# Alignment of Engineering Management and Education Using Facility Condition Assessments

**Derek Hillestad Ph.D, Arizona State University**

Derek Hillestad, Ph.D is a facility administrator, analyst, and educator with 20 years of broad experience in facility engineering and management. He has delivered over 100 individual courses in construction and facility management at three levels (associates, bachelors and masters) with a total of over 1,000 students taught. With direct experience of large-scale construction and facility start-ups as a backdrop, Hillestad focuses on research associated with solving problems at the intersection of construction management and facilities strategic planning.

**Rebecca Kassa, The University of Kansas**

PhD Student in the department of Civil, Environmental and Architectural Engineering at the University of Kansas. Specializing in Construction Engineering and Management.

# Analysis of Facility Engineering Management and Education using Facility Condition Assessments

**Abstract**: Engineering management of Facility Condition Assessments (FCA's) is an underrepresented area of research and study towards application to academic curricula in engineering education. A review of literature on the topic of facility engineering practice identified a gap in known research associated with how engineering disciplines align with the practice of FCA's. An emphasis of this study was how FCA's can be utilized as a pedagogical tool to represent architectural, civil, electrical, mechanical, structural, and technological engineering disciplines. Recommendations for facility engineering practice and education is presented for application to engineering disciplines within academia. Globally, this is the first research attempt to link engineering education and management to the practice of facility engineering. This research can be used by facility managers, engineering service providers and engineering educators alike to foster transparency with facility engineering practice, FCA specifications, and facility management strategy.

**Keywords**: Facility engineering, Facility condition assessment, engineering management, engineering education

## Introduction

Origins of the facilities engineering profession can be traced to organizations supporting the built environment. The industrial revolution in the early 1900's brought to creation a diverse array of buildings, factories, and equipment to support the evolution of the United States of America. To address the challenges associated with a rapidly growing industry, in 1915 thought leaders in plant engineering assembled a forum in Boston, Massachusetts of mechanical engineers, master mechanics, and chief engineers in plants. This forum discussed common problems and facilitated the exchange of ideas in order to assist other members to solve these new problems. These thought leaders, led by Harry Dennison, were knowledgeable in management functions, but lacked understanding in how to operate or maintain production machines and building equipment. The plant engineers, however, understood these machines and kept them operational, allowing plants to run efficiently and gain profit. Dennison realized the success of an organization was linked to the abilities of these professionals to work together, rather than each member's separate abilities [9]. These engineers have since evolved into modern day facility managers, engineering directors, chief engineers, operations managers, and other industry specific positions to support facility engineering practice.

Organizations use the Facility Condition Assessment (FCA) for financial and operational strategic planning. An FCA facilitates; knowledge management of assets under ownership, risk management, capital planning, and real estate decisions [23]. FCA practice includes architectural, mechanical, electrical and structural engineering disciplines towards an integrated engineering practice for buildings. Further, the increasingly complex software and digital operation of buildings includes software and technological engineering including digital twins, AI interfaces, and Building Information Modeling (BIM), and other built environment advances. [1]. Currently, there is no research associated with engineering education and the practice of FCA's. As a starting point, this research aimed to define engineering disciplines associated with an FCA, in an effort to determine which engineering education curricula is best aligned with educational opportunities. Using the latest research on FCA practice, this paper aligns FCA planning functions with engineering disciplines. Planning criterion from a recent doctoral dissertation [23] is mapped to engineering disciplines which then were aligned with engineering education programs for future research directions in facility engineering.

This paper aims to address the following objectives: first, to develop an inventory of previous research associated with the practice of facility engineering. Second, in order to provide a relevant application to facility engineering practice, an FCA project is mapped to engineering disciplines. The results of this paper are intended to bring to light integrative engineering pedagogy through the utilization of an FCA project in the classroom.

## Research Methodology

This study analyzed and categorized existing research on facility engineering practice and facility engineering education from 1993 to 2023 by conducting a search of literature. Limited research exists associated with the topic matter, so an extended search of industry organizations and affiliations that support facility engineering was conducted. Further search criteria included architectural engineering, civil engineering, electrical engineering, mechanical engineering, structural engineering, technology engineering of facilities.

All searches were conducted in English and focused on peer-review journals focused on built environment research. The following databases were used; Google Scholar, ScienceDirect, Emerald, Taylor and Francis, and Elseiver from the range of 1993 to 2023.

Abstracts and titles were reviewed to verify content was applicable to facilities or buildings relative to engineering and or education. Literature focused on civil engineering associated with bridges, highways, and horizontal built assets were omitted from this study.

## Literature Review Results

Bibliometric analysis results were organized into the following categories; 1. sources by literature type, 2. sources by journal, 3. Sources by year, 4. Sources by global origin, and 5. Sources by engineering discipline. 36 of the 45 references for this paper represent academic journal articles, conference papers, dissertations or thesis, and books. The remaining 9 references were built environment organizations that support the facility engineering profession.

