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SMARTS-Based Decision Support Model for CMMS Selection in Integrated Building Maintenance Management

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Abstract: An Integrated Maintenance System (IMS) represents a coordinated methodology including different maintenance policies, such as preventive and corrective. These systems rely on Computerized Maintenance Management Systems (CMMSs), specialized software available from multiple suppliers. Given the diverse features of commercial CMMS software, this work aims to develop a decision support model for CMMS evaluation emphasizing an integrated perspective within IMS. A Simple Multi-Attribute Rating Technique using Swings (SMARTS) method was used to build the decision model. Five existing market software were evaluated, and a minimum profile was defined for IMS requirements. Three of the assessed software types met these minimum IMS requirements, while the absence of certain features limited scores for others. The results obtained from the decision support model provide a simple and synthetic way to support decision-makers and promote a systemic view of the software features. The evaluation model has the advantage of adopting criteria that integrate software evaluation; its framing in a building maintenance management model; and new technological trends, such as Building information modeling (BIM), Virtual Reality (VR), Augmented Reality (AR), and Internet of Things (IoT). Considering these outcomes, future developments and alternatives can capitalize on these trends.

Keywords: building maintenance; maintenance management; Computerized Maintenance Management System (CMMS); decision making; operations and maintenance

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1. Introduction

Maintenance is defined by EN 13336 [1] as the "combination of all technical, administrative, and managerial actions during the life cycle of an item intended to retain it or restore it to, a state in which it can perform the required function". In a building context, although the definition is simple and well-known, there are still many challenges for these actions to be carried out properly.

The cost involved in maintenance is an important issue that demands attention. According to a review conducted by [2], which included a sample of nine studies distributed in North America, Europe, and Australia, results showed that the operation phase constitutes 11 to 34% and maintenance 2 to 20% of residential buildings. The contribution of the different phases is influenced by the premises and limits adopted. Even with significant cost amounts, activities involved in maintenance are often neglected by those responsible for allocating financial resources, considering that deferral of expenditure represents an economy on a limited budget. Moreover, maintenance expenditure, in the case of many companies, is not usually associated with rapid revenue growth.

Maintenance strategies, efficient techniques for planning and scheduling work orders and resources, and monitoring maintenance activities necessitate a systematic approach to information management [3]. This approach is typically operated in software, referred to as Computerized Maintenance Management System (CMMS). Some considerations of benefits and relevant characteristics of CMMS are addressed in several publications, such as a robust digital database on building elements [4,5]; Key Performance Indicators (KPIs) to assess whether maintenance performance is satisfactory [6,7]; an improved performance when addressed with new technological features (Building Information Modeling (BIM), Virtual Reality (VR), and Augmented Reality (AR), as well as the use of Internet of Things (IoT) sensors) [8].

CMMS selection has been the research subject of some authors. Ref. [9] developed a methodological structure that allows an optimized choice among the best CMMS software under aspects of maintenance information technology. Ref. [10] used the TOPIS method associated with the VIKOR technique to develop a method of CMMS choice for a dairy company. Ref. [11] defined criteria for CMMS selection from online tools through a case study in an oil company and then evaluated the software impact on the company's structure functioning. Ref. [12] presented a decision-making method based on the Analytical Hierarchy Process (AHP) multicriteria method to compare different CMMS alternatives. A summary of the criteria and sub-criteria adopted by the authors is presented in Table 1.

Table 1. Criteria and sub-criteria adopted by different authors for choosing CMMS.

Authors	Criteria	Sub Criteria
[12]	Compatibility and portability	Integration level with other software; Portability to mobile devices
	Performance	Ease of in-house customization; Functional fitness; Modules' availability (integration and extension); Reports (availability, reliability, and customization); Updates' availability
	Security	Access control; Backup availability
	Supplier-related	Online support; Proximity (technical assistance); Reputation and experience in the industry; Training and consulting services
	Factors usability	Ease of learning; Ease of operation; User-friendly graphical interface
[9]	Cost	Purchasing cost; Updating cost
	Data and Reporting	Documentation and training; Easy data transfer; Reports accuracy
	Performance	Compatibility with organizational structure; Ease of use; Implementation time
	Quality	Efficiency; Functionality; Maintainability; Portability; Reliability; Usability
	Technical	Cross-module integration; Flexibility for customization; Technical support
[10]	Costs	Software's implementation cost; Software's purchase cost; Software's update and upgrade costs
	Data management	Number of available reports in software; Privatization of software; Software's accuracy of reports
	Performance	Software's flexibility; Software's technical characteristics; Software's user-friendliness
	Software Implementation	Aggregation level with other management software applications; Ease of implementation
	Software security	Automatic system for backup; Security methods to protect systems against illegal access
[11]	Architecture; Flexibility; Functions; Language; License: portability; Scalability; Simplicity; Types of maintenance.	There was no division into sub-criteria by authors

