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Identification of the Criteria for Building Maintenance Decisions in Facility Management: First Step to Developing a Multi-Criteria Decision-Making Approach

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Abstract: Building maintenance is a fundamental practice in facility management, which supports the longevity of a building. Increasing costs of maintenance practices is a challenge for facility management professionals. Given that, building maintenance decisions often comprise complex and conflicting criteria. The primary purpose of this study is to develop and rank a set of criteria needed for constructing a multi-criteria decision-making model for use in building maintenance processes. This study also has an exploratory aspect and tries to establish the decision-making and condition assessment practices currently used in facility management. To do so, a literature review was conducted to reveal the significant criteria for building maintenance decision-making processes. Moreover, the results of a nationwide survey conducted with the members of two globally recognized facility management organizations were utilized. Identified criteria address a gap in facilities management research, i.e., the lack of comprehensive criteria in building maintenance decision-making, and can be used for the development of a multi-criteria decision-making model for use in building maintenance processes. Furthermore, the results of this study can help establish the current status of decision-making and condition assessment practices in facility management.

Keywords: facility management; building maintenance; decision-making criteria; multi-criteria decision-making

1. Introduction and Purpose

Effective facility management (FM) strategies are essential to an organization's ability to achieve its business objectives. FM is a multi-disciplinary process that provides the necessary services for the built environment to support an organization's missions and improve occupant comfort. Organizational needs vary in the pursuit of long-term goals; therefore, the key to an effective FM strategy is to understand and address these needs along with an organization's culture and values [1].

Building maintenance constitutes essential practices to sustain the performance of buildings within required standards as well as decrease the impact of equipment and system failures [2]. Therefore, building maintenance practices have a remarkable effect on the longevity of a building. An online survey conducted in 2012 revealed that maintenance and repair activities comprise 79% of total FM activities in the functional responsibilities of FM organizations [3]. Costs to repair and maintain buildings also continue to rise; the International Facility Management Association's (IFMA) [4]

Operations and Maintenance Benchmarks report noted that average maintenance costs increased by 72% between 2007 and 2017.

Building maintenance decisions ensure that building systems, components, and equipment work effectively together. Cavalcante, Alencar, and Lopes [5] stated that building maintenance decisions are a challenge for most facility management professionals. Since maintenance processes involve a great variety of factors, which complicates making decisions in such environments, the need for a mechanism capable of assisting the characterization of complex scenarios arises. Multi-criteria decision-making (MCDM) emerged as a branch of operations research designed to facilitate the resolution of complex issues with conflicting criteria. A variety of MCDM methods have been developed to solve various problems under different circumstances and fields of application [6].

Given the importance of building maintenance and related decisions, the overarching goal of this study is to develop and rank a set of fundamental and general criteria needed for constructing an MCDM model for use in building maintenance processes across a variety of facility types. Building maintenance decisions in this study refer to repair, replace, defer, or 'do nothing' alternatives for a building system, component, or equipment, which focuses on each maintenance activity as a discrete decision. Given that, the decision-making of the selection of building system, component, or equipment subject to maintenance activity is not in the scope. This study also has an exploratory aspect and tries to establish the decision-making and condition assessment practices currently used. To do so, the study utilizes the results of a nationwide survey conducted with the members of the International Facility Management Association (IFMA) and the Leadership in Educational Facilities (APPA) in the United States, two globally recognized FM organizations. IFMA is the largest FM organization in the world, including more than 23,000 members in over 100 countries and APPA represents more than 18,000 educational facilities professionals from 1300 learning institutions worldwide. The results of this study can help establish the current status of FM and can be used for the development of an MCDM model with a condition assessment framework for use in building maintenance processes.

2. Background

The information provided in the background section of this paper comprises current challenges, the need for MCDM in the context of building maintenance and FM, and applications of MCDM in the built environment. In addition to the current literature presented in the background section, specific studies utilized in revealing various criteria for building maintenance decision-making are presented in the methodology section.

2.1. Current Challenges in Building Maintenance and FM

Building maintenance and FM practices constitute a significant portion of buildings' life-cycle [7]. Building systems are complicated, and FM and maintenance practices aim to ensure the longevity of these systems as well as the built environment. The challenges that limit the development of effective management strategies in FM were highlighted in several studies. These challenges can be summarized as follows: (i) controlling multiple maintenance projects, (ii) integration of energy and workplace management, (iii) performance-based contracts, (iv) utilizing technological advances, (v) the lack of commissioning and hand over models, and (vi) outsourcing and service delivery [8–11].

Resource constraints and aging building stock were discussed in the context of FM and building maintenance as two main challenges that affect the performance and life-cycle of the built environment [12,13]. The impact of aging buildings and the need for effective management strategies to increase the longevity of aged buildings were reported in several public records of the US Government Accountability Office, the General Services Administration, and the National Research Council [14–17]. Moreover, the United States Energy Information Administration (EIA) 2012 commercial buildings energy consumption survey (CBECS) states that more than half of the commercial buildings in the United States were constructed before 1980, and the median age of buildings was reported as 32 years in 2012 [18].

The following studies by respected FM organizations also highlight the aging building stock in the United States and Canadian provinces. The IFMA [4] published a report in 2017 that represents the results of a survey conducted with 2193 FM professionals in 33 broad industry categories with more than 98,000 buildings across 50 states in the United States and eight Canadian provinces and territories. The increasing number of aging buildings in 29 facility categories such as office, industrial, assembly, retail, education, hospital, and residential is highlighted in the report. In addition, 26% of the buildings in the dataset are 31–50 years, and another 27% were 51–100 years, as of 2017 [4]. A Sightlines [19] report that explored more than 52,000 buildings on 360 higher education campuses in the United States stated that almost 52% of these buildings are over 25 years old. Despite the construction of new buildings in the last decade, the total percentage of buildings over 50 years old increased by 4% [19].

