Facility Management Information Taxonomy Framework for Queries in Healthcare Buildings

Abstract

Healthcare facilities need to ensure providing safer services to patients without interruptions since disease diagnosis and treatments highly depend on medical equipment and spaces. Therefore, facility management (FM) of healthcare facilities requires a clear and rapid information flow for decision making processes to impede possible interruptions. Non-availability of information, accuracy problems and incomplete information induce more severe problems such as cost overruns, reduced productivity and decrease in customer satisfaction. Thus, this paper aims to develop a strategic information taxonomy framework for FM inquiries in healthcare facilities to address the research problem. Design Science Research methodology cycles such as relevance, rigor and design are adopted during the flow of the research. In the relevance cycle, research requirements and the importance of FMITs were firstly observed with two scenarios, then in the rigor cycle, 64 FM information types (FMITs) were determined, classified and refined under three categories such as; managerial, technical, and financial as a result of literature review and pilot study. Determined FMITs were analyzed with newly developed MonteCarlo Simulation and TOPSIS Techniques on healthcare facilities. As a result of analysis, 62 FMITs were found important for healthcare facilities. Finally, in design cycle, facility management information taxonomy, which was created from determined FMITs, and importance levels of determined FMITs were evaluated by two case studies. Results showed that while maintenance contracts have a positive impact to prevent negative impact of costs, they can cause interruption in information management in facility management. Additionally, there are some view difference in professions. For example, construction management literature focuses wastes that are incurred at the end of building lifecycle or construction process. However, there aren't much attention to manage wastes that occurred during operation and maintenance stage. Beside this, regulations and standards have importance to store, use and manage FMITs. The analysis results acknowledged that the use of information taxonomy framework can increase the effectiveness of the healthcare FM.

Keywords: Facility Management, Healthcare buildings, MonteCarlo and TOPSIS Techniques (MCTT), Information Taxonomy

1. Introduction

Increase in quality and cost effectiveness is essential in healthcare facility management since they are mostly operated with financial guarantee of public bodies. In the United Kingdom, the annual turnover of Facility Management (FM) companies and business support services reaches to £115bn. Its impact is not limited to turnover in the economy but also offers an employment opportunity for 3% of the national workforce [1]. FM phase of buildings corresponds to 60% of the expenditures of the total life-cycle costs since FM includes planning and management activities of workspaces to support business continuity in a facility [2,3].

Information management in FM plays an important role. Within this context, information from design and construction phases is also vital for FM. However, fragmented structure of the construction projects causes many problems in FM such as information losses, duplications, error-prone data entry, and unorganized data management throughout the life cycle stages. This results in loss of information and causes to expand more effort to find accurate project information, which is essential for FM. Therefore, facility managers have to find the required information from design and construction documents, separate models, or non-updated models or they are faced with lack of information in FM [4].

Moreover, facility managers have issues in the management of the existing information due to conventional or unorgnized approaches in FM such as information checking and verification of information repetitively with real site visits that are inefficient and time-consuming. Nowadays, new technologies such as Computer Aided Facility Management - CAFM, Computer Maintenance Management Systems - CMMS, Building Automation Systems-BAS are used to manage operation and maintenance activities in facilities since facility managers need systems to retrieve the required information and use them in decision-making processes [5,6]. However, all the FM systems have some pros and cons. Selection of FM solutions depend on clients' business needs. However, clients confront problems with incomplete, inconsistent and not accessible information due to lack of coherent structure or stand-alone FM systems. Besides, clients do not have a plan for sharing or storing FM information during the selection of FM system [7]. Additionally, creating unrealistic expectation for these systems leads to disrepute for FM systems [1]. Therefore, identifying drawbacks of the FM systems is necessary in terms of both the new developments and conceiving availability of current information types in these systems. Drawbacks in FM systems are emphasized in the literature as manual data entry, data history, non-visualization, data inaccuracy, data update requirements, data storage problems, lack of building information, interoperability issues with FM systems, not-user friendly interfaces, difficulty in interpretation of output, data transparency, unnecessary data burden in a model, historical data analysis, non-coverage of FM processes for Building Energy Management Systems-BEMS, Building Automation Systems-BAS, Computerized Maintenance Management Systems-CMMS and BIM [7,8,17–19,9–16]. Additionally, every FM system has specific service area in the FM. For instance, while BEMS is used in energy management, CMMS is used in maintenance management. Therefore, different FM systems have to be used in a facility by clients which induces scattered information issue and confusion in FM [20].

Furthermore, Kang and Hong [21] stated that presenting the required information without unnecessary details in the systems is important for FM managers. Otherwise, the authors believed that facility managers can be stuck in huge data resouces, which then leads to increase in failures and inaccurate decisions. Therefore, determination of FM information types is substaintial to improve the efficient use of FM information systematically for sustainable management of healthcare buildings. Thus, developing an information taxonomy framework for the systematic conduct of FM queries can help facility managers for straightforward and effective FM information management and reduce the complexities [22].

Additionally, non-availability of information, accuracy problems and incomplete information induce more severe problems such as clarifying all information over and over again with cost overruns, reduced productivity and decrease in customer satisfaction in FM [24]. Therefore, the management of information without interruption and deterioration is important to fulfill the FM objectives [6,23]. Within this context, Alnaggar and Pitt [24] stated that information types used in FM need to be specified and ranked for the efficient FM. Also, Bortoluzzi et al. [25] stated that identifying critical information requirements is one of the most important barriers for the FM platforms. Wong et al. [26] expressed also that facility managers need to prioritize required information types in FM. Hence, the aim of this research is to develop an information taxonomy framework for FM queries in the decision making processes to prevent information losses causing time and cost increases and to contribute to the systematic use of FM information types in FM platforms in healthcare buildings.

This study contributes to theoretical critics in facility management literature by defveloping an FM information taxonomy for healthcare facilities. Additionally, the study proposes a new hybrid method which consists of MonteCarlo Simulation and TOPSIS methods. With an empirical investigation, the study also contributes to the practice with the FM information types that should be systematically handled and managed in healthcare projects. The research also shows how the developed FM information taxonomy can be embedded in BIM models.

