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Literature Review

Assessing Building Functional Suitability—Methods and Tools

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Literature Review: Assessing Building Functional Suitability - Methods and Tools

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Abstract

A literature review was conducted to identify methodologies that could be used to evaluate the functional suitability of the Department of National Defence real property assets. Suitability indicators communicate how well a building contributes to its occupants' efficiency to achieve their work objectives and goals, by identifying the gap between a building's desired state (as defined by the user requirements) and its actual state. The literature review found that organizations use various criteria and indicators when conducting suitability assessments of their facilities, which depend on their missions and goals. This report provides an overview of the many possible building functions that may be selected, supporting the identification, ranking and prioritization of those aspects that are the most relevant for an organization. The report also describes two existing methodologies that can be readily applied and consulted for guidance when evaluating a building's functional suitability, and when establishing the functional priorities and budget allocations for modernization over a building's life-cycle. These methodologies are: (1) the American Society for Testing and Materials (ASTM) Standards for Whole Building Functionality and Serviceability, which cover a broad range of user requirements and related building functions and services; and (2) the BUILDER Sustainment Management System, a software tool developed by the U.S. Army Corps of Engineers, which can be used to identify a building's functional deficiencies based on user and mission requirements.

Résumé

On a procédé à une analyse documentaire afin de déterminer les méthodes qui pourraient être utilisées pour évaluer la fonctionnalité des biens immobiliers du ministère de la Défense nationale. Les indicateurs de fonctionnalité montrent dans quelle mesure un immeuble permet à ses occupants d'atteindre leurs objectifs de travail en déterminant l'écart entre l'état souhaité d'un immeuble (selon les besoins de l'utilisateur) et son état réel. L'analyse documentaire a révélé que les organisations utilisent divers critères et indicateurs pour évaluer la fonctionnalité de leurs installations, en fonction de leurs missions et de leurs objectifs. Le présent rapport donne un aperçu des nombreuses fonctions possibles des immeubles qui peuvent être sélectionnées, à l'appui de la détermination, du classement et de la hiérarchisation des aspects les plus pertinents pour une organisation. Le rapport décrit également deux méthodes existantes qui peuvent être facilement appliquées et consultées aux fins d'orientation dans le cadre de l'évaluation de la fonctionnalité d'un immeuble, ainsi que dans le cadre de l'établissement des priorités fonctionnelles et des affectations budgétaires aux fins de modernisation au cours du cycle de vie d'un immeuble. Ces méthodes sont les suivantes : 1) les normes de l'American Society for Testing and Materials (ASTM) en matière de fonctionnalité des bâtiments, qui couvrent une vaste gamme de besoins des utilisateurs et de fonctions et services connexes de construction; et 2) le système de maintien en puissance BUILDER, un outil logiciel mis au point par le U.S. Army Corps of Engineers, qui peut être utilisé pour cibler les lacunes fonctionnelles d'un bâtiment en fonction des besoins des utilisateurs et des exigences de mission.

Executive Summary

This report presents the results of a literature review conducted to identify current standards, guidelines and software tools incorporating frameworks and indicators that could be used to evaluate buildings and facilities in terms of their functional suitability for current or future use.

The Assistant Deputy Minister Infrastructure & Environment, ADM(IE), aims to modernize the management of the Department of National Defence (DND) real property portfolio by developing a new analytical/visualization tool that would include a methodology to evaluate and quantify the suitability of DND's building assets. The work described in this report provides evidence that can be used to develop this specific capability of the tool.

Functional suitability is a separate area of asset management to the assessment of a building's physical condition, which aims to identify the physical deficiencies/degradation of the building's structure, infrastructure systems and subsystems. Traditionally, physical condition indicators have been the main metric used to determine a building's maintenance and repair needs. However, buildings may also need refurbishments that go beyond degradation–based renovations, due to: (1) changes in user needs (e.g., a building's capability to provide service to its users is affected when the user or the mission requirements change); (2) technical obsolescence (e.g., existing building components may provide an inferior level of performance compared to new technologies penetrating the market); and (3) changes in regulatory requirements (e.g., buildings must continuously adapt to changes/updates of building codes, regulations, or organizational policies). In some cases, the functional-based needs may be significant and may exceed a building's physical condition-based needs.

Building suitability indicators communicate *how well* a building contributes to the occupants' efficiency and productivity in attaining their missions and goals. Therefore, when conducting a building suitability assessment a clear distinction has to be made between the *functional deficiencies* reported as part of a building's physical condition assessment (which verifies the operational/technical capability of the building components and systems), and the users' *functional requirements* to conduct their activities to the required standard, as supported by the physical features of the building and its surroundings.

This literature review focused on identifying existing methods that could be used to assess the DND real property portfolio using *a building functionality and serviceability approach,* where building user requirements are compared with the capability of a building to meet those requirements, using a comprehensive system of criteria, indicators and measurements. The comparison between the *user demand* and the *building supply* generates a classification rating of a building's *fitness-for-purpose*, which subsequently supports decisions related to retrofit/optimization investments for current or future use, or property disposal.

The process of assessing a building's functional suitability starts with identifying the user requirements at the building level, followed by requirements for spaces, parts of spaces, systems and materials. The user needs are typically formulated in non-technical terms, which are thereafter translated into building performance terms (i.e., technical criteria and metrics), that can be measured and evaluated quantitatively or qualitatively. These metrics are subsequently used to verify the fit between the user demands and the building supply to determine the level of suitability for a specific program or mission.

For example, at the space level, the factors that may need to be assessed to determine a space's functional suitability may include but are not limited to the: physical location of the space relative to other spaces that the same activities need to use; layout of equipment, furniture, circulation and access; flexibility of the space to be modified in response to changing demands (which will depend on the design and layout of the building structural features and

services); servicing requirements such as electrical and data outlets; quality of the indoor environment (temperature, humidity, air purity, acoustics, levels of lighting/daylighting, space aesthetics); degree to which the space represents the values of the organization; need for security and protection of the occupants' assets, etc.

The verification step consists of an onsite assessment performed by a competent assessor who examines the actual state of the building relative to the desired state and reports the findings in detail. The comparison between the desired state and the actual state reflects the gap between the users' demand and the building's supply. This gap is a direct indicator of a building's suitability for a program or mission, (1) assessing how well a proposed design, or an existing facility (either occupied, or to be leased/bought) meets the specific needs of the organizational unit occupying the building; and (2) highlighting the issues that require attention and the facilities that are at risk and require urgent action.

Information about a building's functionality can be combined with other building data (such as importance to mission, physical condition, compliance with codes and regulations, environmental protection, space utilization, etc.), to give a holistic overview of real property assets in relation to their requirements.

The literature review found that there is no generally-accepted methodology for conducting assessments of building functional performance, and that organizations use different criteria and indicators that depend on their goals, objectives, functions and activities. A wide range of complexity and selection of metrics was seen between the tools and guidelines reviewed, with some taking into consideration a lower number of aspects, such as the permanent architectural features of a building's spaces and the fixed elements, whereas others also include aspects related to user comfort (such as indoor temperature, humidity, air quality, lighting and daylighting levels, space aesthetics, etc.), as well as location and configuration of property, adequacy of municipal services, proximity to supporting infrastructure and other operational facilities, development potential, historic significance, etc. The number of criteria and metrics used is even larger for organizations which seek certification from various green building certification / rating systems such a LEED, BREEM, Green Globes, BOMA, or the WELL Standard, which focuses on human health and wellness.

When formulating the user requirements, it is important to keep in mind that user needs:

- may differ based on the various building stakeholders involved such as the building owner, building operators (facility management and service personnel), management and employees of the organization based in the building (e.g., doctors, nurses in a hospital setting), and service receivers (e.g., hospital patients).
- may relate to technical aspects, as well as physiological, psychological, and sociological needs. Typical examples often cited in the literature include: spatial characteristics and appearance, indoor environment (temperature, humidity, acoustics, lighting and air quality), energy efficiency, serviceability, accessibility, health and hygiene, comfort, structural safety, fire safety, security, ease of operation and maintenance, durability and sustainability.
- should define conditions to be provided by the building for a specific purpose, regardless of its venue;
- may include requirements that go beyond the building (e.g., might include a need for proximity to daycare, public transportation, vehicle parking, food services, protective surveillance around the building, waste disposal, etc.).