Along with aging buildings has come an increase in the investment of new building construction, but this has resulted in a lack of interest in existing buildings and their maintenance needs [20]. Furthermore, maintenance and operation costs contain a significant amount of the total life-cycle cost after the completion of construction. Hence, the efforts in developing cost-effective strategies have increased recently and will continue to be important [21].

Cost constraints, lack of funding, budget cuts, and the lack of proper maintenance management are the main reasons for lower performance of facilities [22]. According to Zavadskas and Vilutiene [23], the efficiency of maintenance depends on planning, design, and commissioning processes that require qualified and experienced personnel, proper equipment, and expertise. Additionally, the maintenance process needs a multi-disciplinary approach, including engineering, commercial, cultural, economic, environmental, and social aspects [24]. Given these factors, aging buildings and limited resources are important challenges in developing effective building maintenance and facility management strategies. Moreover, the needs of maintenance processes and buildings depend on many factors, which are usually project-specific, making the decision-making process complex in building maintenance and FM.

The challenges in building maintenance and FM led many researchers to focus their efforts on developing effective management strategies. Technological developments, such as building information modeling (BIM) [25,26], data exchange and computerized maintenance management systems (CMMS), generic asset management frameworks, preventive maintenance strategies, and other advances in building maintenance and FM [27] are discussed in current studies. However, these studies appear to be few or partial in the existing literature [28]. In addition, a comprehensive literature review conducted in maintenance performance measurement [29] identified that the building maintenance and FM areas are in need of more research efforts to address increasing challenges.

2.2. The Need for MCDM in Building Maintenance

One of the ways to address the challenges in building maintenance and FM is to improve the outcome of decision-making process with a structured and a systematic approach. Since building maintenance decisions are complex in nature with conflicting criteria, an MCDM approach may be an effective method to address the challenges.

The application of MCDM enables decision-makers to create their own set of essential criteria for the maintenance strategy selection process according to needed characteristics [30]. Moreover, Yin, Stack, and Menzel [31] determined the importance of different stakeholders' participation in the decision-making process of building maintenance. FM executives, project managers, supervisors, occupants, and property owners are the primary stakeholders in building maintenance decision-making. A decision-making approach enabling group decision-making is essential for effective building maintenance decisions.

Yau [32] stated that it is clear a decision-maker should consider multiple issues when considering the building maintenance process. These issues can cover both physical and social factors, and instead of a single-criterion consideration, a multi-criteria approach has to be used in the process. In addition, reducing maintenance costs and time is also a key maintenance management demand [32]. Wu, Lv, Zhou, Wang, and Yu [33] emphasized that most of the early decision-making models depended on the

single type of event and criteria. Because of the complexity of the process, different requirements of different maintenance needs and possible correlations between different events caused the need for multi-criteria decision-making models for building maintenance.

2.3. Applications of MCDM in the Built Environment

Several studies have investigated the application of decision-making models for complex engineering and management problems, including multiple variables with conflicting goals, uncertainty, and risks. A comprehensive review of the application of 22 MCDMs in 11 categories of the construction industry showed that the Analytic Hierarchy Process (AHP) was implemented more than other methods, whether on its own or in combination with other applicable methods [6]. AHP comprises pairwise comparisons of criteria and sub-criteria within a hierarchical model of a decision-making problem. The main criteria are judged in pairs for their relative importance in a comparison matrix [34]. After AHP, the most common methods were the Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS) and Elimination and Choice Expressing Reality (ELECTRE) in the applications of MCDMs [6]. TOPSIS was developed by Yoon and Hwang [35], and it considers the decision-making problem as a geometric system in which the alternatives were specified with their positive and negative distances to the benefit and cost criteria [35]. ELECTRE is an outranking method with the comparison of concordance and discordance relationship of criteria within specified limits [36].

Another study [37] explored the existing research on architecture, engineering, and construction (AEC) and decision-making to review decision-making trends over the last five decades. The publications in the American Society of Civil Engineers (ASCE)'s Journal of the Construction Division and the Journal of Construction Engineering and Management were analyzed around the subject areas of project management, construction management, bidding and tendering, and performance and productivity. Their results showed that the decision-maker profile has changed over time from an individual to a group in the AEC industry. The increasing trend of including end-users of the built environment in AEC decision-making processes was highlighted in the study's findings as well. Moreover, the change in decision-making tools from a deterministic to probabilistic nature is one possible explanation for the increasing complexity in the decision objectives of AEC [37].

MCDM models have been implemented for building maintenance problems in the literature, though, the context of these problems was limited. Cavalcante, Alencar, and Lopes [5] focused on the maintenance inspection scheduling problem in residential complexes during the builder's warranty period. The preference ranking organization method for enrichment evaluation (PROMETHEE) was utilized based on a delay-time concept in their study [5]. PROMETHEE is an ordering method in decision-making with weighted criteria and a preference function [38].

AHP was implemented for lighting maintenance decision-making, including re-lamping cost evaluation, carbon dioxide emission evaluations, and comprehensive evaluation for decision-making on lighting maintenance alternatives. Carbon dioxide emissions from the crew and travel time for re-lamping were considered in the context of environmental conservation as well. AHP combined cost and environmental criteria for the optimal maintenance alternative selection [39].

Maintenance strategies incorporate several aspects comprising economic, environmental, technical, and social that need to tie into sustainable practices. Ighravwe and Oke [40] implemented MCDM models with sustainability criteria for selecting the best maintenance strategy: predictive, preventive, corrective, and condition-based for public buildings. The lack of a systematic maintenance strategy selection and the prevalence of uncertainty in maintenance decisions were emphasized in their study [40].