2. Background for Facilities Management Information Types

Building Information Modeling (BIM), which is used as a part of CAFM, gives an opportunity to manage building lifecycle data. In the literature, some studies used BIM as a FM tool to manage and query information that is needed during FM. Within this context, FMITs were generally determined BIM related studies. Alnaggar and Pitt (2019a) developed a process model for asset data that is used to transfer project specific information from BIM to CAFM instead of COBie data exchange mechanism that induces some errors and issues in data transfer process. Chen et al. (2016) developed a cloud-based system in which BIM and Big Data Analytics are used to query static and dynamic data. Chen et al. (2018) used BIM and FM system to enable automatic scheduling and to detect sub-optimal maintenance path for facility maintenance work orders. Ammari and Hammad (2019) developed BIM-based mixed reality system to visualize asset information on-site and to increase remote interactive collaboration between workers and FM office. Farghaly et al. (2019) identified linked data process for data transfer between BIM to asset management systems. Farghaly et al. (2017) proposed BIM Big Data framework for asset management. In the proposed system, ifc data types were used and analyzed as information source. Golabchi et al. (2016) used BIM as a component of fault detection and diagnose system to determine potentially HVAC components and to develop maintenance plan. Hu et al. (2016) offered a multi-scale solution for management of mechanical, electrical and plumbing (MEP) elements during FM by including asset definition, performance requirements, indoor path, maintenance plans, logic relations, maintenance records, conditions etc. Matarneh et al. (2019) proposed information exchange process for BIM-based FM system between BIM, CMMS, and CAFM to manage geometric, non-geometric, product data and maintenance data. Pärn and Edwards (2017) developed FinDD application program interface by integrating FM data into BIM 3D objects via totems. Kang and Choi (2018) proposed BIM-based data-mining method to enable energy management in FM. Liu and Issa (2015) conducted a survey to define FM requirements and maintainability problems to develop maintenance database for BIM based FM. Information requirements for knowledge database are defined according to feedback from partcipants. Becerik-Gerber et al. (2011) investigated BIM applicability and application areas in FM with survey and examples. Nongeometric information requirements in examples were also identified for FM. Lucas and Thabet (2018) aimed to create a BIM-FM guidelines and standards for eductional facilities. In the study, information from design and construction stages to FM stage are discussed. Cavka et al. (2017) defined information requirements to support model-based asset management by using the two large owner organizations that use BIM for FM. Lee et al. (2016) developed web-based BIM - FM tool that uses several information types while Passini et al. (2016) combined BIM and Building Management System-(BMS) to observe real time IoT data on model. Pishdad-Bozorgi et al. (2018) used COBie to transfer necessary information from BIM to CMMS. COBie is mostly used data transfer mechanism in the literature (Pishdad-Bozorgi et al., 2018; Sadeghi et al., 2019). However, the reason of non-usage of COBie documents in the industry is attributed to conflict between the COBie requirements and industry requirements and inflexible structure of COBie for the unexpected situations. COBie is not comprehensive to use for the asset management (Abdirad & Dossick, 2019). Existing studies are not comprehensive about BIM-based FM queries, limited FM information types and specific FM problems for information retrieval in the FM applications (Becerik-Gerber et al., 2011; Bortolini & Forcada, 2019; Cavka et al., 2017; Davtalab, 2017; Lee et al., 2016; Liu & Issa, 2015; Lucas & Thabet, 2018; Oti et al., 2016; Pasini et al., 2016; Pishdad-Bozorgi et al., 2018; Sadeghi et al., 2019; Solihin et al., 2017).

3. Research Methodology

Research methodology is formulated by Design Science Research (DSR) approach since it facilitates the development of innovative solutions for industry and organizations driven by information. Its characteristics involve iterative processes in the development of innovative solutions in the problem domain. The DSR methodology integrates both the social context and the knowledge base technical capability to achieve the aim of the information taxonomy framework development for FM queries in healthcare buildings.

DSR starts with the creation of solution artifacts for the issues. These artifacts can be constructs, models, methods or instantiations [40]. However, the first proposed artifacts may not be a solution for the issues. Therefore, iterative process is followed in the DSR methodology that consists of three cycles. They are namely; “relevance cycle, rigor cycle, and design cycle” [41]. The DSR approach used in the research is illustrated in Figure 1.

Figure 1. Cycles of DSR Methodology

In Figure 2, DSR steps and relevant research activities are summarized. According to the research flow, nine research activities were performed. Details of each activity will be shared under related DSR cycles.

Figure 2. Research Flow

3.1. Relevance Cycle

In relevance cycle, research requirements are defined within the research domain and relationships between human, organization and technical systems are identified then the solution artifacts are developed [40]. In this research, the relevance cycle will capture the baseline requirements for the information taxonomy framework for the FM use at the operation phase. Baseline requirements of the framework are considered in the application domain of the DSR methodology (Figure 3); identifying actors (who), technologies and data sources (what), and organizational systems (how) are included in the problem domain.

Figure 3. Application Domain of the DSR Methodology

According to Hevner and Chatterjee [40], good DSR often begins by identifying and representing opportunities and problems in an actual application environment. Therefore, baseline for development of framework is built with two scenarios to conceive the importance of information taxonomy in FM. When interferences in information flow is occurred in process, the concurrent impact can be observed via these scenarios.

Scenario 1: Floor Covering Scenario: This scenario is about how floor covering is performed in a healthcare facility. In the scenario, the required information types are depicted with actors and organizational relationships between actors and the FM systems used. First of all, the scenario is shown to respondents at the interviews with financial and administrative affairs manager with 15 years of experience and technician with 8 years of experience. Necessary information types, relationships between actors and activities are reviewed and approved by the respondents except from location information since location information is queried by the technicians. According to the respondents' experience, "competent personnel, location, vendor information, maintenance history, and warranty information" can queried in the process (Figure 4).

Scenario 2: HVAC Fault Scenario: This scenario demonstrates how HVAC fault is removed in the healthcare facility. In the scenario, necessary information types are depicted with actors and organizational relationship between actors and the FM systems used. Through this scenario, the researchers can detect the outsourcing activity for the FM maintenance activities. In the second scenario, fixing of HVAC fault scenario is shown to the respondents at the interviews with financial and administrative affairs manager with 15 years of experience and technician with 8 years of experience. Before assigning competent staff, information types, which are "energy consumption and energy efficiency, real-time operational parameters, system performance information, operational costs, equipment/system operation schedule, competent personnel, and key plans" were considered for queries. However, the respondents answered that "competent personnel and location" information types are only needed since,the healthcare facility had a maintenance contract for the HVAC system and the process controlled by the FM Office was limited. Additionally, "energy consumption and energy efficiency, real-time operational parameters, system performance information etc." aren't available in the facility management systems. Therefore, the interviewee stated that the maintenance and repair activities depend on experience of maintenance company. Therefore, all relationships and required information types are revised. The process is illustrated in Figure 5.