- can translate into *hard* and *soft* building performance indicators. The hard indicators include established metrics applicable to different types of buildings (e.g., requirements for indoor air, sound, thermal and visual environment, safety and protection, access to special facilities and technologies, etc.). The soft indicators are based on user surveys, which generally aim to identify the occupants' perception of a building and to quantify their level of satisfaction, but can also be used to identify the issues that need improvement, or to establish the fitness for use of a facility. Even though this information is usually comparable for buildings and spaces with similar functions and can be used to guide facility management and design processes, determining the required level of building functionality needs to accurately distinguish between objective/quantifiable functional needs and the users' subjective evaluations or personal preferences. A distinction should also be made between requirements that are mandatory, optional, and 'nice to have'. Nevertheless, occupant satisfaction surveys remain an important tool in the determination of users' well-being and comfort and should be seen as complementary to building functionality evaluations, being indicative of how the occupants feel about the space where they work, as opposed to what they need to do their jobs effectively. Furthermore, research on *building usability* aspects showed that in order for "specified users to achieve specified goals with effectiveness, efficiency, and satisfaction in a specified context of use" (as described by ISO 9241/1998), the building performance assessment should focus not only on the achievement of the program's goals, but also on the building users' satisfaction and experience.

This report provides building functions, assembled from the literature, that offer an overview of the many possible functions that may be selected for a building's suitability evaluation. These lists would help to identify those aspects that are the most relevant for an organization. However, the number of aspects studied should depend on the intended building use, as well as on a ranking and prioritization of the requirements. Case studies were found in the literature where a small number of functional requirements fundamental to an organization were used by some organizations to assess their entire portfolio, while other organizations used 50 topics for typical projects. When a group of buildings are evaluated, such as in portfolio management, the number of performance aspects may also depend on the need to find a common framework of requirements, so that various buildings can be compared and cross-analyzed.

The building functions selected will also depend on the stage of the building life-cycle, as some aspects can only be assessed for suitability only after they have been constructed (e.g., physical size, usability, functional correctness, etc.), while a different profile of requirements may need to be considered after refurbishment or changes in functional use (operational phase) compared to the requirement profile of future occupants or buyers (acquisition or disposal phase).

The building and facility needs of a defence organization are specific to the nature of the activities accommodated. Identifying the key metrics for DND is fundamental to a successful assessment of building functional suitability. Some guides offer specific guidance for some types of buildings (e.g. office spaces), and activities housed in other types of buildings may require adaptation of existing tools to make the criteria specific to occupant and mission demands.

After an examination of over 200 publications, this literature review identified the following two comprehensive frameworks that can be readily applied to assess the functional suitability of real property assets:

- American Society for Testing and Materials (ASTM) Standards for Whole Building Functionality and Serviceability (WBFS), and

- BUILDER Sustainment Management System (BUILDER SMS).

The ASTM WBFS standards use an internationally recognized methodology that can be used to set priorities for budget allocation throughout all phases of a building's life-cycle. The 19 individual standards included in this publication cover over 100 topics of building serviceability and 340 building features, each with levels of service calibrated from 0 (not present, does not have, not applicable) to 9 (indicator of the highest level of functional capability). For each topic of building serviceability, the evaluation criteria reflects the minimum requirements, and other measures and aspects may need to be considered. Likewise, the levels of functionality requirements are also calibrated on a scale from 0 (not required, not applicable) to 9 (functionality most needed). Subsequent to onsite evaluations comparing the two scales, a computerized database and a bar chart profile can be used to visually describe how well a building's services meet each functional requirement.

The focus of the ASTM WBFS standards is on office buildings but the scales provided can be adapted for other types of facilities. Furthermore, new scales for other topics of functionality/serviceability can be developed following the steps provided by the ASTM WBFS standards. Additionally, the following two standards published by the International Organization for Standardization can also be consulted for guidance:

- ISO 11863 (2011), which provides the steps to: (1) determine functional performance requirements for buildings and building-related facilities; (2) check the capability of buildings and facilities to meet the identified requirements; (3) determine the relative importance of each requirement; (4) establish thresholds for capability; and (5) evaluate the significance of differences between what is required and the actual capabilities; This standard incorporates the ASTM WBFS methodology.
- ISO 15686-10 (2010), which provides the timelines and events of when to specify and verify a building's functional performance during its service life-cycle.

Appendices A and B of this report present the functionality criteria incorporated in the ASTM WBFS standards, which have been successfully applied in a military context by the U.S. Coast Guard, who uses the methodology to generate a Suitability Index which measures the gap between the appropriateness of their facilities and their mission requirements. The Suitability Index can also be applied at portfolio level to indicate how well an organization's real property portfolio is aligned with the organization's mission, determining how well its facilities support worker efficiency and productivity.

The BUILDER Sustainment Management System (SMS) is a software application which provides a methodology for assessing a building's functional performance. The methodology was developed by the U.S. Army Corps of Engineers Engineering Research and Development Centre, Construction Engineering Research Laboratory (ERDC-CERL) to assist federal agencies to improve the evaluation and maintenance of their building infrastructure.

BUILDER SMS uses a Knowledge-Based Inspection (KBI) methodology, which prioritizes the resources that are most critical to a mission. A standard set of criteria for evaluating the condition of a building is used to generate a Building Condition Index (BCI), ranging between 0-100, which can subsequently be rolled up into larger groups of buildings or entire portfolios. The software also computes a Functionality Index (FI), which measures how well a building serves its function, as well as a Mission Dependency Index (MDI), which is a risk measure that indicates the importance or criticality of a building to an organization's mission. These two latter indices measure a building's suitability based on both function and mission. The FI can be estimated over a building's life-cycle and can be used as a metric for modernization requirements.

The principle behind the FI is that loss of functionality can be qualitatively and quantitatively described by identifying the functional deficiencies that make a building perform less than optimally for a specific mission, when compared to a newly constructed building that incorporates all of the mission requirements. The following three aspects are reflected in the building functionality metric: (1) functional deficiencies present in the building; (2) a severity factor, which indicates how critically the identified functional deficiencies affect the mission (where applicable, severity levels are defined based on codes and regulations requirements); and (3) the extent the building is affected by each specific functional deficiency (e.g., percentage of building area affected by the functional deficiency, density of functional deficiency).

Coupling the building functionality index (FI) with the building physical condition index (BCI), provides a means for justifying building rehabilitation, supporting decisions related to restoration and modernization, versus demolition and new construction, as well as guiding short- and long-term investment strategies, by prioritizing criteria and taking into account budget constraints.

Appendix G of this report presents the 65 functionality criteria incorporated in BUILDER.

The software can be operated online or on closed networks (own servers) using government-owned software, which supports enhanced security measures. BUILDER follows the ASTM UNIFORMAT II for Building Elements classification (organization of building assemblies by systems and components) and its open data architecture permits free communication with other electronic Army facility management systems and data repositories. Communication links between those systems and BUILDER can be created using web services and Extended Markup Language (XML) exchange features.

Many federal agencies across the United States have implemented, or are currently in the process of implementing, the BUILDER SMS software as a tool to assess the condition and needs of their real property infrastructure.

For adoption of the BUILDER SMS software outside of the U.S. federal government, ERDC-CERL partners with third-party contractors for distributing BUILDER via Cooperative Research and Development Agreements (CRASAs) and Patent License Agreements (PLAs). The following contractors have PLAs for distributing BUILDER: Atkins Global, Cardno, DIGON Systems, FM Projects, North Pacific Support Services and Tetra Tech. The costs associated with the patent license, including royalties are negotiated individually with each contractor.

Development of new tools will take significantly more time compared to adaptation of existing tools. Nonetheless, a clear scope of the objectives of a building functional suitability tool for the Canadian military should be clearly expressed prior to the selection or development of a tool. A starting point to the Canadian need for a tool to evaluate buildings and facilities in terms of their functional suitability for current or future use could be to create an inventory of the current building stock to see the number and diversity of buildings requiring evaluation, categorize them by building type, and then define the functional priorities for each generic type. This will enable the development of a user requirements specification to be drawn up, which could thereafter be used as a criteria to analyze the building infrastructure data in order to verify its suitability and alignment with each specific mission in the Canadian context.

1. Introduction

In response to the Government of Canada's priorities to have a clean environment and a sustainable economy, the Department of National Defence (DND), through its new Strong, Secure, Engaged (SSE)[1] defence policy, plans "to modernize its infrastructure to improve efficiencies and reduce greenhouse gas emissions" (SSE:75-77).