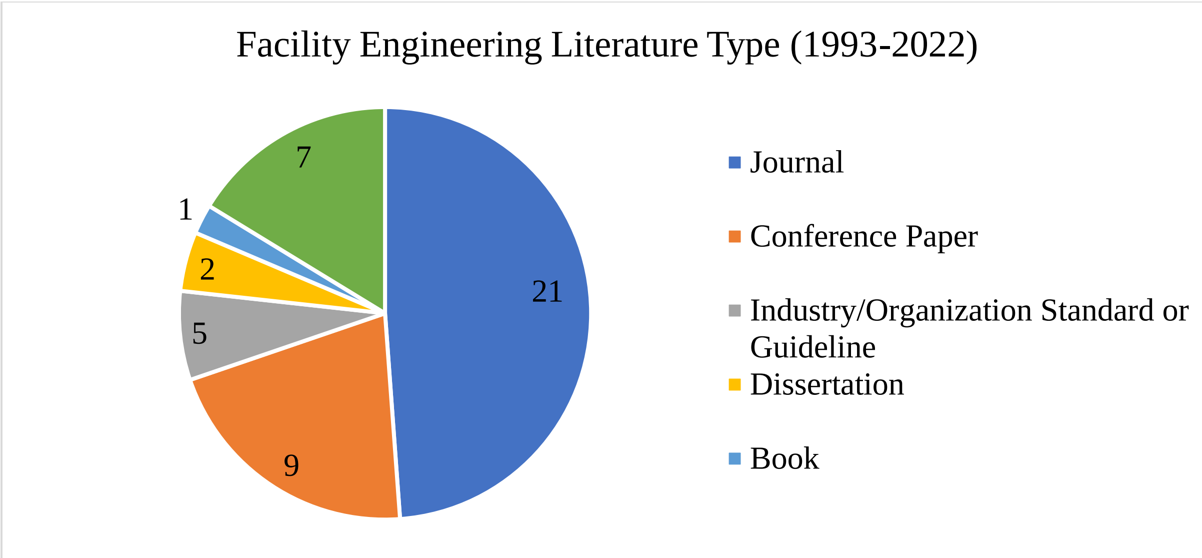


Figure 1: Facility Engineering Literature Type (1993-2022)

The results indicate and upward trend in the past 5 years of research efforts associated with facility engineering.

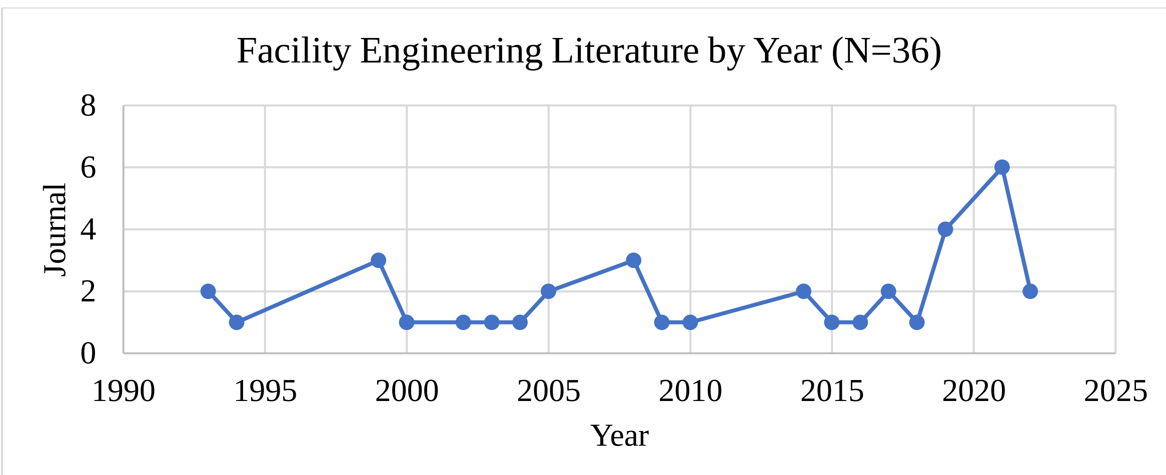


Figure 2: Facility Engineering Literature by Year (1993-2022)

Interestingly, research articles are widely distributed amongst many journals, indicating the broad reach of facility engineering practice amongst various engineering disciplines and built environment as a whole. A trend to perform facility engineering research within the facility management profession is common in modern research efforts.