Figure 4. Floor Covering Scenario

Figure 5. HVAC Fault Scenario

Based on the initial analysis of the two scenarios above and literature review, FM Information Taxonomy (FMIT) framework is developed for the healthcare facilities.

3.2. Rigor Cycle

The rigor cycle emphasizes the research originality and previous studies, experiences, theories and methods [40]. Therefore, literature review is performed to reveal both research originality and previous efforts. The previous studies emphasized that there is a gap in the literature in terms of information taxonomy for efficient use and management of information in FM. Existing studies are not sufficient for BIM specific FM queries for example, and FM queries are limited and specific FM problems for information retrieval in the FM applications are incurring [2,27,38,39,28–33,36,37].

In the development of FMIT, to identify information types, broad and in-depth literature review is performed. The findings from literature review are classified under three categories as "financial information requirements, managerial information requirements and technical information requirements". The result of literature review is given in Table 1, Table 2 and Table 3.

Table 1. Managerial Information Types

Table 2. Technical Information Types

Table 3. Financial Information Types

3.3. Design Cycle

Outputs from relevance cycle and rigor cycle help to create artifacts (FMIT-Figure 8). This cycle also contributes to the existing body of knowledge with the development of new information. Information types are defined via literature review and they should be checked, ranked and evaluated for the development of FMIT since ranking and evaluation of information types will increase validity of FMIT framework for health care facilities and help to fill the research gap in the literature. Therefore, the stages given below are followed;

- Stage 1: Refinement of Identified Information Types via Pilot Study
- Stage 2: Verification of FM Information Types via Focus Groups
- Stage 3: Forming, Filtering and Ranking FMITs via MCTT Analysis
- Stage 4: Evaluation of the framework via Case Study

3.3.1. Stage 1: Refinement of Identified Information Types via Pilot Study

In pilot studies, three top management professionals [42] with 22, 14, and 11 years of experience respectively are interviewed since they have experience in PPP (Public Private Partneship) healthcare infrastructure projects including FM. In the implementation of pilot studies, interviewees were asked to refine information types. As a result, the identified information types are refined and combined. The final version of information types are given in Table 1, Table 2 and Table 3.

3.3.2. Stage 2: Verification of FM Information Types via Focus Group Discussion Technique

Listed information types in the first stage according to the perceptions of FM experts are verfied and rated via focus group discussions with ten participants. The reason why the focus group discussion is used is to enable verification of information types and determination of common weights for the FM success criteria and collection of survey from participants [43]. The number of participants consisted of seven healthcare facility managers and three academicians. The detail of experience of participants is given in Table 4. The total number of participants are gathered together to conduct focus group discussion and to perform TOPSIS methodology [44–46].

Table 4. Profile of Respondents

In order to implement "The Technique for Order Preference by Similarity to an Ideal Solution (TOPSIS) Method", as the first step, the criteria about the success of healthcare FM, were asked for rating: "FM response time"; "FM expense"; and "Service quality". After discussions, the participants had a consensus for the weights of success criteria in FM as "FM response time" - 0.35; "FM expense" – 0.35; and "Service quality" – 0.30. Definitions for success criteria of healthcare FM are given below;

C1-FM response time: In the healthcare FM process, maintenance of equipment and their flawless working are vital [47]. However, FM response time to detection of problems in the facility is affected from incomplete information, usage of multiple systems and poor information management. For example; duration for information exchange is time-consuming in the repair and damage examination. Therefore, if FM response time is not managed properly, the operations such as surgery activities are interrupted or postponed [47,48].

C2-FM expense: FM is the most costly phase of the building life cycle. Timely information access enables to hold operation cost at an optimum value. For example, equipment performance problems can be revealed with necessary information so that business continuity is enabled. Intelligent MEP systems are also used according to occupants' schedule or existence of occupants in spaces. This helps to increase energy savings and reduce FM expense [49].

C3-Service quality: In the PPP healthcare projects, private companies take part to deliver curing quality for patients than public counterparts [50]. Occupants, such as patients, are also susceptible to facility conditions in hospitals. This situation is attributed to the relationship between patient curing quality and efficient FM [51]. Therefore, achieving necessary information and detecting abnormal condition in the facility are important to perform successful FM.

After obtaining weight of success criteria for healthcare FM, rating of the information types are collected from the participants.

3.3.3. Stage 3: Forming, Filtering and Ranking FMITs via MCTT Analysis

Multi Criteria Decision Making (MCDM) methods can be followed to determine importance or rank of FMITs. In MCDM methods, different methods are available such as AHP, ANP, ELECTRE, PROMETHEE and TOPSIS [52]. Within this context, TOPSIS method is chosen due to both simplicity and high understandability by survey participants. In the TOPSIS method, subjective or personal experience is used to evaluate rank of FMITs. This causes sensivity and uncertainty problems in the MCDM methods. Therefore, Monte Carlo method is combined with TOPSIS [53]. Monte Carlo TOPSIS Technique (MCTT) consists of combination of the TOPSIS method and Monte Carlo method. The concept map of MCTT methodology is summarized in Figure 6. These methods and their steps are elaborated in the following sections.

Figure 6. The concept map of MCTT methodology

3.3.3.1. The Technique for Order Preference by Similarity to an Ideal Solution (TOPSIS) Method

TOPSIS is a common multi-criteria decision making (MCDM) approach due to its simplicity [43]. The method is used to rank alternatives by considering the shortest distance from the positive ideal solution and the furthest distance from the negative-ideal solution [54]. Ranking of alternatives in the TOPSIS method is summarized in six steps [54,55].

Step 1: Collection of data and creation of decision matrix (Eq. 1):

$$A_{ij} = \begin{bmatrix} a_{11} & a_{12} & \dots & a_{1n} \\ a_{21} & a_{22} & \dots & a_{2n} \\ \vdots & \vdots & \vdots & \vdots \\ a_{m1} & a_{m2} & \dots & a_{mn} \end{bmatrix} \quad (1)$$

m: alternatives, n: criteria

Step 2: The matrix, which is obtained at the step 1, is normalized by using Eq. 2:

$$r_{ij} = \frac{a_{ij}}{\sqrt[2]{\sum_{k=1}^{m} a_{kj}^2}} \quad (2)$$

r_{ij} =normalized value of the i[th] alternative of the j[th] criterion/attribute; j=1,…,m ; i=1, …,n.

Step 3: the weighted matrix is built by multiplying a normalized matrix with criteria weights. (Eq. 3)

$$v_{ij} = w_j r_{ij} \quad (3)$$

v_{ij} =weighted value of the i^th^ alternative of the j^th^ criterion/attribute; w_j =the relative weight of the j^th^ criterion/attribute ; j=1,…,m ; i=1, …,n.