The Defence Energy and Environment Strategy (DEES) provides supporting guidance for SSE's initiatives (#101-104), which aim the 'greening' of Defence by focusing on: improving energy efficiency; conducting sustainable operations; greening DND procurement processes; and building sustainable real property.

This literature review is part of a project which aims to support the Assistant Deputy Minister Infrastructure & Environment, ADM(IE), to build and manage an affordable and integrated portfolio of DND Real Property assets, and to access research and development on emerging technological areas as they relate to greening of defence. The objectives of the project[2] are to:

1. Develop analytical/visualization tools to modernize the management of the real property portfolio, starting with a new tool to quantify suitable assets.
2. Conduct analytical studies to improve the efficiencies in strategic level planning of the real property portfolio, oriented toward emerging real property initiatives.
3. Conduct research and development in emerging technological areas as they relate to the SSE policy on greening defence, including but not limited to: alternative energy options, green buildings, and infrastructure analytics.
4. Address ongoing and emerging questions by ADM(IE) and their subordinate staff.

The first objective mentioned above will be addressed by Defence Research and Development Canada (DRDC) in a three-phase approach[3]:

Phase 1: Review the literature to identify existing frameworks and methods used by other organizations to measure building functional suitability. Functional suitability is a separate area of asset management to the assessment of physical building condition, although there can be some overlaps. *This report supports the goal of Phase 1*.

Phase 2: DRDC will identify what DND has done in the past to address the specific building type management needs and conduct an analysis to understand the intricacies required of DND's unique building stock.

Phase 3: DRDC will integrate the results of Phase 1 and 2 to identify a DND appropriate method to assess and measure the suitability of DND's real property assets, define the requirements of a software tool, and develop the tool through a contract.

The results of the activities conducted in Phases 1-3 will be used to generate a classification rating that would support reliable decision making on whether or not a building:

- is suitable for the task/functions required;
- is worth maintaining or should be disposed of;
- merits optimization/retrofit investments that would reduce its environmental footprint;

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[1] http://dgpaapp.forces.gc.ca/en/canada-defence-policy/docs/summary.pdf
[2] ADM(S&T) Project Charter, Strategic Decision Support2 Enterprise Resource Management, DRDC, July 2018; Based on personal communication with Manchun Fang (DRDC), October 2, 2018.
[3] Based on personal communication with Manchun Fang (DRDC), October 15, 2018.

- merits optimization investments that would support a change in current function if found unsatisfactory or not appropriate for the current use (e.g., reassignment to a different function or organizational unit);
- is suitable for continued use with normal/regular maintenance (e.g. building supports the function of the organizational unit(s) to which the building is assigned to; is structurally safe; meets the legislative requirements; is energy efficient, sustainable and adapted to climate change; provides an optimal indoor environment for the building occupants).

2. Objectives

In support of Phase 1, the primary objectives of this report are to:

- Identify existing standards, methods, frameworks, best practice guides and software tools, used both nationally and internationally for the management of real property assets and portfolios, *incorporating a building functionality and serviceability approach* (i.e., building performance evaluations linked to the building users functional needs and requirements on one hand, and the capability of the building they occupy to meet those needs on the other hand, using a comprehensive system of criteria/indicators and measurements);
- Provide a comparison of methods to assess the DND portfolio on its functional suitability to support decisions for future investment (i.e., using the method to determine whether a building supports the delivery of the existing service, whether it is worth keeping or not, merits retrofit or optimization investments).

This report lists the documents reviewed, outlines the common criteria and metrics for the quantification of building functional suitability, and provides comparison of the methods and frameworks used for building functional suitability performance evaluations.

3. Method

A comprehensive literature search identified available standards, best practice guides, frameworks, protocols and software tools including metrics and indicators that could be used to assess a building's functional suitability. Over 200 references were reviewed, catalogued and described for this project. The differences/similarities in definitions, scope of building functional suitability and criteria used by the various sources of information were also identified.

The following databases, scientific resources and websites were mined:

- National Research Council Canada (NRC) - National Science Library;
- American Society for Testing and Materials (ASTM) Compass;
- International Organization for Standardization (ISO);
- Scopus website (peer-reviewed scientific publications, including references and recent citations using the snowballing method);
- Google Scholar;
- Publications made available online by national and international federal departments and agencies managing large inventories of property portfolios;
- Publications made available online by international defence and army organizations, describing frameworks for assessing the functional capability of military facilities.

Among the accessed databases, some were public and free, while others were subscription-based or book/e-book purchases paid for by the NRC.

The following keywords were used to identify those documents that contain references to building functional suitability:

- Keywords proposed by the client (DRDC):

- Building/building suitability/functional suitability;
  - Functional performance of buildings;
  - Building/building functionality assessment;
  - Quantify suitability of buildings/suitability quantification of buildings/measure suitability of buildings;
  - Life cycle assessment for buildings;
  - Building performance assessment/evaluation/metrics;
  - Condition assessment for buildings;
  - Building condition assessment/evaluation/metrics;
  - Building sustainability (LEED, BREEAM, HK-BEAM and ENERGY Star)/sustainable building requirements.
- Supplemental keywords proposed by the National Research Council - Construction Research Centre (NRC-CRC):
  - Building user requirements/perspective/satisfaction;
  - Quality of building indoor environment;
  - Post-occupancy evaluation of buildings.

The literature review and report preparation also included:

- Use of NRC Business Support Team resources;
- Consultations with specialized NRC-CRC technical experts conducting work in related fields.

The remainder of this report is organized as follows:

- The concept and definition of building functionality suitability are described in Section 4;
- Results of the literature searches are presented in Sections 5 to 9. These are divided by key data sources and present the indicators of building functional suitability outlined and described by each source;
- A discussion is provided in Section 10 and recommendations are given in Section 11;
- Appendices A and B list the American Society for Testing and Materials (ASTM) / American National Standards Institute (ANSI) standards for whole building functionality and serviceability, describing tools and methods that can be used for setting the functional performance requirements for a building, and for measuring how well the building meets each requirement;
- Appendix C shows an excerpt from the International Organisation for Standardization (ISO) standard specifying when to verify the functional performance requirements throughout a building's life-cycle, and when to check the capability of buildings to meet the identified requirements;
- Appendices D to G present examples of building functionality metrics; functionality rating scales; and functionality assessment templates used by various organizations, including the U.S. Army and various U.S. federal agencies and sub-agencies, to conduct building functionality/suitability assessments of their real property portfolios;
- Appendices H to I present examples of assessment criteria used by relevant national and international building rating schemes, standards, and professional organizations awarding certifications related to building sustainability, environmental impact, and users well-being, comfort and safety;
- Appendix J presents an overview of building functionality and performance aspects.

4. Concept and definition of building functional suitability

From the literature review it became clear that a definition of building functional suitability needed to be developed to enable comparison between methods, concepts and tools. The definition developed drew from the many diverse sources of information found.

In the literature, “building functional suitability” is often described as the capability of a building to support its current function or mission (level of serviceability, or supply) and to meet the building users functional needs (required level of functionality for a particular use, or demand).

Quantitative and qualitative information on the effectiveness of a building to meet program requirements can be obtained by regular building performance assessments conducted throughout a building’s life-cycle. Comparison of the real performance of a building while in service with established targets/benchmarks of performance provides an essential input for long-term investment planning, including building acquisitions, use, maintenance, and disposal.

Building audits usually include a Physical Condition Assessment and a Functionality Assessment.

Building Physical Condition Assessments aim to identify the *physical deficiencies* of a building’s structure and infrastructure systems and subsystems, and to verify compliance with applicable codes and legislation, including fire code and accessibility legislation[4]. Frameworks, metrics and criteria related to building physical condition assessments are out of the scope of this report.

Building Functionality Assessments aim to understand from the user’s perspective:

- How well the design of a space supports the organizational unit to which the space is assigned to;
- How well the space meets present-day functionality needs for the program it is supposed to serve; and
- What corrective actions, including renovation or modernization upgrades, can improve functionality.

In other words, building functionality evaluations aim to identify a building’s *functional deficiencies*, which form an objective criteria for determining a space’s suitability for its current purpose, as well as its ability to support new or alternate uses, regardless of a building’s location, age, shape, structure, and mechanical systems. Functionality audits aim to identify options for refurbishment, redevelopment, or change in usage, and could include assessments of a building’s physical features, as well as of whole or parts of buildings, sites and campuses.