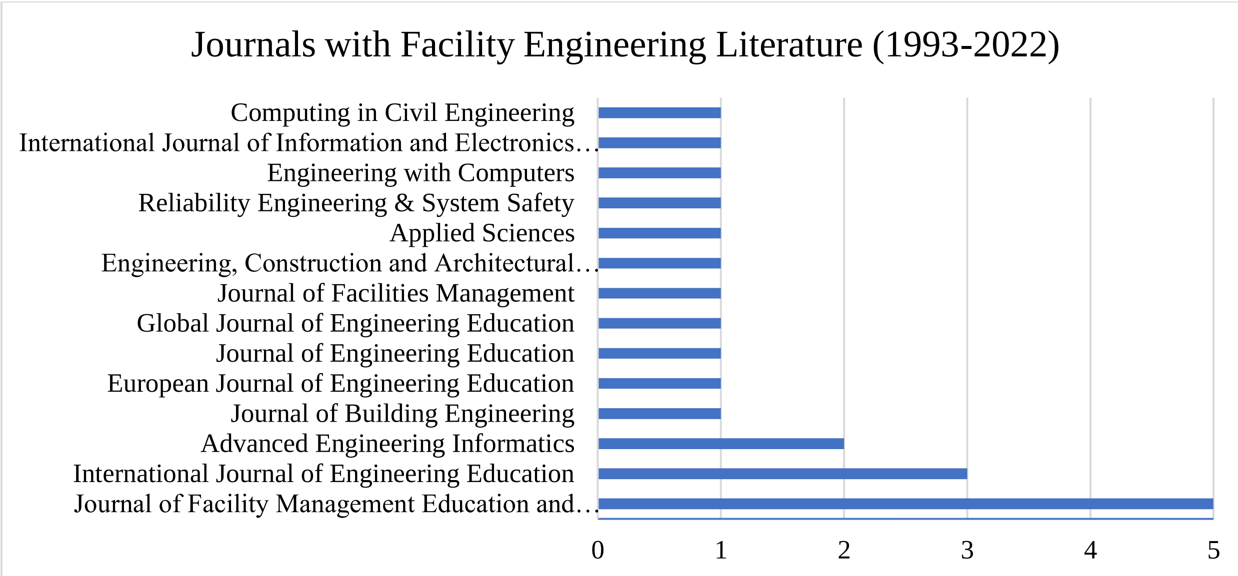


Figure 3: Facility Engineering Literature by Journal (1993-2022)

This study revealed the majority of research associated with facility engineering has been pursued in North America. Interestingly, only Europe and Asia have embarked upon this topic of study, which indicates a need for awareness within a global context.

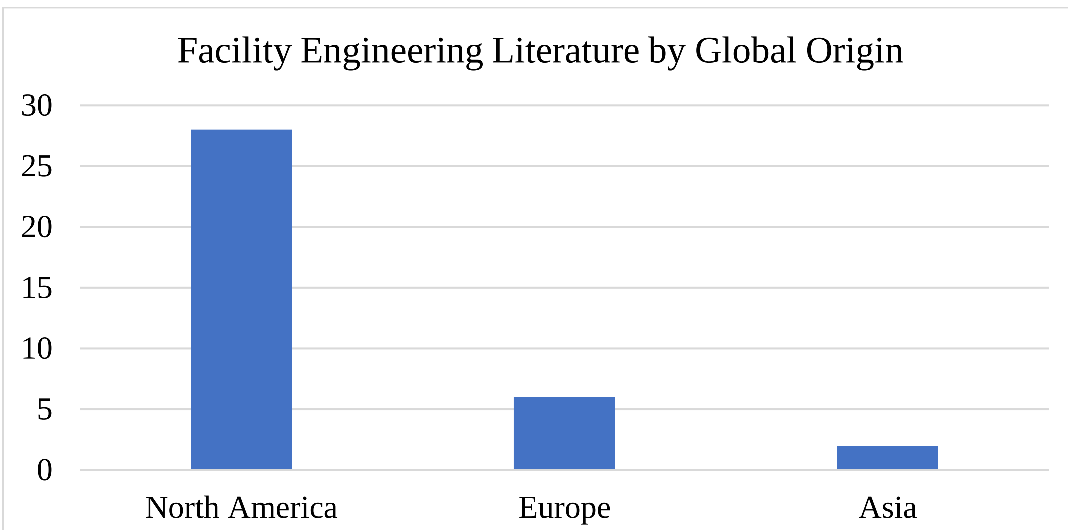


Figure 4: Facility Engineering Literature by Global Origin (1993-2022)

**Literature Review Analysis**

Currently, the facility engineering discipline is fragmented, as individual engineering disciplines contribute to the science of facility engineering as a whole. For example, electrical engineering may address electrical distribution, lighting and low voltage systems, but doesn't address other building systems such as envelope, roofing, HVAC or technological features. The same analogy can be applied for mechanical, architectural, technology, civil and structural engineering disciplines. There is a need to define a facility engineering discipline to fully represent the science of facility engineering and management.

For this study, engineering disciplines aligned with facility assets are presented in Table 1 for reference.

Table 1: Engineering Disciplines Aligned with Facility Assets

| Abbreviation | Engineering Discipline | Facility Assets |
|---|---|---|
| A | Architectural Engineering | roofing, exteriors, windows, doors, interior finishes, space adequacy/layout and design |
| C | Civil Engineering | utilities entry, grading, landscaping, geothermal systems |
| E | Electrical Engineering | electrical distribution, lighting, low voltage systems, fire alarm systems, solar generation systems |
| M | Mechanical Engineering | Heating, ventilation and air conditioning (HVAC), domestic plumbing, fire suppression, vertical transportation, geothermal systems |
| S | Structural Engineering | Steel, masonry, foundations |
| T | Technology Engineering | CAFM (computer-aided facility management), BAS (building automation systems), CMMS (computerized maintenance management systems), digital twins, photogrammetry, BIM (building information modeling), AI interfaces |
| EM | Engineering Management | Commissioning, asset stewardship, capital planning, organizational objectives alignment, workforce development, risk management, energy management, lifecycle costing, code compliance, interpretation of construction drawings, knowledge management |

Using Table 1 as a guide, an inventory of engineering disciplines represented in each source was organized.

