *Autom. Constr.* **2016**, *70*, 14–25. [CrossRef]
30. Langer, T.H.; Iversen, T.; Andersen, N.; Mouritsen, O.; Hansen, M. Reducing whole-body vibration exposure in backhoe loaders by education of operators. *Int. J. Ind. Ergon.* **2012**, *42*, 304–311. [CrossRef]
31. Naskoudakis, I.; Petroutsatou, K. A Thematic Review of Main Researches on Construction Equipment over the Recent Years. *Procedia Eng.* **2016**, *164*, 206–213. [CrossRef]
32. Haggag, S.; Elnahas, S. Event-based detection of the digging operation states of a wheel loader earth moving equipment. *Int. J. Heavy Veh. Syst.* **2013**, *20*, 157–173. [CrossRef]
33. Beleiu, I.; Crisan, E.; Nistor, R. Main factors Influencing Project Success. *Int. Manag. Res.* **2015**, *11*, 59–72.
34. Cheuk, A.N.; Leung, J.T.; Tse, P.W. Effective Architecture for Web-Based Maintenance System and Its Security. In Proceedings of the ASME 2005 International Design Engineering Technical Conferences and Computers and Information in Engineering Conference: 20th Biennial Conference on Mechanical Vibration and Noise, Long Beach, CA, USA, 24–28 September 2005; Volume 1, pp. 601–606. [CrossRef]
35. Bahnassi, H.; Hammad, A. Near Real-Time Motion Planning and Simulation of Cranes in Construction: Framework and System Architecture. *J. Comput. Civil. Eng.* **2012**, *26*, 54–63. [CrossRef]
36. Lee, G.; Cho, J.; Ham, S.; Lee, T.; Lee, G.; Yun, S.-H.; Yang, H.-J. A BIM- and sensor-based tower crane navigation system for blind lifts. *Autom. Constr.* **2012**, *26*, 1–10. [CrossRef]
37. Barati, K.; Shen, X. Modeling and optimizing fuel usage of on-road construction equipment. In Proceedings of the Construction Research Congress 2018: Sustainable Design and Construction and Education—Selected Papers from the Construction Research Congress, New Orleans, LA, USA, 2–4 April 2018; pp. 198–207. [CrossRef]
38. Albrektsson, J.; Aslund, J. Fuel Optimal Control of an Articulated Hauler Utilising a Human Machine Interface. In Proceedings of the 2018 IEEE International Conference on Industrial Technology (ICIT), Lyon, France, 19–22 February 2018; pp. 175–180. [CrossRef]
39. Kokot, G.; Ogierman, W. The numerical simulation of FOPS and ROPS tests using LS-DYNA. *Mechanika* **2019**, *25*, 383–390. [CrossRef]
40. Petroutsatou, K.; Giannoulis, P. Analysis of construction machinery market: The case of Greece. *Int. J. Constr. Manag.* **2020**. [CrossRef]
41. Saaty, T. T. Decision making with the analytic hierarchy process. *Int. J. Serv. Sci.* **2008**, *1*, 83–98. [CrossRef]
42. Shapira, A.; Goldenberg, M. AHP-based equipment selection model for construction projects. *J. Constr. Eng. Manag.* **2005**, *131*, 1263–1273. [CrossRef]
43. Jato-Espino, D.; Castillo-Lopez, E.; Rodriguez-Hernandez, J.; Canteras-Jordana, J.C. A review of application of multi-criteria decision making methods in construction. *Autom. Constr.* **2014**, *45*, 151–162. [CrossRef]
44. Saaty, T.; Ozdemir, M. The unknown in decision making. What to do about it. *Eur. J. Oper. Res.* **2006**, *174*, 349–359. [CrossRef]
45. Nassar, K.; Thabet, W.; Beliveau, Y. A procedure for multi-criteria selection of building assemblies. *Autom. Constr.* **2003**, *12*, 543–560. [CrossRef]

46. Transparent Choice AHP Software. Available online: https://www.transparentchoice.com/ahp-software (accessed on 8 April 2022).
47. Petroutsatou, K.; Ladopoulos, I.; Nalmpantis, D. Hierarchizing the Criteria of Construction Equipment Procurement Decision Using the AHP Method. *IEEE Trans. Eng. Manag.* **2021**, 1–12. [CrossRef]
48. Saaty, T.L. How to Make a Decision: The Analytic Hierarchy Process. *Interfaces* **1994**, *24*, 19–43. [CrossRef]
49. Tsafarakis, S.; Gkorezis, P.; Nalmpantis, D.; Genitsaris, E.; Andronikidis, A.; Altsitsiadis, E. Investigating the preferences of individuals on public transport innovations using the Maximum Difference Scaling Method. *Eur. Transp. Res. Rev.* **2019**, *11*, 3. [CrossRef]
50. Wood, H.; Gidado, K. Project Complexity in Construction. In *The International Construction Conference, Royal Institute of Chartered Surveyors, RICS COBRA*; RICS Foundation UK: Dublin, Ireland, 2008.
51. Tangkar, M.; Arditi, D. Innovation in the Construction Industry. *Civ. Eng. Dimens.* **2000**, *2*, 96–103. [CrossRef]
52. Duffuaa, S.; Alfares, H. Methods and Approaches for Maintenance Capacity Planning. In Proceedings of the 2015 International Conference on Industrial Engineering and Operations Management, Dubai, United Arab Emirates, 3–5 March 2015.