Despite the fact that decision-making is pivotal in building maintenance and FM, a limited number of studies have focused on this problem in the current literature. In addition, very few studies have looked at how MCDM approaches have been integrated into decision-making processes in FM. In light of these gaps in the literature, and as a first step of constructing an MCDM model, this study develops

a set of criteria for use in building maintenance processes in FM based on a literature review and an online survey.

3. Research Methodology

A literature review was conducted to reveal the significant criteria for building maintenance decision-making processes. Additionally, a nationwide online survey was conducted with the members of IFMA and APPA to verify the criteria identified through the literature, rank their importance, and identify any additional criteria for the model.

3.1. Step 1—Criteria Identification through Literature Review

Identifying relevant selection criteria comprises an essential part of any decision-making process. Building maintenance decision-making often must consider complex, conflicting, and competing criteria, as well as to identify the relative importance of the criteria. In this study, current efforts were investigated for a better understanding of the types of decision-making problems and their corresponding criteria in the subject matter. The target of the literature review was studies performed in the last two decades, focusing on the most recent efforts.

The literature search was conducted in a wide range of areas, including maintenance management in manufacturing and industrial production, together with building maintenance. The search strategy comprised the following keywords: "maintenance management", "facility management", "building maintenance", and "decision-making", in several combinations with "criteria", "factor", "strategy", "policy", and "prioritization". Studies reporting criteria or factors that influence building maintenance processes and decision-making practices were included in the literature review for criteria identification. Examples of the criteria and corresponding studies in the literature are listed in Table 1 in chronological order.

Decision-making problems in these studies can be grouped into two main categories: (i) the selection of maintenance strategy or policy and (ii) prioritizing maintenance activities. Not all of these problems were addressed with the MCDM approach; however, the factors or criteria discussed in the selected literature provided the foundation to revealing the criteria utilized in this study. Consequently, criteria were identified from the literature based on the frequency of their occurrence. The most frequent criteria in the studies reviewed were, respectively: (1) cost, (2) occupancy, (3) health and safety, (4) condition, and (5) sustainability.

The example studies present various facility types with a higher frequency of identified criteria in different contexts. It is important to note that the identified criteria are applicable to any facility types as they represent fundamental criteria for decision-makers in building maintenance. In addition, specific criteria depending on facility type, such as "functional spaces", which refers to clinical, nursing, and support areas in healthcare facilities were not included in the criteria list of this study [41].

Table 1. Examples of the criteria in the literature.

Reference	Study Area	Identified Criteria
Johnson and Wyatt, 1999 [42]	Prioritizing major items of maintenance and maintenance programs	- Legal, safety, cost, condition, and operational considerations - Building status - Physical condition - Importance of building occupation, the effect on occupants - Cost implications - Effects on service provision

Table 1. *Cont.*

Reference	Study Area	Identified Criteria
Bevilacqua and Braglia, 2000 [43]	The factors for the selection of the maintenance type of an oil refinery	- Investment cost - Safety and environmental problems - Failure costs - Reliability - Mean time between failures - Mean time to repair - The criticality of the machine maintenance: safety, machine importance for the process, maintenance cost, failure frequency, downtime length, machine type, and production loss cost - Maintenance direct costs - Production costs
Parida and Chattopadhyay, 2007 [44]	The performance measurement criteria for the building maintenance activities	- Mean time between failure - Downtime - Maintenance cost - Type of maintenance task (planned vs. unplanned) - Health and safety - Security and environment - Employee satisfaction
Chang and Pan, 2007 [45]	Airport facilities maintenance policy selection	Breakdown consequences - Safety - Operation - Secondary damage Cost - Loss of production - Repair cost in man-hours - Repair cost of material Importance - Ease of failure detection - Bottleneck - Complexity of the system - Redundancy
Reichelt, Melnikas, & Vilutiene, 2008 [46]	Maintenance strategy selection for municipal buildings	- The costs of maintenance - Fulfillment of building user needs and expectations - The quality of maintenance of building structures and equipment - The efficiency of the maintenance process
Ali, Kamaruzzaman, Sulaiman, & Peng, 2010 [47]	Factors affecting housing maintenance costs in Malaysia	- Building materials - Building services - Building age and condition - Type of structure - Use of property - Failure to execute maintenance at the right time - New health and safety regulations - Budget constraints

Table 1. *Cont.*

Reference	Study Area	Identified Criteria
Flores-Colen, Brito, & Freitas, 2010 [48]	Criteria for prioritization of predictive maintenance of building façade	Physical performance - Type of the maintenance solution - Sustainability impacts - Preventive maintenance - Building's age - Remaining service life - Date of the last intervention Risk - The effects of the maintenance activity on the building and façade - Occupants' criticality of the areas affected Cost - Cost of the maintenance activity - The loss of use - The recurrent issues
Yau, 2012 [32]	Multi-Criteria Decision-Making (MCDM) for homeowner's participation in building maintenance	- Cost affordability - Building condition
Lin, Ali, & Bin Alias, 2015 [30]	Analytical Hierarchy Process (AHP) for procurement strategy selection in building maintenance	- Client's requirements - Project characteristics - External environmental factors
Kim, Sunitiyoso, & Medal, 2019 [49]	Facility Management (FM) decision-making for energy efficiency efforts in building maintenance	- Economic feasibility - Environmental impact - Institutional characteristics - Occupant impact - Technical practicality