Although the investigations mentioned above suggest some CMMS selection criteria (Table 1), they do not have a specific focus on buildings and do not evaluate specific functions inherent to building maintenance use. Issues such as maintenance policy, classification according to urgency, asset classification into maintenance elements, and a robust database based on inspection procedures are some essential aspects not evaluated in the mentioned models. Given these limitations, the present study aims to develop a multicriteria decision support model based on the Integrated Maintenance System (IMS) model for CMMS evaluation. IMS is an action methodology coordinated between different functions involved in building management, in which functional and technical activities are integrated [13]. This integration covers existing or emerging maintenance policies. This decision support model should consider new trends, technologies, and methodologies, such as BIM, VR, AR, and IoT.

2. Toward a Decision Support Model: Integrated Maintenance System (IMS) and Building-Specific CMMS Requirements

Building management involves different activities with distinct characteristics and skill requirements. For technical activities, there are specific interventions in construction elements or components, such as reinforcing a concrete pillar. For functional activities resulting from the use type of the building, the following aspects must be observed: the rules of use by users, legislation, and relationships between people, among others. From an economic point of view, accounting and financial control issues arise from the costs of ownership and building maintenance. In this sense, the management of a building is usually subdivided into these activity areas. However, this segmentation can lead to challenges in establishing an appropriate action strategy that addresses all integration demands.

The objectives of an IMS are to discover the state of buildings through performance indexes, know trends (related to constructive solutions, users, builders, etc.), predict based on trends, and take advantage of trends to typify actions and optimize maintenance/performance costs [13]. The same author suggested an action methodology coordinated among different functions involved in building management, which integrated functional and technical activities, called the Integrated Maintenance System (IMS). This integration covers existing or emerging maintenance policies. Figure 1 shows the different areas of an IMS according to three major groups: registration, maintenance plan, and intervention. For the presented approach, it is considered that the Integrated Maintenance System (IMS) can be implemented through a CMMS applied to buildings. It should cover an integrated maintenance policy, including preventive maintenance, whether systematic or conditioned, as reactive maintenance. An IMS should cover the main requirements of a maintenance management system.

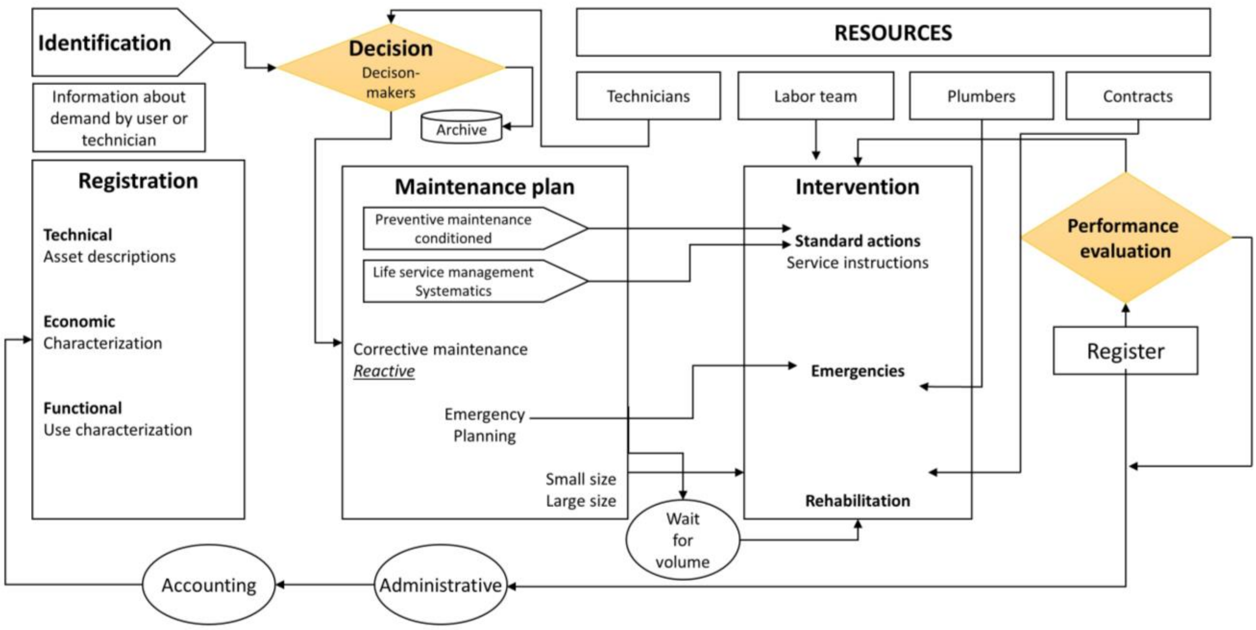

Figure 1. Integrated Maintenance System (IMS), adapted with permission from [13].