53. Alabdulkarim, A.; Ball, P.; Tiwari, A. Rapid modeling of field maintenance using discrete event simulation. In Proceedings of the Winter Simulation Conference, Phoenix, AZ, USA, 11–14 December 2011. [CrossRef]
54. Nepal, M.P.; Park, M. Downtime model development for construction equipment management. *Eng. Constr. Archit. Manag.* **2004**, *11*, 199–210. [CrossRef]
55. Edwards, D.; Parn, E.; Sing, M.; Thwala, W.D. Risk of excavators overturning. Determining horizontal centrifugal force when slewing freely suspended loads. *Eng. Constr. Archit. Manag.* **2019**, *26*, 479–498. [CrossRef]
56. Edwards, D.; Yang, J.; Wright, B.C. Establishing the link between plant operator performance and personal motivation. *J. Eng. Des. Technol.* **2007**, *5*, 173–187. [CrossRef]
57. Jukic, D.; Carmichael, G. Emission and cost effects of training for construction equipment operators. *Smart Sustain. Built Environ.* **2016**, *5*, 96–110. [CrossRef]
58. Edwards, D. An artificial intelligence approach for improving plant operator maintenance proficiency. *J. Qual. Maint. Eng.* **2002**, *8*, 239–252. [CrossRef]
59. Aryal, A.; Ghahramani, A.; Becerik-Gerber, B. Monitoring fatigue in construction workers using physiological measurements. *Autom. Constr.* **2017**, *82*, 154–165. [CrossRef]
60. Sneddon, A.; Mearns, K.; Flin, R. Stress, fatigue, situation awareness and safety in offshore drilling crews. *Saf. Sci.* **2013**, *56*, 80–88. [CrossRef]
61. Dinakar, A. Delay Analysis in Construction Project. *Int. J. Emerg. Technol. Adv. Eng.* **2014**, *4*, 784–788.
62. Petroutsatou, K.; Ladopoulos, I. Integrated Prescriptive Maintenance System (PREMSYS) for Construction Equipment Based on Productivity. *IOP Conf. Ser. Mater. Sci. Eng.* **2020**, *1218*, 012006. [CrossRef]
63. Izetbegović, J.; Nahod, M.-M. The impact of the additional workload on the productivity in construction projects. In Proceedings of the Creative Construction Conference, Prague, Czech, 21 June 2014.
64. Choi, B.; Hwangb, S.; Leec, S.H. What drives construction workers' acceptance of wearable technologies in the workplace?: Indoor localization and wearable health devices for occupational safety and health. *Autom. Constr.* **2017**, *84*, 31–41. [CrossRef]
65. Barlow, J. Innovation and learning in complex offshore construction projects. *Res. Policy* **2000**, *29*, 973–989. [CrossRef]
66. World Health Organization 2015. Available online: https://apps.who.int/iris/bitstream/handle/10665/154589/9789241508513_eng.pdf (accessed on 8 April 2022).
67. Neitzel, R.; Daniell, W.; Sheppard, L.; Davies, H.; Seixas, N. Comparison of Perceived and Quantitative Measures of Occupational Noise Exposure. *Ann. Occup. Hyg.* **2008**, *53*, 41–54. [CrossRef]
68. Duffy, S.; Choi, S.H.; Hollern, R.; Ronis, D. Factors Associated with Risky Sun Exposure Behaviors Among Operating Engineers. *Am. J. Ind. Med.* **2012**, *55*, 786–792. [CrossRef]
69. Eger, T.; Salmoni, A.; Whissell, R. Factors influencing load–haul–dump operator line of sight in underground mining. *Appl. Ergon.* **2004**, *35*, 93–103. [CrossRef]
70. Fang, D.; Huang, Y.; Guo, H.; Lim, H.W. LCB approach for construction safety. *Saf. Sci.* **2020**, *128*, 104761. [CrossRef]
71. Elazouni, A.; Basha, I. Evaluating the performance of construction equipment operators in Egypt. *J. Constr. Eng. Manag.* **1996**, *122*, 109–114. [CrossRef]
72. Parsakho, A.; Hosseini, S.A.; Jalilvand, H.; Lotfalian, M. Physical soil properties and slope treatments effects on hydraulic excavator productivity for forest road construction. *Pak. J. Biol. Sci.* **2008**, *11*, 1422–1428. [CrossRef]
73. Devi, P.; Palaniappan, S. A study on energy use for excavation and transport of soil during building construction. *J. Clean. Prod.* **2017**, *164*, 543–556. [CrossRef]
74. Luo, Q.; Huang, L.; Xue, X.; Chen, Z.; Zhou, F.; Wei, L.; Hue, J. Occupational health risk assessment based on dust exposure during earthwork construction. *J. Build. Eng.* **2021**, *44*, 103186. [CrossRef]
75. Chen, X.; Guo, C.; Song, J.; Wang, X.; Cheng, J. Occupational health risk assessment based on actual dust exposure in a tunnel construction adopting roadheader in Chongqing, China. *Build. Environ.* **2019**, *165*, 106415. [CrossRef]
76. Ahn, C.; Lee, S.H. Importance of Operational Efficiency to Achieve Energy Efficiency and Exhaust Emission Reduction of Construction Operations. *J. Constr. Eng. Manag.* **2013**, *139*, 404–413. [CrossRef]

77. Havard, C.; Rorive, B.; Sobczak, A. Client, Employer and Employee: Mapping a Complex Triangulation. *Eur. J. Ind. Relat.* **2009**, *15*, 257–276. [CrossRef]
78. Mohamed, S. Safety Climate in Construction Site Environments. *J. Constr. Eng. Manag.* **2002**, *128*, 375–384. [CrossRef]
79. Smithers, G.; Walker, D. The effect of the workplace on motivation and demotivation of construction professionals. *Constr. Manag. Econ.* **2000**, *18*, 833–841. [CrossRef]