In addition to these five criteria frequently mentioned in the literature, four more criteria were also discussed in the literature and considered relevant, therefore they are also included in this study: (6) funding availability, (7) code compliance, (8) duration, and (9) scheduling. In light of the selected literature, it is apparent that maintenance cost is critically important in building maintenance decision-making. Thus, if the available funds are not adequate, building maintenance practices will be ineffective or insufficient [50]. Building codes address the structural system, electrical and mechanical systems, fire safety, accessibility, security, building envelope, energy consumption, and materials. These codes are fundamental parts of the regulation of building construction in the United States. Code compliance is mandatory for new construction as well as any repair or replace activity in existing buildings to protect public health and safety [51]. The complexity of maintenance activities with conflicting tasks requires effective planning and scheduling of these activities. Hence, maintenance scheduling, which is the timing of any maintenance activity in the calendar year, should be considered along with business objectives. In addition, the duration of the maintenance activity is an integral part of maintenance scheduling [52]. Subsequently, the identified criteria and their definition in this study are presented in Table 2 in alphabetical order. The authors acknowledge that the identified criteria may be interpreted differently based on the maintenance activity or the context of the decision-making problem (e.g., code compliance requirements differ for roofing and heating, ventilation, and air conditioning (HVAC) maintenance needs), the identified list provides fundamental and general criteria for decision-makers in building maintenance activities. Having said this, it is important to note that based on the needs of individual problems, decision-makers may add specific criteria to this fundamental list.

Table 2. Identified criteria for building maintenance decision-making through literature review.

Criterion	Definition
Code Compliance	Compliance of the equipment with the most current building codes
Condition	Existing condition of the equipment at the time of maintenance activity decision
Cost	Total estimated cost of the maintenance activity
Duration	Total time span of the maintenance activity, such as 2 months, 1 year, etc.
Funding Availability	Available funds of the maintenance budget related to the maintenance activity
Health and Safety	Health and safety threats caused by the failure of the equipment
Occupancy	Purpose of the occupancy of the building where the equipment exists, such as classroom, research lab, office, meeting room, etc.
Scheduling	The time of the maintenance activity in the calendar year, such as from January to March, in July, etc.
Sustainability	Impact of the maintenance activity on the sustainability of the equipment

3.2. Step 2—Survey Development and Data Collection

Prior to developing the survey, researchers had several discussions with local FM professionals in the state of Colorado to determine if the criteria identified through literature review were applicable in the decision-making process from their perspectives. The common feedback gathered from these discussions was that cost and funding availability were dominant criteria in the building maintenance decisions. However, several instances, such as any maintenance need becoming a threat to the health and safety of occupants, require individual consideration with higher priority regardless of cost and funding availability. In addition, current condition, regulatory requirements and code compliance, and sustainability were highlighted in terms of predominating cost and funding availability in certain circumstances.

With these in mind, an online survey was developed with the purpose of verifying the criteria identified through the literature, ranking their importance, and identifying any additional criteria for building maintenance decision-making. Moreover, to support the exploratory nature of this study and to help establish the current status of FM, the survey included questions related to the current decision-making practices of building maintenance and current condition assessment practices.

The online survey targeted members of IFMA and APPA. These associations are well known for having a vast majority of professionals involved in corporate and higher education FM practices in the United States as well as at the global level. The roles of survey participants ranged from directors of facilities, assistant directors of facilities, and facility managers. The target population of the survey comprised the decision-makers in FM and building maintenance.

Twenty-one questions comprising ranking, multiple-choice, and open-ended questions were developed in the survey, with the approximate time of 10–15 min to complete. Qualtrics XM web-based account provided by Colorado State University was utilized for conducting the survey and data storage. A pilot survey was conducted prior to the distribution of the online survey; participation included 23 academic and professional members of FM. The pilot survey participants were selected from the population of FM professionals in the state of Colorado and academics in the researchers' institution. Based on feedback from the pilot survey, minor revisions were made to the multiple-choice questions, such as the ability to select more than one answer as an option.

The online survey instrument was approved by the Colorado State University Institutional Review Board in the exempt category and distributed by personalized e-mails, e-mail listings of IFMA and APPA, online forum groups, and social media networks of FM professionals in LinkedIn. Given that the survey was promoted in LinkedIn groups composed of professionals working in the FM domain who can be non-members of IFMA and APPA, the authors used the demographic questions to confirm that the participants had relevant experience in the FM domain, as presented in Figures 1 and 2.

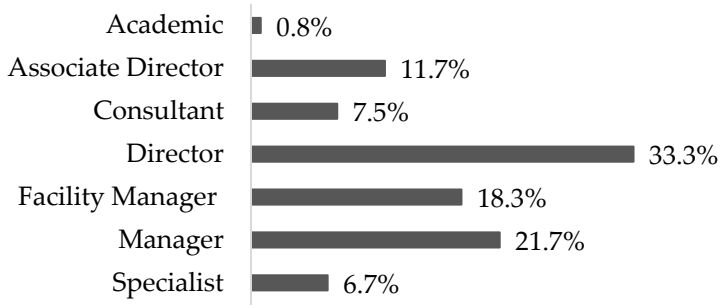

Figure 1. Job titles of survey participants.

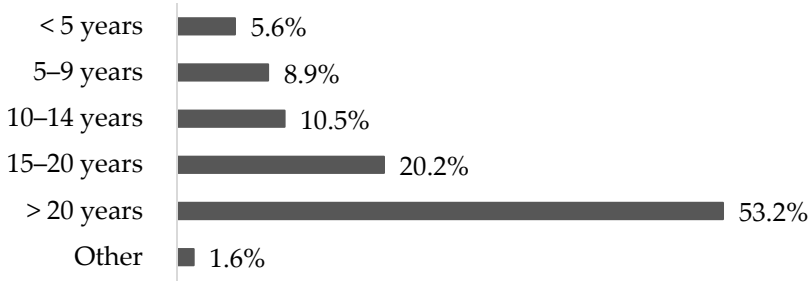

Figure 2. Participants' work experience in FM.