In the group related to registration, all assets should be recorded as:

- Identification of project and construction authors;

- Constructive description by elements;
- Project information and files;
- Relevant characteristics of constructive solutions;
- Subdivision into specialties;
- Historical report (interventions, adaptations, surveys, etc.).

In addition to these technical aspects, detailed information on costs and the use of the building are relevant. In turn, the group related to the maintenance plan is subdivided into:

- Preventive maintenance: this presupposes routines of inspection and observation of pre-pathology symptoms.
- Lifetime management: integrates the set of planned and systematic actions based on expected service life for specific construction components. It seeks to identify the need to reset a component whenever the end of life is foreseen.
- Corrective maintenance: this groups the set of actions resulting from the identification of pathological manifestations.
- Finally, the intervention group provides ways in which a building operates to be typified according to:
- Standard interventions: comprises a uniformity of the most frequent interventions. Information forms and diagnostic support procedures can be elaborated.
- Emergency interventions: a pattern of requests is sought to typify this type of intervention.
- Rehabilitation interventions: should be analyzed in a context outside the scope of maintenance.

An IMS should contemplate receiving and sending external information in the presented structure. An example occurs when information about a call is received and the system provides information to other sectors, such as communicating to third-party companies or sending information for financial control. The human, financial, and infrastructure resources required for the maintenance operations listed in Figure 1 must be scaled appropriately according to the system deployment demand.

For the presented approach, the Integrated Maintenance System (IMS) can be effectively implemented through a Building-Specific CMMS. This CMMS should cover an integrated maintenance policy because it should include both preventive maintenances, whether systematic or conditioned, and reactive maintenance, which can be classified according to the urgency or intervention scale. Consequently, the fundamental requirements of an efficient maintenance management system should be fully addressed within an IMS. In this study, CMMS associated with other software that can compute the IMS functions will be named Compatible Integrated Maintenance Software (CIMS).

Some considerations of relevant characteristics of CMMS, which are considered compatible with an IMS, are addressed in several publications. A study conducted by [14] with respondent participants sampled from industry professionals and researchers pointed out, among its several conclusions, that the CMMS implementation represents a solution that fills a gap between the demand for tools that can promote effectiveness and efficiency at work and integration with academic knowledge generated in publications. The proposed IMS intends to take over this space.

One of the essential functions of the IMS involves maintenance plans and interventions through a database that must be continuously updated. Ref. [4] reports the benefits and characteristics of preventive maintenance software that includes a digital database on building elements. The software allows the insertion of detailed information on preventive inspections so that the respective maintenance team can consult the information in the future and contribute to avoiding high costs incurred by hiring specialists. The referred authors also argue that inspection costs are small, allowing a reduction in the number of unforeseen interventions. By using better actions, maintenance costs can be reduced substantially.

In a study related to identifying requirements for implementing a Maintenance Management System for a Malaysian Polytechnic, a case study was carried out in eight units in the institution [5]. The study's results corroborate the idea of advantages associated with a database. Among the investigation findings, it is stipulated that an approach to a Maintenance Management System should provide a robust database, such as complete information about registered complaints and defect control. In addition, integrating maintenance planning offers better working conditions for the maintenance team through decision-making processes.

Considering the scope of a maintenance management system and the costs involved over time, it is necessary to assess whether maintenance performance is satisfactory. Key Performance Indicators (KPIs) comprise tools for this purpose and are typically monitored in CMMS. The choice of KPIs has been the object of study in different types of buildings, such as hospitals [7,15] and office buildings [6]. A selection must be made according to the objectives to be achieved, related to technical, economic, and organizational aspects, according to standard EN 15341 [16]. In this sense, the software must allow customization, considering the institution's needs and available information.

Finally, an important aspect is that the CMMS must be integrated, in addition to a systematic maintenance policy and a program of development of employees, with technological elements in constant evolution that can influence maintenance performance. The use of Building Information Modeling (BIM), Virtual Reality (VR), and Augmented Reality (AR), as well as the use of Internet of Things (IoT) sensors, consists of technologies that can contribute to performance maintenance [8]. Applying BIM in operation and maintenance reduces operational expenditures. Interaction among different stakeholders, such as customers, construction contractors, design contractors, expertise authorities, commissioning authorities, facility managers, and asset managers, can be digitized and therefore optimized [17]. Challenges for a broader BIM implementation in buildings' operation and maintenance phase involve aspects such as improving information interoperability from the design and construction phase [18]. VR and AR can be revolutionary in supporting designers, technicians, and facility managers in their activities thanks to the ability to provide immersive visualization of the asset and to superimpose instructions, sensor data, or technical schemes right in their field of view, as well as allowing hands-free communication [19]. The IoT network can monitor components, such as HVAC systems for facility management, and detect failures [20]. It can be inferred that these technologies provide better design interpretations and more and faster information, and subsidize better decisions.