Note, however, that a clear distinction has to be made between the “functional” deficiencies reported as part of a building’s physical condition assessment (which verifies the operative/technical capability of the building components), and the user’s “functional” requirements to conduct operations to the required standard as supported by the physical features of a facility.

Functional suitability indicators verify the adequacy of the building spaces and support facilities, communicating how well the building spaces contribute to the occupants’ efficiency and productivity in attaining their missions and goals. For example, factors that may need to be

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[4] Government of Canada, Bill C-81, Accessible Canada Act: An Act to Ensure a Barrier-free Canada; https://www.canada.ca/en/employment-social-development/programs/accessible-people-disabilities.html

assessed to determine the functional suitability of a space include, but are not limited to: the physical location of the space relative to other spaces that the same activities need to use; layout of equipment, furniture, circulation and access; flexibility of the space to be modified in response to changing demands, which will depend on the structural and building services design; space servicing requirements such as electrical and data outlets; quality of the indoor environment (temperature, humidity, air, levels of lighting and daylighting, as well as users perspectives on the aesthetics of the space), or the degree to which the building represents the values of the organization.

However, the literature also makes a distinction between “hard” and “soft” building performance indicators [1]. The hard indicators include established calculation processes and metrics that are applicable to different types of buildings. The soft indicators are based on user satisfaction surveys (also known as post-occupancy evaluations, POE). Such indicators are usually comparable for buildings and spaces with similar functions [2]. Generally, post-occupancy evaluations aim to identify the occupants’ perception of a building and to quantify their level of satisfaction, however, they can also be used to establish what issues may need improvement, or to establish the fitness for use of a facility. This information often guides facility management and design processes [3].

Therefore, in this report, we understand building functional suitability as the capability of a building to support its current function or mission by meeting not only the building users’ technical needs but also their physiological, psychological and sociological needs.

5. Performance-based building evaluations

5.1 **General frameworks**

5.1.1 Introduction and background

According to Huovila [4], "The performance based building (PBB) concept provides a flexible and technically nonprescriptive framework for building design and construction.… Its application consists of translating human needs (functionality, comfort, etc.) first into functional and then into technical performance requirements, implementing them within a regulatory framework and enabling the construction of buildings that provide long term satisfactory performances." Likewise, deWilde [1] also affirms that "Building performance expresses how well a building performs a task or function. This concept thus lives on the interface of performance requirements that define the tasks and functions that are needed and the technical solutions that meet these requirements."

Before the 1980's building standards and codes were mostly prescriptive, focusing mainly on the physical components of a building and their technical performance. In the early 1980's, ASTM set up a Subcommittee E06.25 on Whole Buildings and Facilities, focused on the overall performance of facilities. The aim was to standardize "what is effective in a building", and how to "measure effectiveness" [5].

At that time there was little consensus in the scientific community as to which evaluation criteria and methodologies should be used to evaluate a building's performance. In the late 1980's, at the request of the federal government of Canada, a team led by authors Françoise Szigeti and Gerald Davis, affiliated with the International Centre for Facilities, located in Ottawa, Ontario, published a methodology developed to match an office building's requirements with its performance and serviceability [6]. This methodology became ASTM standard in 1996, and ANSI standard in 1997 [7].

In the early 2000's, fragmentation still existed in the building industry with respect to performance-based regulation and practices. Different approaches were employed in different parts of the world and only a limited number of criteria describing building functional requirements were mentioned in a few, mostly European, voluntary guidelines. These criteria included aspects such as flexibility, adaptability, variability; interaction and rest spaces; lighting and glare; service life; signage, way finding and orientation; space clarity (e.g., separation, demarcations, zoning); space efficiency, capability and capacity (e.g. internal circulation); and space suitability and usability (e.g., size, mix, layout, location) [7].

In 2002, the Federal Facilities Council of the U.S. National Research Council initiated a study to identify Key Performance Indicators (KPIs) that could be used to determine financial and nonfinancial outcomes of investments in portfolios of facilities and to improve facilities asset management [8].

In 2004, the U.S. government issued an Executive Order describing a real property management reform for government assets, which included the reporting on KPIs on a quarterly basis. The Executive Order specifically called for the establishment of "appropriate performance measures to determine the effectiveness of federal real property management."[9]. To implement this order, U.S. government agencies started a comprehensive review of current measures of building performance, and developed tools to assess the performance of their built assets.

In 2005, the Federal Facilities Council published data on facilities portfolio-level performance indicators in use or under development [8]. The study found that the performance indicator used by most federal agencies was the Facility Condition Index (FCI), also called Asset Condition

Index (ACI), which measures the condition of a facility based on pre-established auditable criteria. The acceptable level of condition varied by mission, agency, organization or importance of the facility, which underlined the importance of setting building performance requirements and goals. Federal agencies also used a range of techniques to calculate and report FCI-related information, which included the Malcolm Baldrige National Quality Program[5], the Balanced Scorecard[6], and the Strategic Assessment Model (SAM)[7] developed by APPA: Leadership in Educational Facilities (formerly known as Association of Physical Plant Administrators in the late 1960's through the early 1990's, and Association of Higher Education Facilities Officers from 1991 to 1997[8]).

In 2007, the US General Services Administration (GSA) requested that all software applications used by GSA be *International Alliance for Interoperability-Industry Foundation Class* (IAI-IFC) compliant [9]. As a result, the now predominantly used *Building Information Modeling* (BIM)[10] incorporates an universal open data standard, which allows free transfer of data among various building-related applications. This enables the transfer of knowledge throughout the 30 to 50 year building life-cycle, including planning, design, construction, management and operation, and recapitalization or disposal.

Several other countries, including Australia and New Zealand, and many European and Asian countries, have also integrated performance-based regulations in their building codes to ensure a building performance-based approach as opposed to a prescriptive (material-based) practice [4,7].

Since the early 1980's the International Organization for Standardization (ISO) has developed a wide range of standards pertaining to building performance evaluations, which also address thermal, air, and acoustical requirements. For example, the more recent ISO 19208:2016[11] - Framework for specifying performance in buildings - "provides the framework for specifying the performance of a building as a whole or a part thereof in order to satisfy specified user requirements and societal expectations". The Australian standard AS ISO 16739:2017[12] - Industry Foundation Classes (IFC) for data sharing in the construction and facility management industries - specifies "a conceptual data schema and an exchange file format for Building Information Model (BIM) data", similarly to ISO 16739:2013[13] - Industry Foundation Classes (IFC) for data sharing in the construction and facility management industries. ISO standards have also been adopted into national building codes and regulations, such as DIN EN ISO in Germany and BS EN ISO in the UK.

Mandatory codes and regulations were supplemented with a wide range of voluntary rating scheme such as: BREEM[14] (Building Research Establishment Assessment Methodology),

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[5] http://www.msqpc.com/business-solutions/baldrige-assessment/
[6] https://www.balancedscorecard.org/BSC-Basics/About-the-Balanced-Scorecard
[7] https://www.appa.org/Research/SAM/sam.pdf
[8] https://www.appa.org/aboutus/index.cfm
[9] https://www.gsa.gov/cdnstatic/GSA_BIM_Guide_v0_60_Series01_Overview_05_14_07.pdf
[10] U.S. General Services Administration, Public Buildings Service;
https://www.gsa.gov/cdnstatic/GSA_BIM_Guide_v0_60_Series01_Overview_05_14_07.pdf
[11] https://www.iso.org/standard/63999.html
[12] https://www.standards.org.au/standards-catalogue/sa-snz/other/sa/as--iso--16739-colon-2017
[13] https://www.iso.org/standard/51622.html
[14] https://www.breeam.com/

introduced in the U.K. in 1990 by the Building Research Establishment; LEED[15] (Leadership in Energy and Environmental Design, introduced in 1994 by the U.S. Green Building Council; NABERS[16] (National Australian Built Environment Rating System), introduced in 1998 by the Australian Office of Environment and Heritage; CASBEE[17] (Comprehensive Assessment System for Built Environment Efficiency), introduced in 2004 by the Japan Sustainable Building Consortium; and GSAS/QSAS[18] (Global Sustainability Assessment System/Qatar Sustainability Assessment System) green building certification system developed in 2009. Even though these rating schemes mainly aim to reduce a building's life-cycle resource use by identifying the environmental loads associated with the built environment, they all include indicators related to the quality of the indoor environment. Their certification benchmarks are indicative of building sustainability and are representative of the *smart and intelligent building* concept. Therefore, they should be considered when establishing baseline requirements for space suitability. A recent addition to these rating schemes is the WELL standard[19] published by the International WELL Building Institute, which specifically links building performance indicators with human health and well-being.