The online survey was open for ten weeks, and two reminders were sent to the target groups. A total of 219 responses were recorded in the web-based account, and 127 responses were included for full analysis as the remainder of responses were incomplete. Even though the response rate was impossible to calculate due to promotion of the survey in social media of FM professionals with membership numbers not known, the authors would like to acknowledge that they value the responses that were provided by qualified and experienced FM professionals in this survey. It is important to note that this study does not make any inference about the entire FM population based on our sample size.

4. Data Analysis and Results

Data were exported to Microsoft Excel, and analysis was performed in IBM Statistical Package for the Social Sciences (SPSS) Statistics 26 and NVivo qualitative data analysis software. Quantitative data from the online survey were analyzed using descriptive and inferential statistical analysis methods. The descriptive analysis comprises percentages and mean ranking determination, while the inferential analysis includes a two-sample t-test. Content analysis was performed for qualitative data from open-ended questions with conceptual analysis.

4.1. Characteristics of Online Survey Participants and Their Organizations

Almost 80% of the collected responses were from the United States, provided by 97 survey participants. Ten percent of the responses were from Canada, and the remaining responses were from Australia, China, India, Malaysia, Qatar, Trinidad and Tobago, United Arab Emirates, and the United Kingdom. Forty-four percent of the participants were employed in educational institutions; the remaining 56% were in non-educational sectors. In addition, 46.8% of the participants work in the public sector and 53.2% work in the private sector.

Directors, associate directors, facility managers, and other managerial positions in FM comprise 85% of the survey participants, as the targeted population of the online survey was decision-makers in FM and building maintenance. The distribution of the survey participants' positions is presented in Figure 1. Almost 75% of the survey participants had more than 15 years of FM experience, as presented in Figure 2. Considering these, it can be concluded that the majority of responses were

collected from experienced FM executives who have a significant role in the decision-making process of building maintenance.

These demographics showing that the respondents are composed of professionals with relevant positions and experiences support the reliability of the results. The main purpose of the study is to develop a set of criteria in building maintenance decision-making, and having the vast majority of the survey participants (85%) as decision-makers is a significant indicator of the reliability of their responses. In addition, it is important to note that the years of experience provided by survey responders are specific to their experience in FM, which also supports the reliability with almost 75% of respondents reporting more than 15 years of experience.

Participants were asked to provide information on the size of their department and the scale of the facilities or institutions served by their department. Of the participants' departments, 58.1% include less than 100 employees. Figure 3 shows the distribution of the department size of the participant's FM departments.

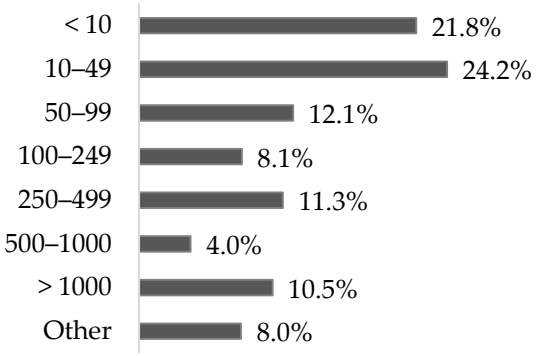

Figure 3. The total number of employees in the participant's FM departments.

The total gross square meter (m^2) of the facilities or institutions served by the participants' departments varies significantly and is presented in Figure 4.

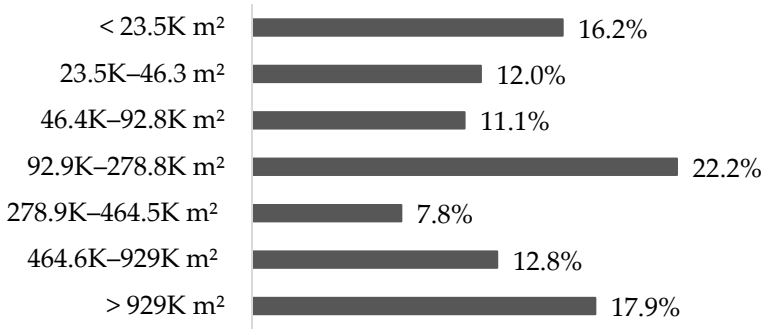

Figure 4. Total gross square meter (m^2) served by the participants' FM departments.

Participants also provided information on the maintenance budget managed by their FM department. The definition of maintenance budget in this study comprises the budget of corrective and preventive maintenance activities and excludes capital and operations budgets in FM. More than 60% of the participants manage less than US $5 M of the maintenance budget, and the distribution of the maintenance budgets of the participants' FM departments is presented in Figure 5.

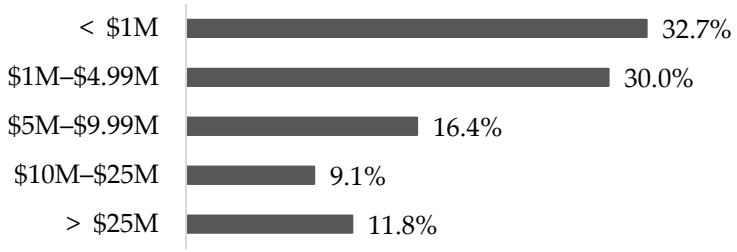

Figure 5. Maintenance budget of participants' FM departments in US dollars.