The requirements derived from the IMS, referred CMMS benefits, and these new technological trends provide valuable insights into the functionalities and capabilities that a CMMS must possess to seamlessly integrate into the maintenance workflow of a building. These insights are a fundamental source of content for the Decision Support Model for CMMS Selection, especially in structuring requirements and criteria, ensuring that the chosen CMMS aligns with the overarching goals of efficient maintenance management.

3. Methodology

The Multi-attribute Utility Theory (MAUT) is a technique to support decision making. It is used when a decision-maker must choose from a limited number of available alternatives. The overall evaluation of an alternative can be achieved by the weighted addition of its values concerning its relevant attributes [21]. Part of the process is qualitative, which involves the identification of objectives, and part is quantitative, in the definition of an objective function in the form of the value model [22].

In this study, the Simple Multi-attribute Rating Technique using Swings (SMARTS) method was used, which consists of a technique of use and measurement of the Multi-attribute Utility Theory (MAUT) [23]. Once the score of each alternative, as well as the marginal replacement rates for each criterion, has been calculated, the alternatives are classified from the highest score (best option) to the lowest (worst choice) [24]. For the SMARTS application, nine steps are considered. It consists of a technique of use and measurement of the MAUT, which adopts the Swing Weighting technique for assigning weights in criteria and Equation (1) to obtain the final scores. SMARTS was selected because it is a simple technique to apply, and the results allow obtaining a score. For the application, nine steps are considered [23]:

- Step 1—Goal and identification of decision-makers: this consists of identifying the value function's purpose and the actors and organizations in the decision context.
- Step 2—Decision tree: this consists of identifying a structure (hierarchy of objectives or value tree) or list of attributes potentially relevant to eliciting values of each decision-taker or group of decision-makers. Attributes must be independent of each other. That is, the evaluation of one attribute must not depend on the evaluation of another.
- Step 3—Identification of alternatives: if the purpose of the identification does not specify the possible actions, the attribute structure of step 2 can be used to create it. The result of this step consists of a complete list of alternatives to be evaluated and becomes more significant the greater the number of attributes. Scoring rules must be well defined before the evaluation process.
- Step 4—Object evaluation matrix: consists of formulating an array of alternatives and evaluations according to each attribute (criterion or sub-criterion). Input data should be scores or physical measures, if available.
- Step 5—Dominated Options: eliminate dominated options if easily recognized by visual inspection.
- Step 6—One-dimensional utility value: defines the one-dimensional value function shape for each criterion type. If a linear function is used, it comprises a simple computational step.
- Step 7—Part 1 of the Swinging Weighting technique application: this technique calculates weights, also called substitution rates, for criteria or attributes. For its use, a hypothetical situation is initially created, in which all sub-criteria receive the worst possible evaluation. This situation is assigned a score equal to zero. Then, the decision-taker is prompted, within a criterion, to choose only a sub-criterion to receive the maximum evaluation. This sub-criterion will receive a score of 100. In the next step, the decision-taker is asked which is the second sub-criterion he would assign the maximum score, and thus, an ordering is performed.
- Step 8—Part 2 of the Swinging Weighting technique application. All multi-attribute utilities are calculated. Considering that the former received a score of 100, the decision-maker is asked what score he would assign to the second, and so on. As an example, considering three attributes that received scores of 100, 70, and 30, a sum is made, and it is possible to obtain percentage values of the weight of each.
- Step 9—Decision making. The result is obtained as defined in Equation (1) by the highest score listed in expression (1).

$$V(a) = \sum_{j=1}^{n} W_j V_j \quad (1)$$

where $V(a)$ is the alternative performance about criterion j, W_j is the weight of criterion j, and V_j is the alternative performance about criterion j.

The SMARTS method was used to assign weight to the criteria and evaluate the alternatives, generating an overall score in each criterion. A global score was not calculated. It generated a performance profile by a radar graphic, with multivariate data of different variables. This format was adopted because it considers that the results presented by criteria comprise a better way to interpret results according to the decision objective. Each criterion's performance was calculated by Equation (1). Five CMMS alternatives were evaluated, and the decision-making process results are presented in topic 4.

4. Application and Results

4.1. Decision Support Model Structure

The model was elaborated to evaluate CMMS software composition regarding fulfilling essential functions in an IMS and consider decision-makers stakeholders involved in the software's acquisition, implementation, and use (Step 1).