The Chartered Institution of Building Services Engineers[20] (CIBSE) provides detailed guidance related to health and well-being issues in the indoor environment, covering topics such as: thermal comfort, internal air quality, ventilation rates, natural lighting, glare control, internal noise and humidification. The *CIBSE KS06: Comfort*[21] publication has been especially tailored for facilities managers and building users, assisting them to understand comfort requirements, as well as giving guidance on how to communicate their needs and requirements. Sections 2, 3 and 4 of this CIBSE publication explain the key factors and main design criteria related to thermal, visual and acoustic comfort, while Section 5 provides guidance on the information needed when deciding the comfort requirements.

5.1.2 Literature reviews

The following two books offer a valuable compendium of information related to performance-based building evaluations:

Presier & Visher [10] provide a comprehensive collection of scientific articles contributed by a large number of authors with wide-ranging expertise in building performance evaluations. Among other topics, the authors present the POE process used to evaluate a building's performance based on users experiences after they have occupied a building for a given period (e.g. minimum 1 year). Appendices A.1 to A.9 of this book show examples of detailed user surveys including aspects of building functionality (for practical considerations this material is not shown in this report, but can be accessed online). The following three aspects were highlighted in order of importance and priority when connecting the user needs with the levels of building performance: (1) Health, safety and security; (2) Functional, efficiency and work flow; (3) Psychological, social, cultural and aesthetic.

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[15] https://new.usgbc.org/leed
[16] https://www.nabers.gov.au/
[17] http://www.ibec.or.jp/CASBEE/english/
[18] http://www.iesgcc.com/services/gsas-qsas-certification
[19] https://www.wellcertified.com/
[20] https://www.cibse.org/
[21] https://www.cibse.org/Knowledge/knowledge-items/detail?id=a0q20000008I7gGAAS

Pieter de Wilde [1] provides a broad overview of the current body of knowledge on building performance analysis. Applicable to the topic of this report is Chapter 3, which addresses building functions and user functional requirements; Appendix J of this report provides an overview of building functionality and performance aspects, as presented in this book.

Hartkopf et al. [11,12] grouped a building's functions and requirements as shown in Figure 1.

Spatial performance: Individual space layout, aggregate space layout, convenience and services, amenities, occupant factors and controls

Thermal performance: Air temperature, radiant temperature, humidity, air speed, occupant factors and controls

Indoor air quality: Fresh air, fresh air movement and distribution, mass pollutants, energy pollutants, occupant factors and controls

Acoustical performance: Sound source, sound path, sound receiver

Visual performance: Ambient and task levels, contrast and brightness ratios, colour rendition, view/visual information, occupant factors and controls

Building integrity: Structural loads, moisture, temperature, air movement, radiation and light, chemicals, biological agents, fire, natural disasters, man-made disasters

Figure 1: Overview of Total Building Performance Criteria

(source: Pieter de Wilde, Building Performance Analysis, Copyright © John Wiley & Sons 2018, [ref.1])

Lavy et al. [13] conducted an extensive literature review to identify current metrics for building performance measurement, and classified them into four major categories: financial, physical, functional and survey-based, depending on the type of information they each addressed. The metrics were obtained from over 250 published books, peer-reviewed journal articles, conference proceedings, federal facilities assessment reports, benchmarking surveys, and building performance measurement presentations.

All performance indicators that measured aspects related to organizational and business mission, space adequacy, building occupant productivity and supporting facilities were grouped under the functional category, as shown in Table 1, because of their potential to influence an organization's long-term business objectives. Indicators expressing the opinions of building users were grouped under the survey-based category, as shown in Table 2.

Table 1: Building functional performance indicators

(source: Lavy et al., 2010, [ref.13])

Performance indicator	Description	Unit of measurement
Productivity	Measures productivity in terms of: (1) occupant turnover rate; (2) absenteeism; or (3) occupants' satisfaction and self-rated productivity	(1) turnovers per year (2) absentees per year, or (3) survey-based data
Parking	Availability of parking spaces	Number of parking spaces per person
Space utilization	Measures over-used and under-used spaces, adequacy of space, and proper space management	Survey-based data
Employee or occupant's turnover rate	It is the ratio of number of employees turned over in a period of time to the total average number of employees in that period	Ratio (number of employees turned over to the total average number of employees in a given period of time) and number of turnovers per year
Mission and vision, and Mission Dependency Index (MDI)	Building's preparedness to fulfill its mission. MDI indicates priority of mission in projects and funding	MDI is measured using a 100- point scale, usually represented by the following colors: blue (0-40), green (40-55), yellow (55-70), orange (70-85), and red (85-100, most critical)
Adequacy of space	Suitability of space for the proper functioning of the building. Sufficiency of space for various building operations, maintenance, equipment, and other supportive systems	Survey-based data

Table 2: Building users survey-based indicators

(source: Lavy et al., 2010, [ref.13])

Indicator	Description	Unit of measurement
Customer/building occupants' satisfaction with products and services	Measures the ability to deliver quality, products and services to customers, effectiveness of their delivery, timeliness, and overall customer satisfaction with building, building services, and building systems	Customer survey-based data
Community satisfaction and participation	Community involvement, interaction and favorability, and satisfaction among the community	Survey-based data
Learning environment, educational suitability, and appropriateness of building for its function	Appropriateness of a building to perform its functions in terms of functional, spatial, and psychological aspects	Survey-based data
Appearance	Exterior and interior visual qualities, harmony with surroundings, scale and proportion of spaces, and visual stimulation of the building	Survey-based data

Expanding on previous work, Lavy et al. [14] narrowed down and regrouped the performance indicators in an effort to avoid the accumulation and evaluation of redundant information. Table 3 shows the resulting core KPIs, which group together more than one aspect of building performance and provide holistic building performance assessments, permitting the application of the same evaluation criteria to various types of facilities.

Table 3: Core key performance indicators for building performance assessments

(source: Lavy et al., 2014a, [ref.14])

Financial	Functional	Physical	User satisfaction
Operating costs Occupancy costs Utility costs Capital costs Building maintenance cost Grounds-keeping cost Custodial and janitorial cost Current replacement value (CRV) Deferred maintenance, and deferred maintenance backlog Capital renewal Maintenance efficiency indicators (MEI) Facility condition index (FCI) Churn rate and churn costs	Building physical condition – Qualitative building physical condition – quantitative Building performance index (BPI) Resource consumption – energy; water; materials Property and real estate Waste Health and safety Indoor environmental quality (IEQ) Accessibility for disabled Security Site and location	Productivity Parking Space utilization Employee or occupant's turnover rate Mission and vision, and Mission dependency index (MDI) Adequacy of space	Customer/building occupants' satisfaction with products or services Community satisfaction and participation Learning environment, educational suitability, and appropriateness of facility for its function Appearance

The indoor environmental quality index (IEQ), including occupant thermal comfort, listed in Table 3 under the *Functional* heading, is an indicator used by many evaluation schemes such as NABERS, CASBEE, LEED, and the Post Occupancy Review of Buildings and their Engineering[22] (PROBE).

In further work Lavy et al. [15] published techniques for the quantification of:

- A Functional Index (FI), to indicate the functionality and deficiencies of a space, building or campus, using a unit less ratio which compares gross square footage required for certain types of spaces (based on a predetermined specification or desired area) to the actual area; and
- An Indoor/Outdoor Environmental Quality (IOEQ) indicator, calculated based on the measurements, metrics, and benchmarking standards listed in the LEED Green Building Operations and Maintenance Reference Guide [16].

Lavy et al. [15] further emphasized the importance of POE surveys, which should be carried out to assess health, safety and security aspects; functionality and efficiency aspects; and psychological, aesthetic and socio-cultural aspects, as shown in Table 4.