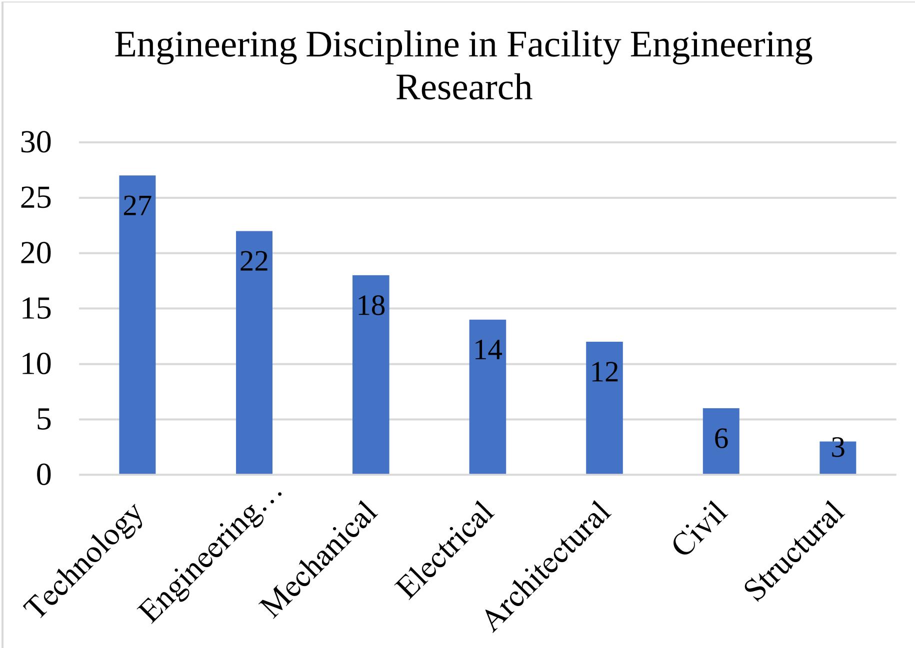


Figure 5: Literature Representation of Facility Engineering Disciplines

The built environment is supported by organizations in the delivery of facility engineering. These organizations can be a crucial resource for engineering educators to fuse career pathways for students. Industry affiliations and organizations supporting the facility engineering profession are presented in Table 2.

Table 2: Organizations Representation of Facility Engineering Disciplines

| Organization | Facility Engineering Discipline | | | | | | |
|---|---|---|---|---|---|---|---|
| | A | C | E | M | S | T | EM |
| AIA (American Institute of Architects) | X | | | | X | | X |
| AEE (Association of Energy Engineers) | | | X | X | | | X |
| AFE (Association for Facilities Engineering) | | | X | X | | X | X |
| APPA (Association of Physical Plant Administrators) | | | | | | | X |
| ASCE (American Society of Civil Engineers) | X | X | | | X | | X |
| ASHE (American Society of Healthcare Engineering) | X | | X | X | | X | X |
| ASHRAE (American Society of Heating, Refrigeration and Air Conditioning Engineers) | | | | X | | X | |
| ASME (American Society of Mechanical Engineers) | | | | X | | | |
| ASTM (American Society for Testing and Materials) | X | X | X | X | X | | X |
| BOMA International (Building Owners and Managers Association) | | | | | | | X |
| BOMI International (Building Owners and Managers Institute) | | | X | X | | | X |
| IAEC (International Association of Elevator Consultants) | X | | | X | | | |
| ICC (International Code Council) | X | X | X | X | X | | X |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| IIEBC (International Institute of Building Enclosure Consultants) | X | | | | | | |
| IISE (Institute of Industrial and Systems Engineers) | | | | | | | X |
| IFMA (International Facility Management Association) | | | | | | X | X |
| NAVFAC (Naval Facilities Engineering Command) | X | X | X | X | X | X | X |
| NCSEA (National Council of Structural Engineers Association) | | | | | X | | |
| NFPA (National Fire Protection Association) | | | X | X | | | |
| NIBS (National Institute of Building Sciences) | X | X | X | X | X | X | X |
| NIST (National Institute of Standards and Technology) | X | X | X | X | X | X | X |
| NSPE (National Society of Professional Engineers) | | X | X | X | X | | X |
| RICS (Royal Institute of Charted Surveyors) | X | X | X | X | X | | X |
| SFPE (Society of Fire Protection Engineers) | | | X | X | | | |
| U.S. Army Corps of Engineers | X | X | X | X | | | |

Further analysis of organizations supporting the built environment can be defined through sector-specific specialization. For example, looking specifically at the healthcare sector, the “American Society for Health Care Engineering (ASHE) is dedicated to optimizing the healthcare-built environment. ASHE’s 12,000+ members design, build, and operate hospitals, and are involved in improving the health care physical environment from the time hospital blueprints are drawn throughout the lifespan of a facility.” [4].

Academically, ASCE offers specialized institutes for the facility engineering profession, focusing on architectural (AEI – Architectural Engineering Institute) and structural (SEI – Structural Engineering Institute).

The National Institute of Building Sciences (NIBS) – offers the whole building design guide as a solution for holistic facility engineering. Further, BRIK (Building Research Information Knowledgebase) is a joint venture between NIBS and AIA which advances building engineering research and knowledge [3], [13], [37].