Where the total value of the weights of criteria is 1 ($\sum_{i=1}^{n} w_i = 1$):

Step 4: Find the positive ideal - (A^*) (Eq. 4) and negative ideal solutions - (A^l) (Eq. 5).

Positive distance formula

$$A^* = \{v_1^*, \dots, v_n^*\} \tag{4}$$

Where $v_i^* = \{\max(v_{ij})\ if\ j\epsilon J; \min(v_{ij})\ if\ j\epsilon J^l\}$

Negative distance formula

$$A^l = \{v_1^l, \dots, v_n^l\} \tag{5}$$

Where $v_i^l = \{\min(v_{ij})\ if\ j\epsilon J; \max(v_{ij})\ if\ j\epsilon J^l\}$

Step 5: Using the n-dimensional Euclidean distance, the shortest positive distance (Eq. 6) and the farthest negative distance (Eq. 7) are calculated.

Positive ideal formula (D^*_i):

$$D_i^* = \sqrt[2]{\sum_{j=1}^{n}\left(v_{ij} - v_j^*\right)^2}, i = 1, \dots, i \tag{6}$$

Negative ideal formula (D^l_i):

$$D_i^l = \sqrt[2]{\sum_{j=1}^{n}\left(v_{ij} - v_j^l\right)^2}, i = 1, \dots, i \tag{7}$$

Step 6: The alternatives are ordered according to ration C_i* (Eq. 8).

$$C_i^* = \frac{D_i^l}{(D_i^* + D_j^l)}, i = 1, \dots, i. \tag{8}$$

C_i^* = closeness of the i^th^ alternative to ideal solution

3.3.3.2. Monte Carlo TOPSIS Technique (MCTT)

In TOPSIS, as in other Multi-Criteria Decision-Making (MCDM) method, evaluation of criteria with exact numbers causes not to consider sensitivity and uncertainty at the evaluation phase [53]. Arithmetic or geometric means of all views of decision makers are used to rate the criteria to obtain common evaluation in TOPSIS [56]. Sometimes decision makers do not have enough information in all its parts and they use their judgements to evaluate the criteria.

The decision makers can find the rating process difficult to determine the most important criteria. Therefore, TOPSIS method need to be integrated with probabilistic distributions (Monte Carlo applications) to increase screening capability and to see different respondents' view [53,57,58]. Literature showed that Monte Carlo AHP is more reliable than conventional AHP [59]. Rosenbloom [60] suggested that probabilistic distribution can be preferred if the scores of the criteria are very close. Scores are also getting closer as several criteria increases. Therefore, the probabilistic approach should be integrated into MCDM approaches such as TOPSIS.

In the literature, TOPSIS integration with Monte Carlo methodology is very rare. In some examples, integration of TOPSIS and Monte Carlo Simulation is performed after obtaining a ranking of criteria with TOPSIS to show the sensitivity of the results or to make a prediction [61,62]. However, in this study, the output of Monte Carlo results is used in the TOPSIS analysis against to existing studies. Therefore, MCTT can overcome reliability, human judgement and score closeness problems. Steps of Monte Carlo application into TOPSIS are summarized below inspired by Monte Carlo AHP steps [53];

Step 1: Beta-pert distribution is applied to every element of the decision matrix. 'betarnd (alpha, beta)' function was used to create a_{ij} (Eq.9-12). For instance, the respondents' answers for maintenance history information type are collected and calculations are performed according to Eq. 9-12. This calculation is also performed all success criteria (FM Response time, FM Expense, and Service Quality).

$$mean = \frac{min+4modal+max}{6} \tag{9}$$

$$stdev = \frac{max-min}{6} \tag{10}$$

$$\alpha = \left(\frac{mean-min}{max-min}\right)\left(\frac{(mean-min)(max-mean)}{stdev^2} - 1\right) \tag{11}$$

$$\beta = \left(\frac{max-mean}{mean-min}\right)\alpha \tag{12}$$

Step 2: For a_{ij} replications (between 100 and 10000) 1000 random draw is performed [53,59]. For instance, by using Eq. 9-12, variables for Eq. 13 are identified and 1000 random draw are performed for the pair of maintenance history information type and FM Response time with beta random distribution. Also, the same operations are performed other FMITs and all success criteria. In other words, 3000 data are created for each FMITs (1000- from pair of maintenance history information type and FM Response time/1000- from pair of maintenance history information type and FM Expense /1000- from pair of maintenance history information type and Service quality). The reason of not to give explicit example in the study is that there are 3000 sample for each FMITs.

$$a_{ij} = min + betarnd(\alpha, \beta)(max - min) \quad (13)$$

Step 3: After obtaining 1000 data per success criteria for each a_{ij}, the steps of TOPSIS, which are given above, are implemented. In other words, before applying the steps of TOPSIS, one data set is created by taking one a_{ij} from 1000 data per success criteria. For instance, one data from 1000 data (from pair of maintenance history information type and FM Response time), one data from 1000 data (from pair of maintenance history information type and FM Expense), and one data from 1000 data (from pair of maintenance history information type and Service quality) are taken and the same process are performed for other FMITs. As a result of this process, one data set, which is combination of one data from data sets of FMITs, is created and it is analyzed by applying TOPSIS steps. The same process is applied for remaining data (999 data sets). So that 1000 C_j^* (1000 ranking) are obtained.

Steps 4: Ranking distribution of every variable is plotted by using kernel distribution function. In Kernel distribution function, 1000 C_j^* for each variable are entered as data. In this study, all steps are developed and analyzed in MATLAB program. When specifying order of information types, projection of the peak point of curve of information types to range 0 and 1 are used. According to this projection, information types are ordered from big to small. Another important inference from these curves is to make comments about consensus of expert judgements. Therefore, the distance between two tails of curves are used. If the distance is high, it means that the experts have different experience about information types and there is no much consensus. Nonetheless, if the distance is low, it means that experts have a consensus about related information type. Monte-Carlo TOPSIS codes for financial information can be seen in Supplemental File.

Kernel distribution is also obtained by MATLAB Distribution App (Figure 7) with the use of MCTT results (Cc).

Figure 7. Kernel Distribution Graphics of Information Types

The analysis results showing projections of peak point are given in Table 5. In other words, the peak point from C_i^* values for each FMITs are showed in Table 5. These values are used to determine order of importance of information types. As being in TOPSIS method, the best alternative/important is the one which is the closest value to 1. For instance, M11 in managerial information types is 0.985, which is the closest value to 1. In other words, M11 is the most important information type in managerial information types. The other FMITs are ordered within their groups according to closeness to 1.