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[22] http://www.cibse.org/knowledge/probe-post-occupancy-studies

Table 4: Key performance indicators for post occupancy evaluations

(source: Lavy et al., 2014b, [ref.15])

Health, safety and security		***Functionality and efficiency***		***Aesthetic and socio-cultural***
Maintenance and serviceability (human comfort and work safety)		Learning and environment		*Sustainability*
Light, noise, temperature, ventilation		Space, windows		View out, privacy, general environment
Internal environment, citizen satisfaction		Use, access, space, performance, engineering, construction		Urban and social integration, character and innovation
Internal environment		Use, access, space, performance, engineering, construction, form and material		Urban and social integration, character and innovation, form and material
Personal control, comfort, noise, overall comfort, health, lighting		The building overall, quickness of response, response to problems, productivity at work, your desk or work area, travel to work		Travel to work
Quality of work life, personal productivity, psychological and social well being		Operating/maintenance cost, cost of building related litigation, resale value of property, rentability of space, process innovation, work process efficiency, product quality, time to market		Public image and reputation, customer satisfaction, community relationships
Availability of natural light, security of personal possessions, temperature changes, effect of solar glare, ability to see out, informal relaxed atmosphere, general background noise, quiet rooms, variations in noise level, mobile phone noise, indoor relaxation areas, internal visibility, circulation space noise, occupation density, privacy, hub noise, personal control of temperature		Access to printers; Quality of artificial light ; Amount of desk space; Window proximity; Formal meeting facilities; Quiet rooms; Support facilities; Intranet information; Workspace ownership; Personal storage; Outdoor areas; Catering; Location in building; Entrance impact		Casual meeting areas; Feeling of equality; Internal visibility; Internal aesthetics; Access to colleagues
Personal control, privacy, personalization		Windows and lighting		Interior planting, color windows and lighting
Accessibility, safety, internal views, Housekeeping and cleanliness, physical comfort, surrounding environment		Signage, layout, waiting time and waiting rooms, treatment		Image of the hospital building, privacy and respect for patients, space requirements, support of family and friends

5.2 **Military frameworks**

The U.S. Army's Engineer Research and Development Center, Construction Engineering Research Laboratory (ERDC-CERL) developed an Engineered Management Systems (EMS) targeting condition assessments and maintenance planning of military facilities. EMS consists of a set of modules used by the U.S. Air Force to manage its inventory of runway and airfield surfaces, and by the U.S. Army and Navy facility managers to maintain, restore and modernize their military infrastructure [17]. All EMS modules provide a procedure for the calculation of condition indexes that assess the condition of a facility's components and systems. The EMS methodology identifies the status (or defect) of the facility's components and reports this information as a value deducted from a theoretical, user-defined, standard condition of 100.

The newest addition to EMS is a software application called BUILDER Sustainment Management System (SMS), which calculates a Building Condition Index (BCI) by rolling up the condition of each building component (using an equivalent level of granularity as the Facility Condition Index mentioned above in section 5.1.1). BUILDER SMS also includes a methodology that assesses and measures the functional performance of a building (FI), which communicates how effectively, safely, and efficiently a building performs its mission at any time during its life cycle, and a Mission Dependency Index (MDI), which evaluates the building's importance to the mission [18]. Additional details on the BUILDER SMS software are provided in Section 8.1 of this report.

Other KPIs that could be used in the management of real property portfolios include those used by the U.S. Coast Guard [8], as follows:

- *Suitability Index*, which measures a facility's appropriateness to the mission requirements. The Suitability Index uses the ASTM Standards for Building Functionality and Serviceability, which provide a side-by-side comparison between the occupant functional requirements (demand side) and the facility's serviceability (supply side), identifying the gap between demand and supply. The Suitability Index can be applied at building level, as well as at portfolio level to indicate how well the portfolio is aligned with an organization's mission and how well its facilities support worker efficiency.
- *Space Utilization Index,* which aims to identify surplus space by comparing the actual space versus the allowable space based on commandant space standards. An index of 1.00 means the space complies with the current standards, while a range between 0.95 and 1.15 is considered to be acceptable. Values outside this range indicate a need for better operation and mission support, redistribution of space, space funding, or standard update.
- *Life Safety or Building Code Index*, which determines the level of compliance with existing life safety measures and building codes. This index assesses the quality of the work environment and determines potential unsafe conditions for the building occupants.

6. Existing standards covering aspects of building functional suitability

6.1 American Society for Testing and Materials (ASTM) Standards for Whole Building Functionality and Serviceability

The ASTM Standards for Whole Building Functionality and Serviceability [19], provide a set of functionality criteria that are baseline level for the requirements of a program. The 19 individual standards part of this publication describe tools and methods that can be used for setting the functional performance requirements for a building, and for measuring how well the building meets each of those requirements [20-39]. Appendix A of this report lists these standards and the aspects and topics of functionality (i.e., user-requirements) and serviceability (i.e., facility performance) they each address. ASTM E1480-92(2013) can be consulted for the standard terminology used in building management [40].

Taken together, the ASTM standards include over 100 calibrated/matched pairs of scales (one for occupant requirements and one for building rating), and 340 aspects of building serviceability which will indicate if a facility is likely to meet a required level of functionality.

The rating scales are not comprehensive and other aspects of functionality may need to be considered and evaluated. The guidance provided in these standards is intended for a "quick scanning to estimate approximately, quickly, and economically, how well a building is likely to meet the needs of one or another type of occupant group over time. The entries are not for measuring, knowing, or evaluating how a building is performing." [21]. These standards focus on office buildings but can be adapted for other types of facilities with minor modifications.

6.1.1 Methodology of the ASTM standards whole building functionality and serviceability

The approach employed by the ASTM standards consists in a gap analysis between the required level of functionality (demand) determined by the users' needs, and the level of serviceability (supply) provided by the physical features of a building, as an indicator of a building's capability to meet each user requirement, as shown in Figure 2.

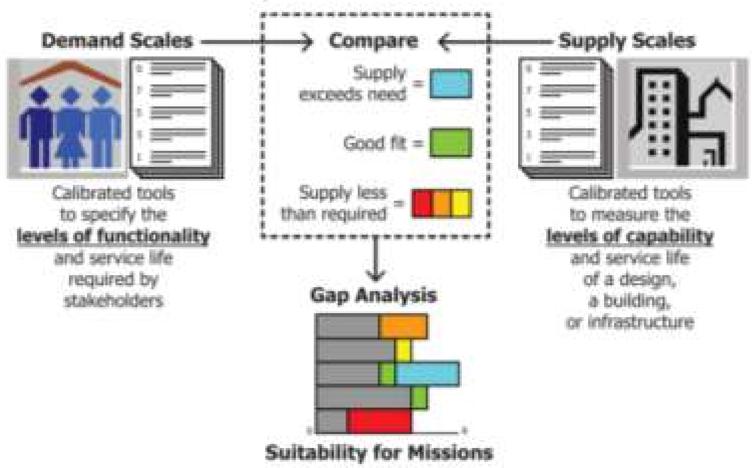

Figure 2: Framework used to determine the gap between a building's functionality (demand) and its serviceability (supply)

(source: ASTM E1679-13, Copyright © ASTM International, [ref.33])

The demand and the supply scales resemble multiple choice questionnaires, allowing: (1) the *building users* to select among the presented statements the ones that best describe the functionality needed to support their work; and (2) *the auditors (evaluators) of the building* to establish the building's level of serviceability.

The requirement (demand) scales describe the user needs in non-technical terms. Each demand scale is classified in a range from low to high (e.g., Level 0=low, Level 9=high), and presents a set of possible answers to the question: *Which of these statements best describes the functionality and service life you need from this facility to do your work?* Functionality requirement levels for a particular organization are independent of the building the organization occupies.

The serviceability (supply) scales measure the service life of a building and its capability to meet each functional requirement. Each supply scale includes a set of descriptions of the physical features or level of support provided, classified in a range from low to high (e.g., Level 0=low, Level 9=high), and presents a set of possible answers to the question: *Which of these statements best describes what is physically present in the building?*

The two sets of levels (demand and supply) are then compared to determine a building's functional suitability (i.e., whether supply matches demand or is more, or less, than required) for *each* of a broad range of aspects important for an organization (see Appendix B of this report for a complete list of aspects and topics of serviceability covered by the ASTM standards).

The principle behind the calibration of the demand and supply scales is presented in Figure 3.

Examples of scales for setting the functional requirements (demand) and for rating a building's serviceability (supply) are shown in Figure 4.

Procedures for setting a profile of required functionality and a profile of building functional capability are shown in Figures 5 and 6, respectively.

Figure 7 shows an example of a bar chart profile generated after the evaluations are completed to visually describe how well the building meets each functional requirement.

Guideline to construct a functionality requirements scale

9 = Most functionally demanding.