Criteria and sub-criteria involved in the model were structured in a decision tree (Step 2) and are detailed in Table 2, in checklist form. The criteria were structured based on the characteristics of the IMS explained in this study and were revised considering the criteria cited in the studies addressed in this study. The result led to objective subdivision into six main criteria: registration, divided into general information and access to documents; maintenance plan; intervention; resources; usability and safety; and performance evaluation and incorporation of features. The last criterion evaluated the current technological advancement and customization demands.

Table 2. Structuring the decision tree with criteria and sub-criteria.

(A) Registration.
(A.1) General information. Software must allow the registration of:
A.1.1. Functional records: institution or condominium identifications and address; Information on the types of uses of the building; Identification of those responsible for the operation of the building (manager, liquidator, etc.); Numbering of licenses and deadlines (Examples: get used and leave the fire department)
A.1.2. Construction data—Dates of technical delivery, obtaining and sealing of permits (Example: fire department), start and end of construction; Identification of the technician responsible for the enterprise; Measures and indicators (number of floors, built-up areas, total area, perimeter, occupancy rates, among others)
A.1.3. Designers, builders, and technological consultancies (during the design and construction phases): functional classification of projects, the scope of services, identification and contacts of companies or professionals, start and end dates of services
A.1.4. Designers, builders, and technological consultancies completed (during the phases of use and operation): functional classification of projects, the scope of services, identification and contacts, start and end dates of services
A.1.5. Registration of elements—Functional classification, involving a structure with subdivisions from the enterprise to the source element of maintenance; Description of the maintenance source element; Location of assets and elements sources of maintenance; Specifications of the materials used, concerning models and brand; Specification of service life of materials and components
(A.2) Access to documents. You must upload these files in software:
A.2.1. Projects in digital files
A.2.2. Approvals documents and project permits during construction
A.2.3. Codes and conventions on the use of the building (e.g., condominium convention), manuals and specifications on the use of the building
A.2.4. Consulting Reports and Technological Control
A.2.5. Budgets and spreadsheets
(B) Maintenance Plan. The software must allow:
B.1. Receipt of demand identification (called), validated by decision making
B.2. Record the description of procedures (inspection, cleaning, preventive maintenance, corrective maintenance), according to the element of maintenance source and/or functional assembly
B.3. Classification of the registration into categories (inspection, cleaning, preventive maintenance, corrective maintenance), according to the element source of maintenance and/or functional assembly
B.4. Schedule of tasks related to maintenance routines, according to the functional structure of the element's sources of maintenance
B.5. Service order forwarding, through the software, to the team that will perform the designated activities in the task scheduled
B.6. Present a pre-existing database with typical procedures for cleaning, inspection, and maintenance operations of buildings
B.7. Record the identification of utilization indicators, and reading of operating parameters after an inspection or in real time (regardless of the mode of registration)
B.8. Record evaluation of the general state performance after inspection
B.9. Record general state cleaning, and deterioration, among other information after inspection
B.10. Issuing alert about the need for replacement of components due to the end of their useful life or due to failure recorded by a sensor or any other type of registration

Table 2. *Cont.*

(C) Intervention. The software must allow:
C.1. Typification of intervention demand: standard, emergency, rehabilitation
C.2. Indication and referral to the team that will carry out the intervention (contracted company, permanent team, emergency guidance) in case of unplanned emergencies
C.3. Registration and provision of access by the team responsible for the type forms and technical information of conduct
C.4. Management and control of small and large demands that will lead to the need for rehabilitation
C.5. Record the progress of implementation of the intervention, with beginning and end
C.6. Record the performance evaluation after the intervention performed
C.7. Photo registration, reports, or similar
C.8. Registration of projects and any other document prepared after the intervention
(D) Resources. The software must allow:
D.1. Identification and registration of information on current contracts with third-party companies
D.2. Identification of permanent employee registration and over-notice
D.3. Material inventory control
D.4. Issuing orders or communications for requisitioning materials
D.5. Control of financial resources
D.6. Identification and registration of the allocation of costs (appropriation) in each intervention
D.7. Identification and registration of the allocation (appropriation) of materials in each intervention
D.8. Issuance of information report of resources consumed (material or financial) for technical and economic registration after confirmation of services and expenses
(E) Usability and Security. The software must allow:
E.1. Operation via smartphone or tablet
E.2. Operation of the system through a web application
E.3. Communication of calls (or service orders, alerts, among others) through external communication to the software (email, SMS, among others)
E.4. Schedule data backup in a scheduled manner
E.5. Providing online support during business hours
E.6. Providing training through online or EAD videos
(F) Performance evaluation of maintenance and functionalities incorporation. The software must allow:
F.1. Set up KPIs according to available information or database and generate reports
F.2. QR code generation for asset identification and opening of user calls
F.3. Possibility of reporting configuration: Service Level Agreement (ANS), failures, among others
F.4. Connection with Business Intelligence (BI) software
F.5. Connection to sensors and/or controllers for reading data
F.6. Use of Near-Field Communication (NFC) in equipment
F.7. Customization of solution for the customer that is not in the commercial proposal
F.8. Access the elements sources of maintenance and registration through virtual reality, augmented reality, and BIM