Table 5. MCTT Analysis Results

Information taxonomy framework for the FM queries is given in Figure 8.

Figure 8. Information Taxonomy Framework for the FM Queries

3.3.4. Stage 4: Evaluation of the Framework via Case Study

A case study strategy is used to obtain better understanding about the findings. The reason for this is to evaluate importance levels of managerial, technical and financial information types. Therefore, theoretical findings are also supported with practical implementation in FM.

To perform case studies, the authors performed two half-day interviews. Profiles of interviewees were summarized in Table 6.

Table 6. Profiles of Interviewees

In the first case study, the respondents were benefited from three different software solutions (TrTEK, AirTEK, and Excel). TrTEK software solution is used for fault requirements, material requirements, inventory management, the query of limited information types, medicine inventory, and pay-office records. The AirTEK system is used to monitor and control building indoor air quality. Excel is used to manage some preventive maintenance requirements. In the second case study, the respondent was used MYM, RFM (the company produces software technologies like CAFM), Biopro, and BMS to conduct FM activities. In

MYM FM software, T1-T3, T6, T7, T9, T10, T12, T17-T19, T24, T25, T30 (technical FMITs); M1-M5, M8, M16, M20, M22, M23 (managerial FMITs); and F6 (financial FMITs) information types are stored and managed. In RFM software, T1-T3, T6, T7, T9, T10, T12, T14, T17, T19, T24, T28 (technical FMITs); M1-M6, M8, M9, M11, M16, M20 (managerial FMITs); and F5, F6 (financial FMITs) information types are stored and managed. In Biopro FM software, T1-T3, T6, T7, T10, T12, T14, T17-T19, T24, T25, T28 (technical FMITs); M1-M4, M7, M10, M20 (managerial FMITs); and F5, F6 (financial FMITs) information types are stored and managed. In BMS, T1, T3-T8, T10, T12, T18-T20, T24, T25, T32, T33 (technical FMITs); and M4, M20, M21 (managerial FMITs) information types are stored and managed.

The respondents were firstly asked to assess the identified essential information types. Secondly, all information types are shown to the respondents to determine information types other than the information types obtained from Monte-Carlo TOPSIS analysis. However, respondents did not append any information types.

3.3.5. Findings from the Case Studies

The ranked information types from MCTT analysis are asked to participants for evaluation. Findings are elaborated below according to respondents' answers.

- **Identification of hazardous or other risks to people or property:** In the first case study, risk analysis for FM is performed from Patients, Employee rights, and Safety department. The department performed risk analysis and conveyed their findings to the FM Office. The respondents said that "the identified risks directly affect the life of patients and medical staff." According to the respondents' experience, the story height of car park was identify as a risk by the Patients, Employee rights, and Safety department since the story height of car park was relatively low and the piping system of extinguishing installation on the ceiling could hurt someone. Hence, the department opened corrective and preventative action with two months period for the solution. As a result of the process, identified FM risk is eliminated. In the second case study, the interviewee stated that all systems needs to be able to work continuously due to patients' critical health conditions. Additionally, the interviewee stated that human related risks needs to be kept under control. Therefore, interviewee agreed that regularly risk identification in facility is important. Within this context, the interviewee stated that they performed risk identification regularly to detect gas leak, fire, chemical poisoning, shutdowns, medical gas leak etc.

- **Maintenance plans/Maintenance routes:** In the first case study, respondents had maintenance plans for assets. However, maintenance plans were managed in excel files. These files were used to manage and record information such as the user of an asset, location, maintenance cycle, the last maintenance date, the next maintenance date, and process of maintenance. For example, respondents gave an example from previous maintenance process: Air pressure control, water pressure control, leakage control, reflector adjustment, tests, and visual inspection were performed for an asset sequentially. In the second case study, the interviewee stated that they use MYM, RFM and Biopro software to perform maintenance management. The interviewee also stated that regular maintenance on all equipment and systems are performed to prevent shortening their service life.
- **Hazardous waste management:** Basically, hazardous waste management is evaluated by the Ministry of Health periodically. Therefore, in first case study, respondents said that "we give utmost importance. However, we have an issue with the identification of hazardous wastes since there are no warning signs. Moreover, we do not have necessary educational background to assess chemical ingredients of wastes. Therefore, we have to do research. However, we still have an issue with the identification of hazardous waste management in healthcare FM. We need manuals for hazardous materials." The second interviewee stated that this FMIT is important to keep hazardous wastes that occurs as a result of healthcare activities from environment. Therefore, they give high importance waste management process up to dispose of hazardous wastes.
- **Work order (Maintenance requests):** Work orders are performed on the TrTEK FM system. The respondents said that "For example, a doctor can request sterilization of equipment, medicine, part of medical equipment via the TrTEK FM system. In the request, name-surname, location (polyclinic number), identity number, number of material, and fault reasons are inputted by a requester. When the request is completed on the system, it is then sent to the administration system (Figure 9). After that,

competent technician is assigned to task and the technician investigates FM request. If there is a need for medicine or spare part for equipment, technician control inventory. If necessary medicine or spare part is available in inventory, they are dropped from inventory. These operations can also be observed for each asset via identity numbers by the Health of Ministry.

Figure 9. Review of Work Orders via FM Software

The second interviewee was found this FMIT important since it enables to keep access times of patients to the service at a minimum and to increase user satisfaction. Also, the interviewee stated that work orders especially in medical equipments are priority to prevent negative impact of faults on patients. They benefited from FM software to obtain work orders automatically.

- **Emergency management:** There is a separate department for emergency management in first case study healthcare facility. The respondents obtained the necessary information from this department. The second interviewee stated that they prepare emergency management plans and support these plans with trainings. Also, the interviewee mentioned about their urgent case procedure (red alarm) for fire alarm. First of all, fire information is given by staff and the information is confirmed with the usage of cctv. After that, evacuation of patients is performed, if it is necessary. Also, they evaluated power failure under emergency management. To prevent negative impact of emergency, they are organizing regularly drills in the facility.
- **Real-time operation parameters/Post-occupancy data integration:** In the first healthcare facility, there is an automation system for monitoring and controlling the indoor environment (temperature and humidity). This operation is conducted on the AirTEK FM system that also enables to monitor the air conditioning system. The first respondent said that "observation of real-time operation parameters are fundamental in terms of patient comfort and continuity of operation in the healthcare facility. For example, in the surgery room, there are sensors that measure temperature and humidity. The setpoint of the surgery room needs to meet regulations of the Ministry of Health. To keep air quality within limits, the system should work continuously. This real time data is also stored and it is not possible to query." The FM system is shown in Figure 10.