**The Facility Management Profession & Engineering of Facility Condition Assessments**

Facility Management (FM) is “a profession that encompasses multiple disciplines to ensure functionality of the built environment by integrating people, places, processes, and technology” [32]. Most facility managers have backgrounds related to building management, such as construction management, engineering, architecture, interior design, and more [39]. We can look to Facility Condition Assessments (FCA’s) to best explain the facility engineering and management discipline, as by nature assets and building systems within an FCA intersect with various engineering disciplines presented in this study.

FCA’s are the structured development profiles of existing facilities' conditions typically placed in an electronic database format and populated with detailed facility condition inspection information [31]. Facilities Managers face significant challenges as they have to adapt to the rapidly evolving field of smart buildings and facility technologies. FCA’s are essential in providing valuable information for facility managers regarding these developments. FCA’s can mitigate organizational risks and support more accurate capital funding projections. As buildings age, the practice of FCA's in the built environment guides organizations in their strategic decision-making within facility management departments [26]. A comprehensive FCA requires robust and scalable methodologies that ensure accurate and consistent outcomes [31].

Conducting effective FCA's involves following a multi-disciplinary approach. According to Bartels [11], the typical team responsible for conducting FCAs consists of architects and engineers, working in collaboration with facility engineering staff. Hillestad [24] discovered consistent emphasis being given to a multi-disciplinary approach in FCA service delivery, supporting the finding by Bartels. Hillestad [24] suggests specialty FCA firms that integrate architecture, engineering, capital planning, asset management, and energy engineering may be well-suited to meet the evolving needs of facility managers. According to ASTM [7], a well-rounded knowledge of building systems and components is essential for conducting effective FCA's. ASTM [7] further explains how a single individual may not have the necessary knowledge, expertise, or experience with all building codes, building systems, and asset types. It is unlikely that a single engineering discipline consultancy (such as standalone architecture firm or standalone mechanical engineering firm) can provide all the necessary disciplines [42].

FCA's may be carried out for various purposes, depending on the specific facility's needs. The scope and extent of the assessment may vary depending on the intended purpose of the information gathered. Hillestad [26] performed an extensive literature review evaluating existing research on the purpose of FCA's in the built environment. After reviewing 94 journal articles, dissertations, textbooks, and industry standards that explore the various purposes of conducting FCA's, the study noted a general limitation in existing research regarding the validation of FCA's in the facility management field. Nevertheless, the authors identified three primary purposes for FCA's. These included an operational purpose, which identified FCAs as a fundamental aspect of asset management, a financial purpose, which pertained to capital planning and facilities portfolio benchmarking, and a transactional purpose, which focused on real estate transactions and construction project scope development. Although the authors put forward that these purposes are interrelated, they stated how the classification of FCA purposes facilitates conversations between facility managers and AEC FCA service providers, leading to better alignment and more effective use of FCA results for decision-making in facility management.

FCA standards are essential in the field of facility management. These standards can promote transparency, facilitate clear communication of expectations, and provide a means to evaluate service providers. Hillestad [25] studied standards and guidelines associated with the practice of FCA's. According to the study, the facility management field is facing a lack of proper asset performance documentation and strategy development during the design and construction phases of facilities. Hillestad [25] did a comparative analysis of the three main FCA standards (ASTM, ASCE, RICS) to determine similarities and differences in FCA project management. The study noted that a planning framework for conducting an FCA from an owner's perspective did not exist. Additionally, while a variety of ancillary standards and guidelines support the practice of FCA's, the study identified a gap in pointing out a framework that set forth how a facility manager or chief decision-maker within an organization should conduct an FCA. Overall, the study propounds the significance of a standardized method for integrating the practice of FCA with asset management and facility management systems to the facility management profession.

FCAs can be administered using different project delivery methods. Hillestad [27] identified three primary FCA project delivery methods. The first method is an in-house self-performed FCA utilized by expert facility management departments with the resources to conduct condition assessments of their assets and systems internally. The second method is an outsourced service provider team, which can comprise a stand-alone or combination architectural, engineering, and/or asset management firms. A third method is a hybrid approach, where the facility management department oversees the project management of the FCA and brings in consultants or engineers to supplement the FCA effort. This approach combines the use of in-house personnel with contracted FCA service providers.

FCA projects may have discrete inputs and outputs based on the project delivery method. Hillestad [27] identified the key inputs and outputs of FCA's. According to the study, the common inputs while conducting an FCA include interviews with a chief engineer or lead maintenance personnel, and a walk-through survey of the building, spaces, and equipment. Other inputs may also include occupancy surveys and information from previous FCA reports or client-owned asset information systems. FCA outputs, on the other hand, include condition reports, opinions of probable costs for capital projects, asset useful life analysis, and the calculation of the Facility Condition Index (FCI) as a portfolio measurement of building conditions. These outputs provide valuable information to facility management teams and decision-makers to plan and allocate resources for building maintenance and improvement projects.

Hillestad [23] developed a multi-phased project delivery model for FCA's. The model outlines the lifecycle of engineering management in the context of FCA practice. Figure 6 represents the model which initiates with phase one, referred to as organizational strategy alignment, serving as the foundation for conducting an FCA. Phase one puts the FCA's in order with the strategic direction of the organization and provides a framework for determining the overall scope and anticipated deliverables of the FCA.