Each criterion was subdivided into attributes that represent functionalities to be objectively measured. The detailed items were listed in “yes” or “no” questions and grouped into categories. Ease of use, a typically subjective criterion, can be associated with objective parameters, such as the availability of online support from the provider and training videos, which were considered in the model. The model conception is that the software evaluation by different decision-makers can generate similar results. The evaluation is expected to be completed with a simple software demonstration. Weights were assigned to each category, and the score was equally distributed in the categories of each group.

For evaluation (Step 3), five CMMS alternatives were selected. A summary of features listed on commercial websites is presented in Table 3.

Table 3. Software alternatives and key features announced by suppliers.

Software	Features Listed on the Commercial Website
S1	Asset management, mobile app, service orders, requests, preventive maintenance, reports and dashboards, IOT sensors, supplier management, and multiple languages.
S2	Registration of assets, maintenance plan, and work orders with the possibility to attach manuals, QR Code or NFC identification, resource control, evaluation of the work performed, IoT sensors, and condition-based maintenance (CBS).
S3	Maintenance planning, maintenance indicators, inventory management, procedure library, service order requests, preventive maintenance, metrics with or without sensors, team chats, and expense indicators.
S4	Preventive maintenance plans, reports, corrective maintenance, audits, inventory management, and real-time information.
S5	Dashboard, QR code, automation of routines, reports and graphs, geolocation of technicians, performance indicators, inventory management, and service level agreement.

The criteria and alternatives were grouped in an evaluation matrix, to meet Step 4. No dominated options were identified (Step 5). To indicate the score in each attribute, the utility value function, the score scale listed in Table 4 was created, depending on the degree of service of the software about the requirement evaluated by the decision-maker (Step 6). An adaptation was created in the method through the possibility of the evaluation called "does not apply" to allow the sub-criterion not to be considered in the decision model, in case of interest in customizing the decision model. This situation can arise in cases where the decision-maker seeks to evaluate only a partial solution, such as CIMS software. Although contemplated in the model, it was not adopted in the evaluation of the alternatives listed in this investigation.

Table 4. Value function for the criteria evaluation.

Evaluation	Points
Yes, fully meets the requirements	100
Strongly meets requirements	75
Partially meets requirements	50
Deficiently meets requirements	25
Do not meet requirements	0
Do not apply	-

As reported in the steps described, the swing weighting technique (Steps 7 and 8) was used to assign the sub-criteria weights. For this, three professionals who act as maintenance managers were consulted. The first profile is civil and electrical engineering, with four years in maintenance management: three years in building maintenance and one year in the maintenance of electrical equipment. The second profile is a civil engineer who worked for seven years in maintenance management. He has experience in the chief positions of a university hospital maintenance management and mayor of a university campus. The last profile is a civil engineer with 30 years of experience in works of vertical buildings and horizontal condominiums. He worked for five years as a residential condominium manager and one year in the technical assistance sector of a construction company.

This work presents the result as a performance profile, using a radar-type graph instead of a single final score. Also, a minimum evaluation profile was assigned to be considered IMS software. Authors regarding IMS features defined this minimum performance score. This score does not require points for new technologies, such as NFC (F.6), VR, and BIM (F.8). Relating to A.2 (access to documents), it needs to at least partially meet the requirements (50 points). For other sub-criteria, the premise was analyzed between 75 and 100 points.

4.2. Software Evaluation

The evaluation result in each criterion is summarized in Figure 2 (Step 9). A minimum profile (M) was also assigned, in which the lowest scores are considered IMS's lowest requirements. Alternatives evaluation detailed values and weights obtained in the criteria and sub-criteria by the swing weighting technique are presented in Figure 3. During the CMMS alternatives evaluation in each criterion, the means used for data collection consisted of demonstration videoconferences with a supplier representative. In some cases, more searches were made in instructional videos, demo versions, or contact by email or support with the supplier.