Figure 10. HVAC Monitoring and Control System

The second interviewee stated that this information type is important to prevent possible failure before issues occur. According to given example, when medical oxygen pressure level is lower that specified level, automatically backup system is activitated.

- **The equipment performance information/ system performance information:** Equipment or system performance information are not recorded by FM Office. The respondents only recorded warranty documents in their system in the first case study. Therefore, they have a problem with a vendor about the periapical dental x-ray machines that are broken down time to time. They have also the same issue in tube transformers. The respondent said that "the vendor asserted that seventy shoots can be performed with the device in daily operations and he blamed us to use x-ray machines excessively. Additionally, the performance criteria for number of the shoots were not specified under the technical specifications during the tender stage." However, the respondents stated that "it is not possible to make too much shoots with these devices since there is time restriction (time for shoot and calm down duration). If we had these performance information, we will not face this type of problem. Additionally, we used uptime information for the evaluation for the performance of assets. Every asset must have 95% uptime duration (means that if the device needs to work hundred days, it can be only five days out of service.)" . The second interviewee stated that some tests, which needs to be performed due to regulations (particle testing, fire pump performance tests etc.) or operational, are organized and followed by facility management team.
- **Energy consumption and energy efficiency rating:** Energy consumption and energy efficiency information for each asset are not kept in the first healthcare facility. However, some general information such as general electrical utility bills, water consumption bills and natural gas consumption bills are inputted into the system of the Ministry of Health. The second interviewee stated that energy savings scenarios need to be implemented without giving any damage actions on patients' health. Within this context, they calculate the energy consumption rate which is calculated by dividing total energy consumption with total square meter and benchmark the rate with international standards.

- **Key plans:** MEP, architectural, and structural drawings are available in the first healthcare facility. However, this information cannot be queried on the system. The FM Office performs manual document investigation. In the FM system, some information types such as room intended use and type of room are predefined. The FM Office cannot also achieve the detailed drawings for the building zones, which are given in the key plans. For example, the respondents said that "we cannot achieve elementary square meter information from the system. Therefore, we had to measure all rooms' dimensions manually since square meters are necessary to manage the planning of cleaning service and furniture placement. For instance, we could not place anything except for sickbed in a room due to lack of information."
- **A predicted lifetime of assets:** This information type is used to make a decision for scrapping equipment or fixing of assets in the first healthcare facility. Respondents said that "we need information about initial purchase cost, fixing cost and economic life of the asset. If the fixing cost exceeds 40% of asset initial purchase cost and economic life of an asset is expired, we can give a decision to scrap assets. However, the threshold value (40%) is not solely enough for purchasing new medical equipment. We need to exchange correspondence with either Local Health Authority or Ministry of Health to take permission for purchasing of new equipment. Additionally, officers come from the Local Health Authority or the Ministry to make technical tests". In the second case study, a healthcare facility with nearly 2.500 beds was constructed with a public-private partnership contract and 25 year concession periods were determined under this contract. Therefore, the interviewee stated that a predicted lifetime of assets is very important for this type partnership. However, they cannot make any prediction for lifetime of assets. Instead of it, they give high importance to preventive maintenance activities.
- **Downtime cost of equipment/systems:** This is monitored on uptime duration information in the first healthcare facility. The uptime information monitoring example is given in Figure 11. The respondent stated that "we have a maintenance contract for some equipment. If the maintenance or fixing of equipment exceeds defined hours/days, the maintenance company needs to compensate the loss of earnings, which are equal to the number of patients to care during the downtime duration. If the equipment

has vital importance, we are demanding the replacement of new equipment until fixing or maintenance of equipment is completed. By using this information type, we decided contractual obligations".

Figure 11. Uptime Information Screen

The second interviewee stated that any shutdowns in medical equipment cause more dangerous issues on patients' health and it has indirectly cost impact. The interviewee emphasized the importance of tomography equipment which needs to work uninterruptedly, since tomography is a vital equipment in diagnosis of disease during healthcare services.

- **Cost savings to a prompt response to maintenance request:** The respondents stated that "we have contractual obligations. If the maintenance company cannot manage maintenance, we give a warning or fine to companies". The second interviewee stated that when prompt response to maintenance request is performed, service life of equipment isn't only prolonged, but also labor costs related to maintenance are decreased. Moreover, the interviewee gave examples about air conditioning systems that give a service for Covid-19 isolation rooms. The interviewee stated that if there is a failure in air conditioning equipment in these rooms, it requires prompt response to prevent the spread of air into other areas of the healthcare facility.

4. Discussion

FM information taxonomy framework developed with DSR incorporates two scenarios and Monte Carlo TOPSIS (MCTT) method (Figure 8). In two scenarios, information flows in the organization to perform FM service are observed. This helped to understand importance of FMITs and the effect of lack of information on the FM process. To eliminate unnecessary data in FM systems and to reveal the rank of FMITs, MCTT method was developed and used to analyze data obtained with group discussion technique. As a result, the priority order of information types was obtained separately. The most important five managerial information types are discussed below.

- "Identification of hazardous or other risks to people or property" was found to be the most important information type by the respondents since the information can be used in the proactive maintenance. This finding is also parallel to findings of Patacas et al.'s (2015) study. Authors stated that maintenance activities need to be performed continuously to maximize building use and minimize risk and operational costs. Furthermore, according to the results, it was found that this information type has an effect on "FM response time", "FM expense" and booster effect on "Service quality" if the managers reach this information timely.
- Secondly, the study results demonstrated that the facility managers need "Maintenance plans/Maintenance routes" to perform efficient FM as second the most important managerial information types. These queries help facility managers to hold facility response time within the tolerable limits, monitor maintenance budget in the facility and increase service quality. Furthermore, this finding is compatible with Xu et al.'s (2014) study in which authors expressed that building maintenance plan and daily maintenance plan of the building information need to be managed during the operation phase.
- "Hazardous waste management" is one of the most important management areas in the healthcare FM since the facility manager needs to handle waste problem that may cause to health problems on the patients [63]. For instance, if the hazardous wastes are mixed with general wastes in the facility, bacteria and virus problems can be observed. Thus, patients or healthcare staff would be exposed to infections. One of the worst impact of the infection can be Covid-19 or Aids [64]. The facilities needs also to pay money for disposing of hazardous wastes [65]. In the literature, BIM is introduced as a hazardous waste management tool to manage disposal of building materials at the end of building lifecycle or construction phase (Bilal et al., 2016; Pishdad-Bozorgi, 2017). However, FM also requires special focus on waste generation during the operation and maintenance phase (Potkány, 2015; Vaccari et al., 2018). Against to available studies about identification of FM information types, this result showed that there is a need for information related to waste generation and disposal during FM.