7 = Clearly more than level 5, but not the most demanding

5 = Typical mid-range and normal functional requirement

3 = Least requirement of this occupant function, program or service

1 = Least required, or functionally demanding, or can be a temporary requirement, or minimal, or not accepted in a permanent facility, or appropriate because minimal.

0 = Never acceptable, "must not have" or not required or not applicable.

☐ Decision postponed ☐ Lack information.
☐ In-depth evaluation required

☐ Exceptionally important (9) ☐ Important (5)
☐ Minor importance (1) ☐ None

Minimum allowable level (threshold); or, level of criticality (if any) = 9 8 7 6 5 4 3 2 1 0

Guideline to construct a serviceability rating scale

9 = Indicators of the highest level of functional capability likely to be found in facilities.

7 = Clearly more than level 5, but not the most capable.

5 = Typical mid-range facility in the inventory for this functional category of facility, in the whole country or region.

3 = Clearly less than level 5, but appropriate for some situations.

1 = Lowest level of functional capability likely to be found.

0 = Not present or do not have or not applicable.

☐ Decision postponed ☐ Lack information.
☐ In-depth evaluation required

Figure 3: Rules for calibrating a building's functionality and serviceability scales for one aspect of building serviceability

(source: ASTM E1679-13, Copyright © ASTM International, [ref.33])

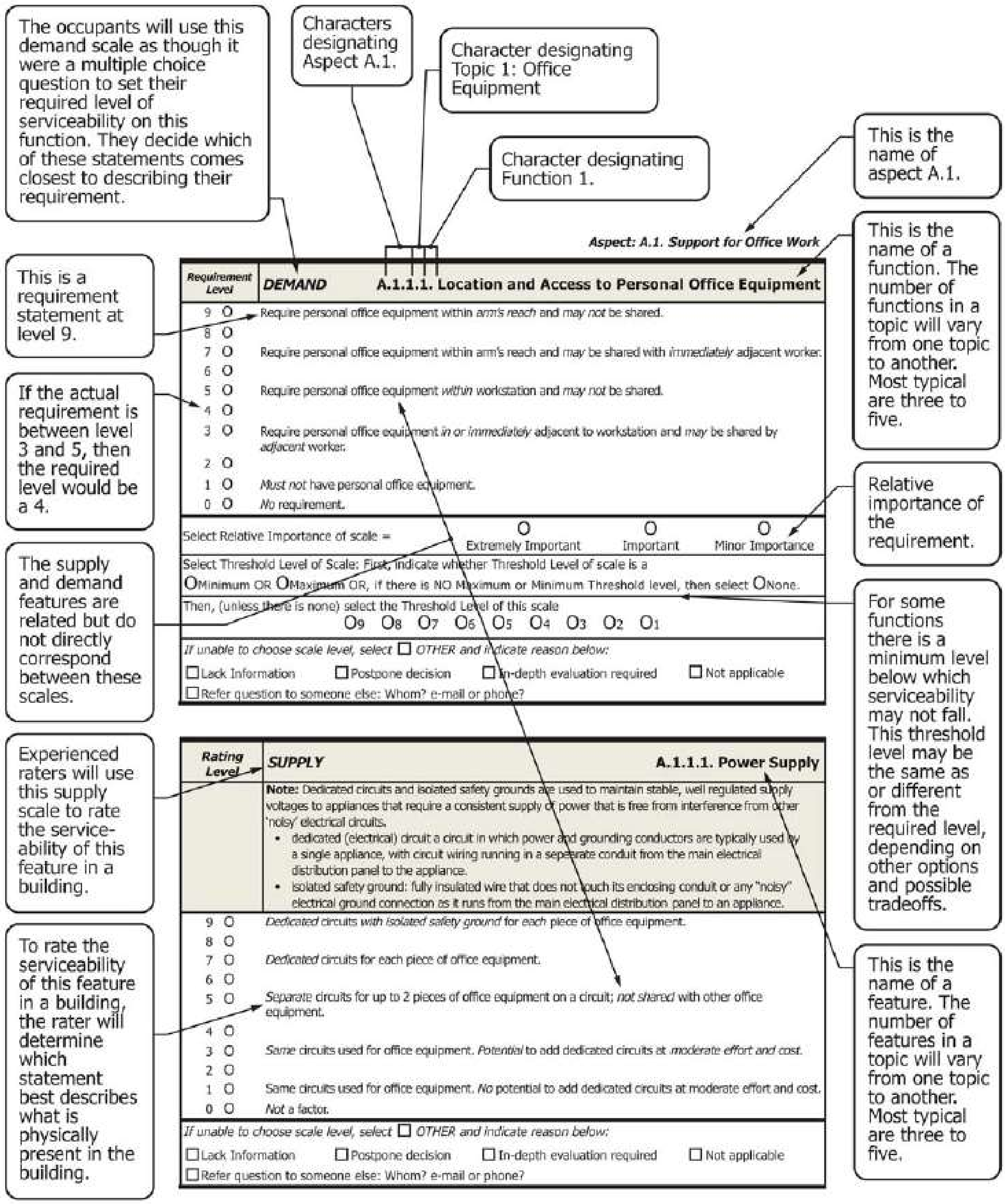

Figure 4: Example scales used for setting a building's functional requirements (demand) and for rating its serviceability (supply)

(source: ASTM E1679-13, Copyright © ASTM International, [ref.33])

Note: Example is shown for 'Location and access to personal office equipment' as the required function (demand), and 'Power supply' as the building provided feature (supply), both reviewed under topic 'Support for Office Work'.

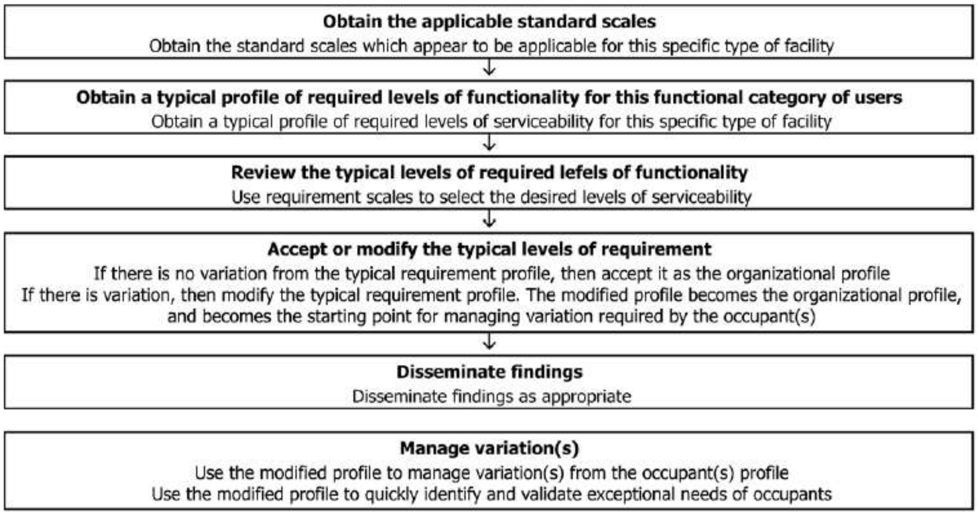

Figure 5: Steps for setting a building's functional requirement profile

(source: ASTM E1679-13, Copyright © ASTM International, [ref.33])

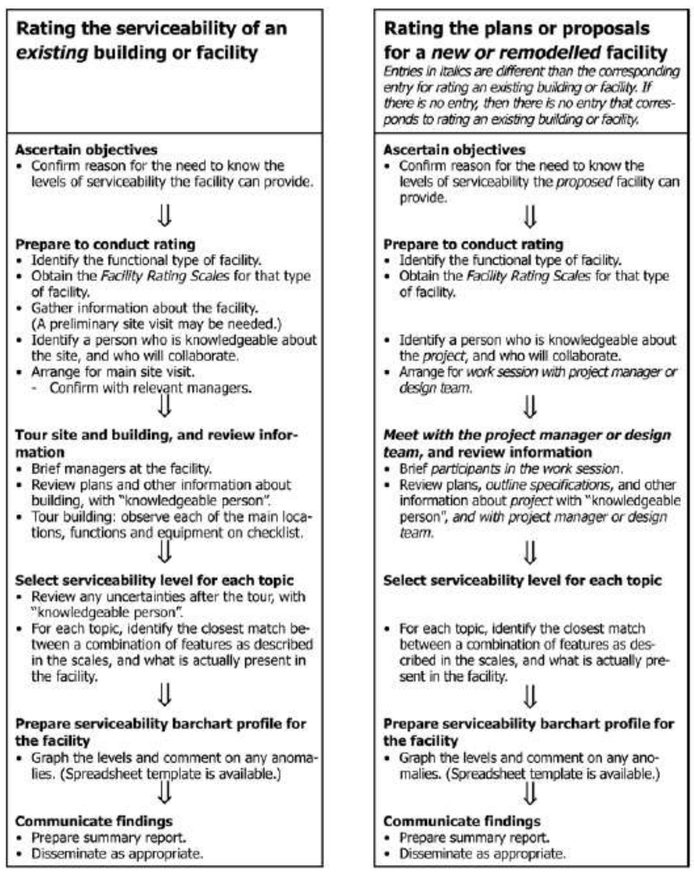

Figure 6: Steps for setting a building's functional rating profile

(source: ASTM E1679-13, Copyright © ASTM International, [ref.33])