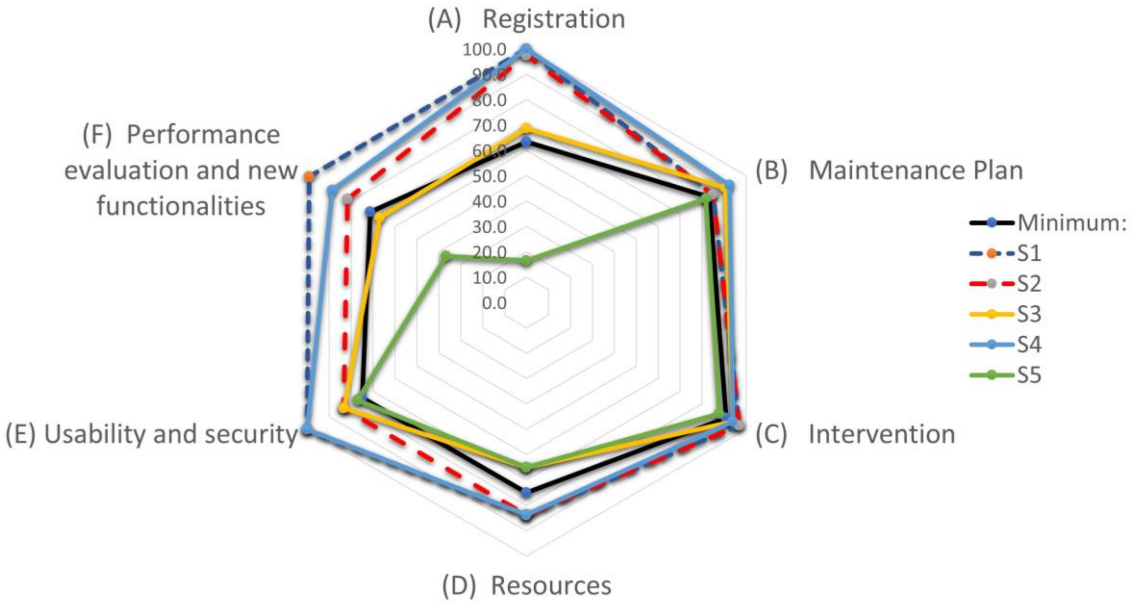

Figure 2. Evaluation results.

Criteria and subcriteria:		Weights:	M	S1	S2	S3	S4	S5
A	A.1.	53.2%						
	A.1.1.	22.0%	75	100	100	75	100	75
	A.1.2.	21.2%	75	100	100	25	100	0
	A.1.3.	18.9%	75	100	100	0	100	0
	A.1.4.	18.6%	75	100	100	0	100	0
	A.1.5.	19.3%	75	100	75	100	100	75
	A.2.	46.8%						
	A.2.1.	21.9%	50	100	100	100	100	0
	A.2.2.	20.4%	50	100	100	100	100	0
	A.2.3.	20.0%	50	100	100	100	100	0
	A.2.4.	18.1%	50	100	100	100	100	0
	A.2.5.	19.6%	50	100	100	100	100	0
B	B.1.	11.7%	100	100	100	100	100	100
	B.2.	10.9%	75	50	75	100	75	100
	B.3.	10.9%	100	50	75	100	100	100
	B.4.	11.1%	75	100	100	100	100	100
	B.5.	10.3%	100	100	100	100	100	100
	B.6.	9.5%	75	0	0	0	50	50
	B.7.	8.7%	75	100	100	100	100	50
	B.8.	8.9%	75	100	100	100	100	100
	B.9.	8.9%	75	100	100	100	100	100
	B.10.	9.1%	75	100	100	100	100	0
C	C.1.	14.1%	100	100	100	100	100	100
	C.2.	13.8%	100	100	100	100	100	100
	C.3.	12.2%	75	100	100	100	100	75
	C.4.	12.2%	100	100	75	100	100	50
	C.5.	11.9%	100	75	100	75	50	100
	C.6.	12.2%	75	100	100	75	100	75
	C.7.	12.2%	100	100	100	100	100	100
	C.8.	11.5%	75	100	100	100	100	100
D	D.1.	12.5%	75	75	75	25	100	25
	D.2.	12.5%	75	75	75	0	100	25
	D.3.	13.0%	75	100	100	100	100	100
	D.4.	12.5%	75	100	100	100	100	100
	D.5.	13.2%	75	25	25	25	0	0
	D.6.	12.5%	75	100	100	75	100	100
	D.7.	12.3%	75	50	100	100	100	75
	D.8.	11.6%	75	100	100	100	100	100
E	E.1.	17.4%	75	100	100	100	100	100
	E.2.	18.3%	75	100	100	100	100	100
	E.3.	16.8%	75	100	25	0	100	100
	E.4.	16.5%	75	100	100	100	100	100
	E.5.	15.9%	75	100	75	100	100	50
	E.6.	15.0%	75	100	100	100	100	0
F	F.1.	16.0%	100	100	100	50	100	50
	F.2.	13.8%	75	100	100	100	50	100
	F.3.	16.0%	75	100	100	50	100	50
	F.4.	15.2%	75	100	50	100	100	0
	F.5.	14.9%	75	100	100	100	100	0
	F.6.	12.6%	0	75	50	0	100	0
	F.7.	13.8%	75	100	50	50	50	50
	F.8.	13.8%	0	0	0	0	0	0

(M, S1–S5: CMMS alternative evaluation)

Figure 3. Alternatives evaluation matrix and criteria weights results.