- “Work orders” have a vital role in FM to detect abnormal situation in the working environment and to transfer related information to facility managers. For instance, the nurse can detect abnormal situation in the space and report to facility managers with work orders. These work orders don’t only present faster interfere opportunity but also impedes more severe problems on patients’ health, since the document includes information about the issue roughly [51]. In parallel to this research, Becerik-Gerber et al. (2012) emphasized the importance of work order information to troubleshoot broken equipment and enable an increase in occupant comfort. Therefore, the finding shows parallelism with literature.
- The fifth most important managerial information type was found as “Emergency management” as a result of the analysis. Becerik Gerber et al. [27] classified emergency into four groups; “human-caused emergencies, natural disasters, internal disturbances and attacks”. These four groups have vital importance since healthcare facilities are public intensive places. Authors stated that emergency management requires organized and displayed data. Additionally, authors emphasized that data requirements in emergency management are based on spatial nature. Therefore, identification of data types and appropriate actions for the emergency scenarios will facilitate decision-making process and impede possible issues on patients’ health [27].
- The most important five technical information types are discussed below. “Real time operation parameters/post occupancy data integration” information type was found the most important technical information type according to respondents’ rating. Becerik-Gerber et al. [27] stated that real-time operation parameters are used in preventive, predictive and corrective maintenance by the FM personnel. Author also gave an example about coldness of the rooms. In parallel to this example, in the healthcare facilities, the ideal temperature-humidity conditions must be ensured for medical personnel and patients due to regulations such as DIN 1946-4, EN 13779:2008, ASHRAE 170 standards etc. Besides, humidity parameter affects “eyes, skin, nose and mouth”. Increase in the number of bacteria depends also on ambient temperature. If it is not managed very well, the facility can be sources of possible health issues [66]. Within this context, IoT devices present promising feature to monitor and

control these parameters. Thus, facility managers can have information about space condition, comfort conditions, and failures in facilities. Therefore, IoT devices are commonly used in facilities as an information resource (Pasini et al., 2016).

- The second and fifth important technical information types are found as "The equipment performance information", and "System performance information". These two information types ensure operation of equipment and systems properly in the facility. Li et al. [67] needed equipment and system information to understand system or equipment whether working properly or not by reading physical and real-time operation parameters in Shangai Disaster Control Centre case. Similarly, the results showed that healthcare facilities require performance information to conduct operations without interruptions. Additionally, this finding shows parallelism with Cavka et al. (2017)'s study. Authors stated that operation and maintenance personnel needs system and equipment performance information to perform maintenance, building systems operation and monitoring, and manage assets.
- "Energy consumption and energy efficiency rating" is found as third important technical information type relatively other information types. Energy consumption is one of the important expenditure items in the healthcare facilities. Garcia-Sanz-Calcedo et al. [68] asserted that the facility managers could save energy 8.60 kWh/m^2 per year with the implementation of appropriate energy management. Similarly, the given importance to "Energy consumption and energy efficiency rating" information type by the respondents shows that the facility managers try to find a way cost-optimum energy management strategies. Beside this, Patacas et al. (2015) stated that "Energy consumption and energy efficiency rating" information type is important to register assets. Xu et al. (2014) and Becerik-Gerber et al. (2012) stated that this information type can be managed data integration into BIM, since energy consumption of buildings have considerable rate in the World energy consumption and have negative impact on environment.
- "Key plans" are found the fourth important technical information by the respondents. Actually, "drawings" and "key plans" intersect with each other. However, in large projects, drawings that show all information within single view cannot be illustrated onto a sheet without scaling. The respondents

could highly choose this information type due to the fact that PPP healthcare facilities have high volume compared to other infrastructure facilities.

- The most important three financial information types are discussed below. “Predicted lifetime of assets” information type is found the most important financial information. In the FM, FM budget is under pressure due to limited monetary resources. Therefore, effective management of existing assets does not only help maintenance costs, but also has positive effect on financial performance of facility. Besides, this information type is also important in renewal strategies for assets. For instance, repairing activities for assets cannot be long economic activity since service quality, and interruptions in production/services can be emerged [69]. Also, the case study of Lavy and Shohet [70] in healthcare facility showed that maintenance cost increases with age of building , occupancy, ambient environment, service life information and particular design help to allocate financial resources to maintenance activities. In parallel to Patacas et al. (2015), and Lee et al. (2016)s’ studies, “Predicted lifetime of assets” information type was found important by healtcare facility managers.
- Secondly, “Downtime cost of equipment/systems” was found as the second important information type in financial information types. Depending on corrective maintenance activities in the facilities, the facility managers encounters high equipment downtime [71]. According to Mishra and Pathak [72] downtime cost can be very costly. Therefore, the authors stated that when creating a maintenance policy, facility managers need to take this information into consideration. Ridgway et al. [73] stated that most healthcare organizations seek a way to reduce downtime of medical equipment and to present excellent patient care. In parallel to the study of Ridgway et al. [73], this study showed that PPP facility managers need “Downtime cost of equipment/systems” information to enable cost-effective FM and to increase service quality.
- “Cost savings to a prompt response to maintenance request” is found in the third important information type. Miller [74] stated that if the issue is not dealt with quickly, it will be source of larger issues. Similarly with the study of Heaton [75], the analysis results showed that achieving “Cost savings to a

prompt response to maintenance request" information makes easier the decision making process of the facility managers.

The FM Information Taxonomy Framework in Figure 8 represents a novel approach and contributes to knowledge in literature and practice to develop asset information requirements during the project delivery from contractor to owner in terms of healthcare facilities. Besides to handover process, identification of FMITs (Figure 7) for healthcare facilities will increase efficiency by showing which information types need to be handled and managed in healthcare facilities. Therefore, an increase in labor hours depending on a manual search of the required information can be eliminated by the help of FMITs taxonomy.

Furthermore, this can be seen in scenario 2. In scenario 2, the lack of "energy consumption and energy efficiency, real-time operational parameters, system performance information, etc." leads to trust in the experience of the personnel. Thus, the identification of FMITs or the usage of the proposed taxonomy will show which information types need to be managed during FM. Additionally, if FMITs identification and management aren't performed, this will induce longer lead time and higher working hours for healthcare FM [76]. Moreover, queries in the FM process in accordance with the information taxonomy framework provides a systematic approach in improving decision making the management of healthcare facilities. Therefore, it is believed that the developed framework will pave the way for information types which are needed to be embedded or query in FM healthcare software.