4.2. Ranking of Criteria Identified through the Literature Review

Participants were asked to rank the nine criteria identified through the literature review based on the order of importance for maintenance alternatives: code compliance, condition, cost, duration, funding availability, health and safety, occupancy, scheduling, and sustainability. The ranking scale was from 1 to 9, representing: "1" is the most important, and "9" is the least important. The mean ranking values of each criterion showed that "Health and Safety" ranked as the most important criteria with the mean ranking value of 1.90. "Code Compliance (2.93)" and "Condition (3.28)" criteria were ranked as the second and third most important criterion, respectively. The mean importance of rankings of the identified criteria is presented in Table 3.

Table 3. The mean importance ranking of building maintenance decision-making criteria.

Criteria	Mean Ranking
Health and Safety	1.90
Code Compliance	2.93
Condition	3.28
Cost	4.44
Funding Availability	4.94
Occupancy	6.02
Sustainability	6.98
Duration	6.98
Scheduling	7.52

The mean importance of rankings for the identified criteria provided an overall understanding of their significance within the entire sample population. The feedback from the local FM professionals in public organizations prior to the survey development highlighted that cost and funding availability are the most important in building maintenance decision-making. However, the ranking values established that "Health and Safety", "Code Compliance", and "Condition" are predominant compared to "Cost" and "Funding Availability". Considering these, the researchers aimed to reveal any statistically significant differences within criteria ranking among the sample population between public and private organizations. Consequently, the mean importance of criteria rankings and their statistically significant differences (if any) were investigated between public and private organizations.

A statistically significant difference was identified ($p < 0.05$) in public vs. private organization participants for the ranking of the "Condition" criterion. The public organization participants ranked "Condition" higher than private organization participants. Moreover, the "Sustainability" ranking was significantly statistically different ($p < 0.05$) between public vs. private organization participants. Private organization participants ranked "Sustainability" higher than public organization participants. The *p*-values of two-sample t-tests are presented in Table 4 within related sample groups.

The mean ranking importance of criteria has the potential to identify possible differences in FM and building maintenance practices among participant groups. Given that, statistically significant differences for individual criterion can be considered as an indicator to determine the FM organizations' efforts based on their existing challenges. Particularly in the "sustainability" criterion case, the reason

behind the higher ranking of this criterion in private organizations compared to public ones might be due to the additional costs of sustainable practices. Although it is not possible to determine the causes of the statistically significant differences in the mean rankings as part of this study, these results are interesting in terms of supporting the need for further research.

Table 4. Mean importance ranking and two-sample *t*-test *p*-values for private and public organization participants.

	Public	**Private**	
	Mean	**Mean**	***p*-Value**
Health and Safety	1.9123	1.7879	0.6080
Condition	**2.8421**	**3.6212**	**0.0030 ***
Code Compliance	3.0702	2.8788	0.6240
Cost	4.4912	4.4545	0.8810
Funding Availability	4.7895	5.0455	0.4800
Occupancy	5.9649	6.0758	0.7700
Duration	7.1053	6.9545	0.5620
Sustainability	**7.3860**	**6.6212**	**0.0450 ***
Scheduling	7.4386	7.5606	0.6460

* $p < 0.05$.

4.3. Additional Criteria through the Survey Results

Participants were also asked to provide additional decision-making criteria that were not suggested in the ranking question of the survey. Eighty-one survey participants provided 198 additional criteria or factors for building maintenance decisions. However, 51 out of 198 were similar to the identified nine criteria of the study, such as "regulatory issues", "financial considerations", "occupant satisfaction", etc., and they were excluded from further analysis. The remaining 147 criteria or factors were analyzed in NVivo qualitative data analysis software. The purpose of the content analysis performed in NVivo software is to identify the frequency of the additional criteria suggested by the respondents in the survey. NVivo grouped linguistically similar words in single word categories with their frequencies from the list of 147 criteria. The participants also had the opportunity to provide the importance of their suggested criteria as "major" or "minor". The provided importance for the suggested criteria was "major" for 124 criteria out of 147.

The results of the NVivo analysis provided a preliminary understanding of concepts related to additional criteria provided by the survey respondents. Word categories and their frequencies of the additional criteria (including synonyms or closely related words) are presented in Table 5. The presented results are provided by NVivo as they were exported, and there is no additional clustering performed prior to the data upload into the software.

The researchers observed two main concepts from the word category and frequency results of the NVivo analysis: "Strategic Business Planning" and "Impact of Failure". The word frequencies of "plan," "business," "operations," "critical," "future," and "requirement" were associated with the concept of "Strategic Business Planning". The two key fundamentals of strategic business planning are effectively setting the direction of the organization and implementing operational processes to achieve business objectives within that direction [53]. In the concept of FM and building maintenance, strategic business planning can be defined as aligning FM functions with the organization's business continuity with a clear understanding of the organization's goals and objectives in the short-term and long-term [11,54]. For instance, in the case of relocation planning of the organization, maintenance activities need to be rescheduled or sustained.

In addition, "impact," "failure," "consequence," "risk," and "replacement" were connected with "Impact of Failure". The failure of any system, equipment, or component has several consequences, such as threats to health and safety, environment, occupant comfort, and loss of energy and operational

efficiency [55]. For example, the failure of HVAC equipment or systems may affect the entire building, since these systems are complex and centralized [2].

Table 5. The results of content analysis in NVivo software.