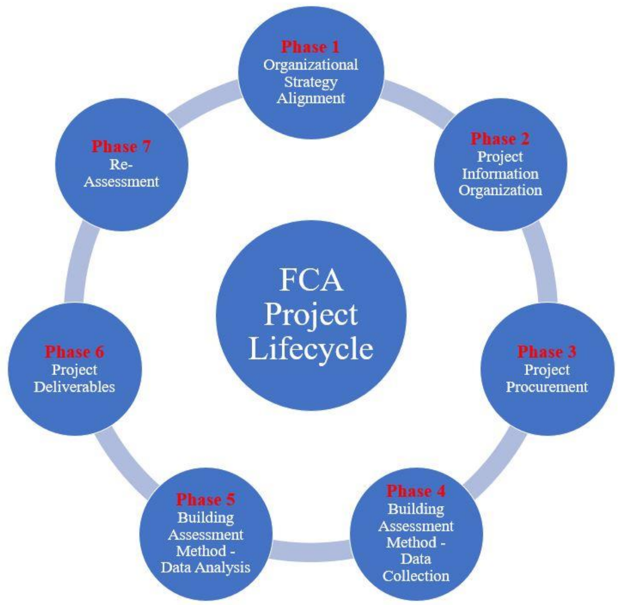


Figure 6: Facility Condition Assessment Project Lifecycle

**Engineering Disciplines Associated with Facility Condition Assessments**

The practice of FCA's in the engineering profession represents a diverse array of building assets and systems. FCA's are comprehensive evaluations that determine the overall physical condition, functionality, and maintenance needs of facilities. Their planning criterion can be organized into engineering management, architectural, electrical, civil, mechanical, structural and technology engineering disciplines.

Architectural engineering is a discipline that plays a significant role in carrying out FCA's. The technical expertise architectural engineers possess is essential to evaluate building systems and components, including their compliance with codes and accessibility requirements. One of the major elements of the FCA process is the assessment of the physical condition and overall operation of interior and exterior finishes. Evaluations such as the performance of windows, doors, walls, floors, ceilings, and roofs require the expertise of an architectural engineer [18], [23]. Providing an assessment of a facility's current state, including any necessary repairs or upgrades, architectural engineering supports decision-making for facility management and informs maintenance, renovation, or replacement strategies.

Civil engineering and FCA's are similarly connected in that civil engineers often possess expertise in the design, construction, and maintenance of structures, making them well-suited to assess the site and landscape features [12]. Civil engineers evaluate elements such as the grading, drainage, erosion control, and vegetation of the site during an FCA to determine their proper functioning and alignment with the intended purpose. Additionally, the civil engineer may assess hardscaping features such as parking lots, sidewalks, and retaining walls to evaluate their condition, functionality, and maintenance requirements. The information gathered from the site and landscape assessment is used to determine the effectiveness of these features and any necessary repairs or improvements.

Electrical engineering is also closely associated with FCA's as it deals with electrical systems that are a vital aspect of buildings. An electrical engineer conducting FCA's evaluates the state and operational efficiency of the electrical components within a building. This may include power distribution systems, lighting arrangements, and communications systems [22], [21], [14], [23], [30], [36]. The electrical panels, switchgear, wiring, and lighting systems require the electrical engineer's expertise. The engineer can identify any inefficiencies in the electrical system and provide recommendations for repair or upgrades while considering potential energy-saving opportunities. Furthermore, electrical engineers are pivotal in ensuring the relevant electrical codes and standards are met. This promotes the safety of building occupants and avoids code violations that could incur fines or penalties.

Mechanical engineering is another field interconnected with FCA's. Mechanical engineers performing FCA's evaluate building systems, including heating, ventilation, and air conditioning (HVAC) systems, plumbing systems, and fire protection systems [12], [21], [14], [23], [29], [30]. Additionally, mechanical engineers have the expertise to assess vertical transportation systems, such as elevators and escalators, during FCA's [23]. These systems and their proper function are critical for ensuring the comfort, health, and safety of building occupants. In conducting FCA's, a mechanical engineer guides in maintaining the building's performance and longevity. Furthermore, the mechanical engineer assesses system efficiency and identifies potential energy-saving opportunities, making recommendations for repairs or upgrades as needed. The input of mechanical engineering in FCA's is critical in securing a thorough and accurate evaluation of the building's mechanical systems and identifying potential problems or opportunities.

Structural engineering is also considered during the evaluation process of a building or facility to assess its structural integrity and safety [12], [43]. The engineer performs an analysis of the foundation, walls, roof, and other structures to determine their stability, strength, and ability to withstand external loads such as wind, earthquakes, and heavy snow. FCA's include examining materials such as steel, concrete, and masonry looking for any indications of corrosion, cracking, or other forms of distress that may affect the structure's safety or durability. The findings are then utilized to identify any immediate safety issues and establish a prioritization of repairs or upgrades. Information from the structural engineer can be used to create a maintenance plan guaranteeing the optimal condition of the facility and facilitating informed decision-making regarding budgeting for future repairs or renovations.

The use of technology in facility engineering has aided advancements in practice, yet widespread adoption of technology appears adhoc and scattered [23]. The term CMMS (computerized maintenance management systems) itself is an outdated term as CMMS technology is now deployed on smartphones, tablets and other digital formats. As buildings have become more sophisticated and complex, BAS (building automation systems) have become common in the management of HVAC equipment. Despite a common presence in modern and post-modern facilities, the engineering of BAS systems is nearly absent in engineering education academic research. Attempts were made by Hutzel [28], [29], [30], in the mid 1990's, but since then limited modern research efforts have been made.