Within this context, Figure 12 is given to show how FMITs can be applied in FM. In Figure 12, the application of FMITs in Revit was depicted as an example. In the first process, identified FMITs are chosen. These information types are inputted in excel file by defining their group name (such as maintenance, etc.), type of information (such as text, URL, etc.), and categories which show information types where they will be applied in Revit (such as electrical equipment, rooms, etc.). After the creation of an excel file, Dynamo Visual Programming Language is used to Shared Parameters in Revit. Also, an excel file is used to retrieve FMITs and to define them in the Dynamo. After the creation of shared parameters with Dynamo, the FMITs are embedded in the project with the usage of Project Parameters feature in Revit. After the third step, the

FMITs can be observed in the Revit file when the object is selected. Moreover, the information needs to be stored in the database since the information can be updated during maintenance and operation stage of the building. Additionally, some information types cannot be stored directly as a text due to data size limit in text. Therefore, direct data storage can be performed with the usage of databases (such as MongoDB-NoSQL Database). Finally, database will help to query FMITs with the development of user interface.

Figure 12. An example of the implementation of FM Taxonomy Framework

As a result of the usage of the system, which is given in Figure 12, the facility manager can observe and manage FMITs on the BIM model. Also, the given an example helps to create query on user interfaces which cooperate with the external database. Therefore, the lack of required FMITs and its query during the maintenance and operation stage can be prevented. Moreover, the "energy consumption and energy efficiency, real-time operational parameters, system performance information, etc.", which cause non-information-based decision making in scenario 2, can be eliminated with the usage of a collaboration of BIM and FMITs.

5. Conclusion

Facility management plays an important role to support business continuity. FM is a complex and costly process compared to other processes of building lifecycle. To make FM process easier, facility managers need to reach necessary information rapidly. However, these information types are either not delivered to facility manager, or not updated, or not organized or not managed well due to the usage of different systems. Therefore, in this study a FMIT framework is developed with the DSR methodology, encapsulating MCTT technique and conducting a case study of healthcare building with FM scenarios.

Monte Carlo TOPSIS (MCTT) method is developed and used to analyze data collected from healthcare facilities. As a result of the MCTT analysis, 62 FMITs from 64 FMITs were found necessary for healthcare FM. According to results, "Identification of hazardous or other risks to people or property", "Maintenance plans/Maintenance routes" and "Hazardous waste management" information types come into prominence in managerial information types. Case studies showed that these information types were collected and managed by healthcare facility managers to enable maintainability of facility. However, while “Identification of hazardous or other risks to people or property”, and “Maintenance plans/Maintenance routes” information types show parallelism with literature, findings for “Hazardous waste management” information type show differentiation from literature, since construction management literature focuses on waste management as only construction material or hazardous construction material waste produced at the end of the building lifecyle or construction process. However, case studies showed that waste generated during operation and maintenance needs special focus. In technical information types, “Real time operation parameters/post occupancy data integration”, “The equipment performance information”, and “Energy consumption and energy efficiency rating” information types were found as the most important three information types. The main characteristics of the results for the technical information is to enable continuous operation, and more convenient condition for patient healthcare services. Additionally, case studies showed that restrictions or regulations which are established by Ministry of Health and international standards to prevent spread of disease or enable more convenient recovery process for patients are important in terms of information types. In the financial information types, “Predicted lifetime of assets”, “Downtime cost of equipment/systems”, and “Cost savings to a prompt response to maintenance request” were found as the most important financial information types respectively. Financial impact of interruption in services play an important role in healthcare facilities’ financial information requirements. First case study showed that “predicted life time” information type is important to make a decision about buying or repairing assets. Additionally, it was obserbed that “Downtime cost of equipment/systems”, and “Cost savings to a prompt response to maintenance request” information types aren’t managed by facility manager that takes responsibility in first case study, since case facility has maintenance contract. In the second case study, the interviewee stated clearly that it has a reducing effect on labor costs. However, the first case study showed that facility manager was aware of negative impact of downtime costs, since facility manager integrated “Downtime cost of equipment/systems” as a maintenance contract clause that needs to be met by maintenance company.

The practitioners can follow the below steps for the usage of the proposed FMIT taxonomy in the management healthcare facilities;

- All FMITs need to be reviewed to detect the priority of the management of the healthcare facility. Thus unnecessary FMITs can be identified by the facility manager. This will help to eliminate the data stack.
- The available data sources need to be reviewed. If the data source is not available for determined information types, the acquirement of the necessary information from contractors, vendors, or archive needs to be provided. If the information is related to real-time data, the system installment needs to be procured. If the healthcare facility is at the planning stage, the identified or determined FMITs need to be stated with contract clauses. Also, another critical criterion for FMITs in the FM system is to store historical data and to use them in decision-making process. So that, the necessary FMITs and their storage criteria can be used in the procurement of the FM system.
- After all FMITs and data sources are identified, the steps which are given in Figure 12 can be implemented to manage all FMITs.
- As the last step, the usage of FMITs in various FM analysis needs to be performed to improve the healthcare facility (It is a further study).

The proposed framework in Figure 8 enabled the use of information types for effective healthcare facilities management. The contribution of the study into existing body of knowledge is to reveal critical information types and FMIT taxonomy framework specific to healthcare facilities. These information types can be put into contracts to deliver necessary information to facility managers. These information types also help to eliminate data burden in FM systems. Therefore, only necessary information is delivered to facility manager. This helps to decision making process by preventing confusion via correct filtering with the proposed taxonomy, which can also contribute to the FM software developers.

Integrated use of Monte Carlo and TOPSIS techniques is considered significant for the development of the FM information taxonomy. It is considered that this method makes TOPSIS method more useful and effective in terms of discussion of the findings and increase understanding of different respondents' choices. On the other hand, the development of the taxonomy framework is limited to two FM scenarios and FMITs were evaluated with two case studies. Moreover, only TrTEK, AirTEK, Biopro, MYM, BMS, and RFM software and systems could be evaluated in terms of developed FMIT taxonomy. This study can be further extended through the test and trial of the framework on the other scenarios, building types and other FM software solutions. Additionally, the given structure in Figure 12 will be implemented with the extension of Big Data Analytics implementation to enable efficient and faster queries on developed NoSQL database.

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