Word	Count	Weighted Percentage (%)	Similar Words
plan	13	3.77	plan, planned, planning, plans, program, project, projects
business	9	2.83	business
impact	9	2.67	affected, impact
operations	9	2.15	control, function, operational, operations, performance, run, work
critical	8	2.52	critical, criticality
failure	7	2.20	failure
risk	7	2.20	risk
requirements	6	1.89	demands, expectancy, need, needed, requirements
consequence	6	1.42	consequence, effect, effective, event, issues, results
future	5	1.57	future
replacement	5	1.57	renewal, replacement
support	5	1.57	funding, support
initiatives	5	1.10	initiatives, innovative, institution, institutional, knowledge
asset	4	1.26	asset, assets
customer	4	1.26	customer
expenditure	4	1.26	expenditure, expenditures, spending
management	4	1.26	deal, management
space	4	1.26	space
staff	4	1.26	staff
technology	4	1.26	technological, technologies, technology

As a result of the content analysis, researchers incorporated "Strategic Business Planning" and "Impact of Failure" into the list of identified criteria in this study. The two additional criteria were synthesized based on the researchers' observations of the similarities and frequencies of the linguistic meanings of keywords, as described above. Table 6 represents the criteria for building maintenance decision-making identified in this study.

Table 6. The final list of building maintenance decision-making criteria in this study.

Criteria
Code Compliance
Condition
Cost
Duration
Funding Availability
Health and Safety
Impact of Failure
Occupancy
Scheduling
Sustainability
Strategic Business Planning

4.4. Decision-Making Practices in Building Maintenance

Around 45% of the participants provided that "Past Experience and Expert Opinion" were their current primary decision-making practices in building maintenance. Past experience and expert opinion refer to obtaining the input of project managers and supervisors related to maintenance needs and decision-making. The two other practices provided in the survey were "Run-to-Failure" and "MCDM models". Run-to-failure is considered making maintenance decisions when the system or

component or equipment breaks down, and MCDM models are identified as mathematical models that help decision-makers based on a set of criteria. MCDM models and run-to-failure practices constitute around 20% of the responses individually, and 15% of the participants provided different practices for their building maintenance decision-making under the "Other" category. Each of the answers provided under the "Other" category reflected the individual practices of the participants, and they could not be grouped under similar categories. However, common themes in the mentioned practices are identified as follows: life cycle assessment, life cycle cost analysis, deferred maintenance, and maintenance history. The distribution of the building maintenance decision-making practices of survey participants is provided in Figure 6.

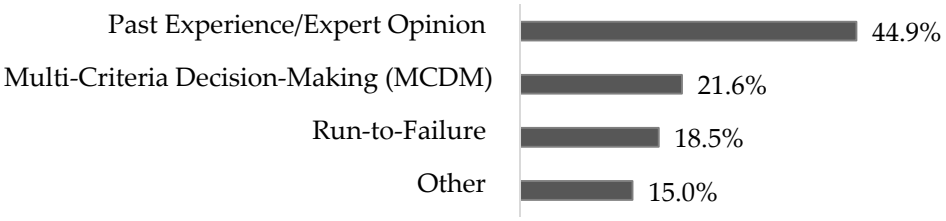

Figure 6. Distribution of decision-making practices in building maintenance.

An open-ended question followed the multiple-choice question to gather the participants' recommendations on the best practice of building maintenance decision-making. Based on the qualitative analysis conducted in NVivo software, the common themes in the best practice of decision-making recommendations can be summarized as follows: (i) energy consumption and performance analysis, (ii) return of investment (ROI), (iii) cost–benefit analysis, (iv) life cycle cost analysis, (v) financial policy of the institution, and (vi) facility condition index (FCI). These recommendations can be considered as part of effective FM practices, which then lead to better decisions. However, none of them can be referred to as a decision-making practice, let alone a best practice.

4.5. Condition Assessment Practices in Building Maintenance

Local FM professionals involved in the discussions prior to the survey development indicated that due to the lack of resources, condition assessment had not been practiced sufficiently in their institutions for more than a decade. Following this feedback, the researchers collected information about existing condition assessment practices of survey participants. Two specific questions were asked to participants: (i) who conducts condition assessments and (ii) how condition assessments are performed in their institutions. The first question indicates the individuals and/or parties involved in the condition assessment practices such as consultant, contractor, and in-house staff. The way condition assessments are performed was the second question, including remote sensors, non-destructive testing, and visual inspection. These questions were designed as multiple-response, and the participants had the opportunity to select more than one practice in each question.

The results show that 126 participants provided 247 answers for the individuals and/or parties involved in their condition assessment practices. Consultant and in-house staff comprised the majority of the answers. In addition, visual inspection was mentioned as the most common way of condition assessments were practiced, with almost 50% of the answers. The distribution of condition assessment practices is shown in Figures 7 and 8. Additionally, other methods utilized in condition assessment included analysis of historical maintenance records, review of the energy use and repair costs, and occupant observations and comments.

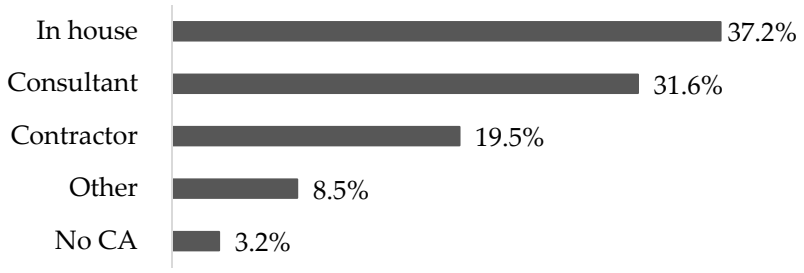

Figure 7. Distribution of the individuals conducting condition assessment.