Engineering management is an emerging topic in facility engineering research yet challenges exist with building management knowledge [1]. Facility engineering management includes a broad spectrum of professional practice including commissioning, asset stewardship, capital planning, organizational objectives alignment, workforce development, risk management, energy management, lifecycle costing, and code compliance. Each of these engineering management topics deserves dedicated research efforts to further define, develop and advance engineering practice. It is also argued these advancements play a critical role in sustainability efforts as energy efficiency is a natural byproduct of facility engineering. Interestingly, researchers in facility engineering can look towards the Institute of Industrial and Systems Engineers (IISE) for basics in engineering management that connect to facility engineering. The IISE offers training programs focused on root cause analysis, process mapping, and basics of project management which aids in the engineering management of facilities.

Surprisingly, given an emphasis of engineering management in industrial engineering, limited research exists pertinent to the science of managing the engineering of building core systems such as HVAC, electrical, plumbing, roofing and envelope systems. The authors located just one article connected to facility engineering within industrial engineering, of which was programmatic in focus as it addressed layout of production equipment in a factory setting.

## Facility Engineering Education

What efforts have previously been pursued to define facility engineering education? There is a limitation in modern research of facility engineering education. Nevertheless, researchers have established skills identification as a starting point. Shortage of workforce and lack of formal training opportunities for healthcare facility engineers, for instance, have been identified as concerns by Call [14]. According to Call [14], there are few academic programs specifically tailored to facility engineering technicians (FETs) in the healthcare industry. The role of a FET necessitates a broad understanding of building operations and the development of specific skills on the job. To address this issue, Call [14] proposed classifying essential skills and establishing talent development programs to improve the recruitment, training, and maintenance of competent FETs. The study identifies technical skills and level of proficiency required for FETs working in the healthcare-built environment. According to Call [14], trainers can use these findings to develop a relevant curriculum and determine which skills to emphasize.

Hutzel [28] recognized a growing demand for technicians and mechanical and electrical systems engineers in the construction industry as it shifts towards energy efficiency. Training facilities engineers in using instrumentation and computer controls for building management is imperative. According to Hutzel [28], The Purdue School of Technology introduced a graduate-level course called "Facilities Engineering Technology". The main objective was to educate and train students with interdisciplinary technical backgrounds on energy conservation measures and their economic impact on mechanical and electrical systems. This course is intended to produce multi-skilled employees who can address issues with building systems. The covered content was evenly divided between mechanical and electrical subjects and received positive feedback from participating students and faculty members. Both groups recognized the benefits of the interdisciplinary approach to evaluating building systems and the value of the basic knowledge gained in the course for their future careers. Other colleges and universities (such as NC State, UC-San Diego, Cal-Maritime and others) may offer dedicated facility engineering programs or courses, however Purdue’s scholarly research (although over 20 years old), provides a starting point to build upon for facility engineering education research efforts.

Similarly other studies have evaluated different categories of FCA’s which could be offered in different engineering education programs. Table 3 summarizes these studies and the respective engineering education program.

Table 3: Engineering Education Program Alignment with Facility Condition Assessments

| Engineering Education Program | Facility Condition Assessment Category | Literature |
|---|---|---|
| Engineering Management | Organizational Objectives Alignment | [1], [23], [24], [25], [26], [27] |
| Architectural | Building Envelope (Windows, Exterior Doors, Curtainwall) | [18], [23] |
| Architectural | Interior Finishes (Walls, Doors, Floors, Ceilings) | [14] |
| Architectural | Roofing Systems | [23] |

| | | |
|---|---|---|
| Mechanical | Heating, Ventilation & Air Conditioning (HVAC) | [12], [16], [23], [28]. [30] |
| Mechanical | Domestic Plumbing Systems | [14] |
| Mechanical | Fire Suppression Systems | [14], [21], [23] |
| Electrical | Fire Alarm Systems | [14], [21], [23] |
| Electrical | Low Voltage Systems (Security cameras, IT) | [14], [36] |
| Electrical | Lighting Systems | [14], [23], [28] |
| Electrical | Electrical Distribution | [14], [23], [28] |
| Civil | Landscape & Site | [12] |
| Structural | Structure | [12], [43] |
| Mechanical | Vertical Transportation (Elevators, Escalators) | [23] |
| Mechanical | Other Mechanical Systems (Generator) | [23] |
| Technology | Facility asset management digital systems | [23], [33] |
| Technology | Digital building information modeling | [17], [18], [23], [38], [45] |
| Technology/ Mechanical | BAS (Building Automation Systems) | [14], [23], [28], [30] |

ABET (Accreditation Board for Engineering and Technology) has recently recognized Facility Management (FM) education through partnership with FMAC (Facility Management Accreditation Commission). FM is becoming increasingly important for college students preparing for employment. The FMAC aims to ensure that FM college students acquire the necessary skills, competencies, and knowledge while joining the industry. However, a gap was identified by Call and Sullivan [15] between the industry's expectations of entry-level facility manager competencies. The contemporary student learning outcomes at FM academic programs did not meet the presumption of hiring organizations. The authors determined that FM academics incline towards teaching students general FM principles, with the expectation that industry-specific knowledge will be acquired in the workforce after graduation. The study put forward how incorporating industry-specific knowledge into academic programs would better prepare graduates and help overcome industry recruiting bias. Integrating the learning competencies adopted by FMAC in accredited undergraduate programs and outside of a classroom environment through internships may help solve this gap.