The results show that the selected software S1, S2, and S4 presented the best results and fully met the minimum score profile to be considered an IMS software. The S3 software presented a good profile, but with some limitations. The S5 software displayed less diversity of features. Regarding the registration criterion, the maximum score was obtained by software that had flexibility in the development of the registration fields, in the organization of the functional structure, and in the location of the maintenance sources elements, and that allowed the upload of files. Software S5 has a rigid structure in the registration field, which does not allow customization and does not meet the criteria defined in the model.

In the Maintenance Plan criterion, all software performed well in scheduling, procedure creation, and task scheduling. The typical absence gap corresponded to the absence of a prior database on maintenance procedures, such as inspections. In the intervention criterion, the main gaps observed are related to the categorization of small and large interventions and the limitation, in some cases, to access saved data related to interventions. In the resource criterion, the overall evaluations were positive. The prominent absences are the need for more financial resource management, labor control, and outsourced companies. As a highlight point, all software were favorably evaluated regarding the material resources and cost appropriation.

In terms of usability and safety, the overall evaluations were also satisfactory. There was a limitation in software S3 regarding sending by email or SMS. One of the software, S5, was limited in usability by not having online chat features and instructional videos that allowed greater ease in its operation. Finally, in the criterion related to the maintenance evaluation and functionalities incorporation, there was a certain variability in the evaluations. This criterion is very much related to the evolution of maintenance management in the face of technological developments. Software S1 and S2 obtained the best evaluations. As a limitation, none of the software incorporate aspects related to BIM, virtual, and augmented reality.

5. Discussion and Conclusions

This paper proposed a SMARTS-based decision support model for CMMS selection in building management maintenance. As a result of the decision model application, among the evaluated software, similar characteristics could be identified in some alternatives: scheduling tasks, receiving and forwarding calls, generating QR codes for assets, materials consumption appropriation, and operation through online software and smartphones. Through model results, differences were identified in the flexibility of customization in the software. Another field of differentiation occurred in the criterion related to performance evaluation and incorporation of functionalities. Among the five alternatives evaluated, three exceeded the profile called Minimum.

The proposed model showed benefits. Different from models cited in the references of this work [9–12], focused only on generic software features, the evaluation model combines criteria in the building maintenance management context using the IMS approach and includes new technological trends, such as Building information modeling (BIM), Virtual Reality (VR), Augmented Reality (AR), and the Internet of Things (IoT). These features are in growing development and are relevant criteria for decisions. Furthermore, the proposed assessment method can be easily provided using electronic spreadsheets and provides a useful approach that covers a comprehensive range of building maintenance requirements. This approach empowers decision-makers to make informed choices by evaluating vital criteria relevant to building maintenance from an IMS perspective.

Some limitations can be cited, such as the influence of negotiation conditions, the language, the supplier availability in the region, and the subjective criteria related to the use, among other specificities. It should also be considered that the sub-criteria weighting may differ depending on the decision-maker. In this study, only three professionals evaluated the model, suggesting that results may be different in a study with a larger sample of participants and with more diverse profiles. However, it is considered that the weights obtained in this work can be used as an initial reference for many contexts. Related to the judgment process, we cite a possible risk of uncertainty and ambiguity in decisions. In this Decision Support Model, the decision-maker may have a subjective level of judgment when selecting score, such as between 50 and 75 in a sub-criterion. These features also relate to decision-making contexts [25,26] and do not invalidate model support.

In recent years, many technological innovations have been developed in the context of building software. BIM, NFC technologies, QR code generation, IoT sensors, smartphones, cloud data applications, and many industry 4.0 features are increasingly common features that can simplify management, reduce costs, improve productivity, and enable upscale software adoption for asset management and building maintenance. In these fields, future decision-support model improvement and alternatives can capitalize on these trends.

In addition, this study draws some general research recommendations and scope for future work:

- Deeply study the criteria and sub-criteria adequacy;
- Improve the value function of the sub-criteria, as well as deepen the minimum requirements for an IMS;
- Evaluate the new demands associated with IMS, such as Industry 4.0 features;
- Quantify the impacts and growth of CMMS adoption for building management;
- Identify drivers and barriers to CMMS improvements for buildings regarding new technologies and methodologies, such as BIM, VR, AR, IoT, and others;
- Expand the current study to a more significant number of alternatives.

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