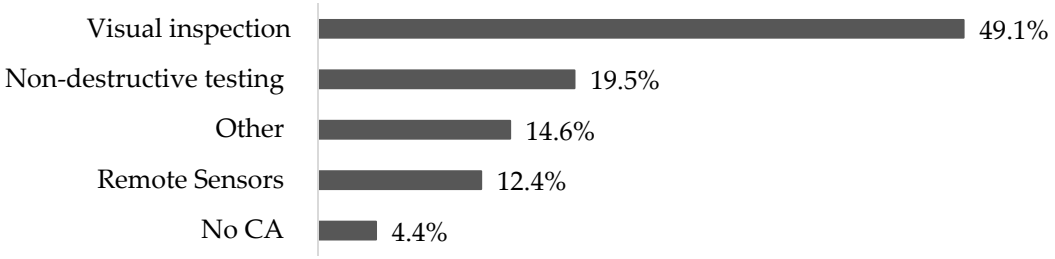

Figure 8. Distribution of the methods utilized in condition assessment.

5. Discussion and Conclusions

The primary purpose of this study was to develop and rank a set of criteria needed for constructing an MCDM model for use in building maintenance processes in FM. To do so, the study incorporated a literature review and an online survey with FM professionals, including ranking, multiple-choice, and open-ended questions. The findings provided as a total of 11 criteria to use in building maintenance decision-making: code compliance, condition, cost, duration, funding availability, health and safety, occupancy, impact of failure, scheduling, strategic business planning, and sustainability. It is important to note that these criteria comprise a fundamental and general list for building maintenance decision-making problems, and individual systems and facility types might require the consideration of additional criteria.

The survey results assisted in revealing the importance of nine of these criteria identified through the literature review, respectively: (1) health and safety, (2) code compliance, (3) condition, (4) cost, (5) funding availability, (6) occupancy, (7) sustainability, (8) duration, and (9) scheduling. Interestingly, the mean importance rankings highlighted the importance of "Health and Safety", "Code Compliance", and "Condition" above "Cost" and "Funding Availability," which were anticipated to be dominant criteria. In addition, the researchers determined two more criteria from the feedback of survey participants regarding additional criteria to be considered in the process: "Impact of Failure" and "Strategic Business Planning". All of these criteria will be utilized in the researchers' future implementation of MCDM within a case study.

The findings suggest that "Condition" was identified as one of the top criteria in building maintenance decision-making, highlighting the need for effective condition assessment practices. Further research is required to better reveal the time interval, capacity, and process of condition assessment practices. In addition, documentation and reporting of condition assessment practices are important to get the maximum benefit from condition assessment outputs.

"Sustainability" criterion was ranked with lower importance compared to other criteria in the survey. Possible reasons behind this might be the misconception of sustainability, the multifaceted nature of sustainability as a concept in terms of social, economic, and environmental considerations, and the additional upfront costs of sustainable practices. In some cases, repairing equipment might be considered as more sustainable compared to replacement, and overall building maintenance practices assist sustainability concepts in the long-term. However, it is not possible to determine the main

reason for the lower importance of the sustainability criterion within this study, and further research on sustainability practices in FM is necessary.

To support the exploratory nature of this study, current building maintenance decision-making and condition assessment practices were revealed in the survey results. Almost half of the participants provided that "Past Experience and Expert Opinion" is their current primary decision-making practice in building maintenance. Furthermore, the survey results showed that around 75% of the participants had more than 15 years of FM experience, and more than 70% of these participants were serving in director, facility manager, or other manager positions in the FM industry. While this shows a large amount of experience, it also reveals that the workforce is aging in the administrative and executive levels of the FM industry. As a consequence, this aging workforce of executives in FM will be transitioning to retirement in the near future, and the need for a systematic and structured way for building maintenance decision-making is important. Additionally, training, scholarship, and education programs, as well as effective pipeline strategies, have the potential to address the aging workforce of FM professionals in the administrative and executive levels.

Visual inspection was identified to be the most common method utilized in condition-assessment, and only 4.4% of the participants reported the lack of condition assessment method in their FM practices. On the other hand, the discussions with local FM professionals prior to the survey development highlighted the lack of condition assessment practices. In addition, condition assessments conducted by in-house teams, consultants, or contractors, who comprise the majority of entities in the survey results, increase the need of additional funding. Given that, resource effective condition assessment practices are essential in building maintenance and FM.

Resource allocation with the focus of maximizing the outcome has a significant effect on the performance of the built environment. It is evident that the resource constrained environment of FM affects the quality of maintenance services, which then affects occupant satisfaction, the performance of the built environment, and the mission of organizations. The criteria identified in the context of this study fills a gap in the lack of comprehensive criteria in building maintenance decision-making. Additionally, the findings of the study revealed that criteria such as "Health and Safety", "Code Compliance", and "Condition" have higher importance compared to "Cost" and "Funding Availability". Even though financial constraints influence FM practices to a large extent, the nature and complexity of building maintenance requires comprehensive criteria, as evidenced by the summarized findings.

In addition to the criteria developed, this study revealed statistically significant differences in the mean rankings of some of these criteria between public and private organization participant groups. These differences support the need for the development of an MCDM framework that could be customizable by each organization. As a first step in developing an MCDM approach, the scope of this study is limited to identifying and ranking a set of criteria that can be used for building maintenance decisions. Future studies can utilize the identified criteria in the development of a full scale MCDM model. Moreover, the applicability and significance of identified criteria in different FM contexts such as healthcare, industrial, educational, and office can be investigated. In addition, the future studies can reveal the differences in building maintenance and decision-making practices in public and private institutions.

The findings further revealed that the current decision-making practices depend mostly on expert opinion; however, the decision-makers in the FM industry are aging. Systematic and structured decision-making practices in building maintenance will have a significant contribution to address this challenge as well as establishing effective FM strategies.

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