## Discussion

### FCA’s in Engineering Education Programs

In what engineering programs is the practice of FCA’s being addressed? Is there a need for an integrated engineering curriculum to address the inter-disciplinary nature of FCA practice and more broadly the facility engineering profession? How is the need for educating AEC-FM professionals in industry currently being met? As a starting point, engineering education can be mapped to FCA categories.

| Engineering Education Program | Facility Condition Assessment Category |
|---|---|

| | |
|---|---|
| Engineering Management | Organizational Objectives Alignment, Strategic Planning |
| Architectural | Building Envelope (Windows, Doors, Exteriors) |
| Architectural | Roofing Systems |
| Mechanical | Heating, Ventilation & Air Conditioning (HVAC) |
| Mechanical | Domestic Plumbing Systems |
| Mechanical | Fire Suppression Systems |
| Electrical | Fire Alarm Systems |
| Electrical | Low Voltage Systems (Security cameras, IT) |
| Electrical | Lighting Systems |
| Electrical | Electrical Distribution |
| Civil | Landscape & Site |
| Structural | Structure |
| Mechanical | Vertical Transportation (Elevators, Escalators) |
| Mechanical | Other Mechanical Systems (Generator) |
| Technology | Asset management digital systems |
| Technology | Digital building information modeling |
| Technology/Mechanical | BAS (Building Automation Systems) |

Through using an FCA project in the classroom environment, engineering educators can fuse together an integrated engineering approach, applied to industry practice. As a starting point, guest lectures with FCA service providers in an introductory engineering course may provide an orientation to facility engineering practice and create new thinking of integrative engineering for students as they start their engineering education journey. FCA's can be conducted for varying purposes within the built environment. As a result, a diverse array of AEC-FM (Architects, Engineers, Contractors, Facility Managers) professionals provide FCA services for building owners and managers. The broad reach of FCA practice across multiple AEC-FM disciplines in the built environment may allow an innovative pathway for educators in engineering education. Students in turn benefit through awareness of careers and disciplines by the natural diversity of engineering disciplines pertinent to FCA practice. Yet mechanisms to trigger an FCA in classroom experiences lack a formalized structure and opportunities exist to introduce curriculum guidance.

Secondly, using an FCA project as a case study or major project in a course allows experiential learning and relevancy to industry practice. Students can use this project as an example during their interviews for entry level positions in industry to help explain how what they have learned in the classroom is applied to engineering practice. Group work and the ability to work together as a team on the FCA project enables students to learn the importance of inter-disciplinary coordination.

**Recommendations for Future Research**

Engineering service providers that practice FCA's should be engaged in research efforts to determine engineering educational topics pertinent to entry-level engineering positions in industry. Basic skills such as reading and interpreting construction drawings, using software to create visualizations, and determining asset or systems type through a visual walk-through of building mechanical rooms and spaces (amongst other FCA engineering scope) are needed in industry. These skills (and others to be identified through research) should be measured, ranked and prioritized to increase relevancy of facility engineering education.

Further research efforts should identify which colleges and universities throughout the United States (and globally) offer curriculum in facility engineering at each level (certificate / diploma, associates, bachelors, masters and doctoral). In this pursuit, it is recommended that continuing education programs at colleges and universities are also identified to further investigate why facility engineering courses are offered in the continuing education arena in lieu of formalized academic associate, bachelors, masters, and doctoral programs.

Interestingly, no research exists on how FCA engineering supports an organizations' ESG (Environmental, Social, Governance) posture. FCA's can be used for ESG related organizational objectives with an emphasis on sustainability as an FCA can reveal systems and or assets that are not operating efficiently due to poor condition. Further research can explore how FCA's contribute to an organization's ESG strategy.

## Conclusion

This study conducted a literature review on facility engineering practice and facility engineering education. The literature review analyzed existing research and discovered a gap in integrating FCA practices within engineering disciplines. The current facility engineering discipline is perceived as fragmented, as the science of facility engineering is the collective contribution of several engineering disciplines. These include architectural, electrical, civil, mechanical, structural engineering and engineering management. The need for defining a facility engineering discipline that fully represents facility engineering and management persists. The emphasis of this study was to show how FCA's can best explain the facility engineering and management discipline as the practice of FCA's by nature intersects with various engineering disciplines. FCA's can be used as communication tools to bridge the fragmentation gap of facility engineering. The application of FCA's in engineering represents a diverse array of building assets and systems. The broad reach of FCA practice across multiple engineering and facility management disciplines in the built environment may allow an innovative pathway for educators in engineering education. Students benefit through awareness of careers and disciplines through the natural diversity of engineering disciplines pertinent to FCA practice. This research provided the first attempt to link engineering education and management to the practice of facility engineering. Facility managers, engineering service providers and engineering educators can use this approach to foster transparency within facility engineering practice, FCA specializations and facility management strategy.

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