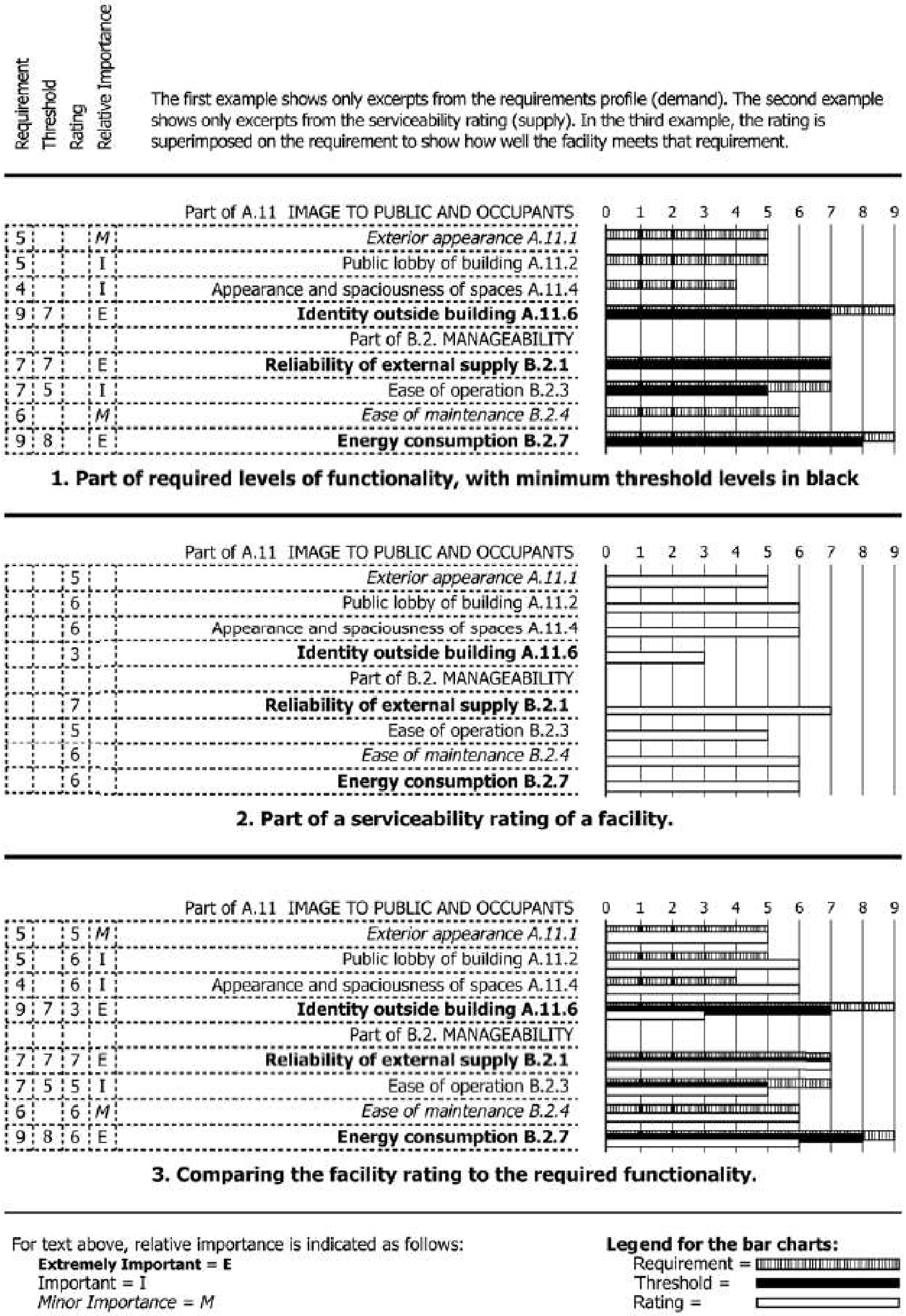

Figure 7: Examples of bar-chart profiles comparing building serviceability ratings to the building user required functionality

(source: ASTM E1679-13, Copyright © ASTM International, [ref.33])

6.1.2 Using the ASTM standards for whole building functionality and serviceability

Figure 8 presents an example of three aspects of functionality and serviceability metrics that could potentially be chosen by an organization for rating a building's functional suitability: A.2 Meetings and Group Effectiveness; A.5 Typical Office Information Technology; and A.6 Change and Churn by Occupants.

Each of these aspects includes various topics of serviceability (e.g., topics A.2.1, A.2.2., A.2.3 and A.2.4 for aspect A.2 Meetings and Group Effectiveness). Below the topic titles are the physical features of the building that would need to be rated to determine serviceability.

A.2 **Meetings and Group Effectiveness = *an aspect***

A.2.1 **Meeting and conference rooms = *a topic***
1. Mix, quantity = *a feature*
2. Floorplate and access
3. Acoustic control
4. Environment
5. Fixtures and fixed equipment

A.2.2 **Informal meetings and interaction**
1. Internal circulation node(s)
2. Entrance node(s)
3. Pause area(s)
4. Food and public facilities

A.2.3 **Group layout and territory**
1. Layout for efficient group work
2. Layout for various group sizes
3. Environmental control
4. Separation
5. Legibility of boundaries and territory

A.2.4 **Group workrooms**
1. Group or project workroom(s)
2. Acoustic control for information security
3. Environment
4. Fixtures and fixed equipment
5. Access from individual workstations

A.5 **Typical Office Information Technology**

A.5.1 **Office computers and related equipment**
1. Zones for high density of equipment
2. HVAC services
3. Illumination
4. Acoustic control

A.5.2 **Power at workplace**
1. Power distribution
2. Plug-in points per workplace
3. Uninterruptible power supply (UPS)

A.5.3 **Building power**
1. Present capacity
2. Potential increase
3. Reliability and quality of supply

A.5.4 **Data and telephone systems**
1. Distribution
2. Future capacity
3. Shielding of data cables
4. Local area network
5. Rooms for data and telephone connections

A.5.5 **Cable plant**
1. Unshielded twisted pair
2. Distance to cable connection rooms
3. Coaxial cable
4. Fibre optic cable

A.5.6 **Cooling**
1. Increased capacity

A.6 **Change and Churn by Occupants**

A.6.1 **Disruption due to physical change**
1. Disruption during relocation
2. Disruption to neighbouring occupants

A.6.2 **Illumination, HVAC and sprinklers**
1. Relocating light fixtures
2. Relocating air diffusers
3. Special air exhaust
4. Relocating sprinkler heads

A.6.3 **Minor changes to layout**
1. Changes in workplace layouts
2. Consequences of minor changes

A.6.4 **Partition wall relocations**
1. Floor to ceiling partition walls
2. Extent of salvage

A.6.5 **Lead time for facilities group**
1. Planning major realignment
2. Ordering and installation

Figure 8: Applying the ASTM standards for Whole Building Functionality and Serviceability

(source: ASTM E1679-13, Copyright © ASTM International, [ref.33])

A large body of literature references the ASTM Standards for Whole Building Functionality and Serviceability. Only some of these studies are highlighted below.

Szigeti and Davis [41] applied the ASTM methodology to determine the functional suitability of a building occupied by five divisions of a major organization, and described the steps taken to generate: (1) the organization's profile of functional requirements; (2) the rating profile of the capability of the building to meet the stated requirements; and (3) the match between the two profiles to answer the question "How suitable was the building for its intended purpose?". A numerical level of functionality was obtained for each of the five divisions, covering about 100 topics of serviceability. The authors used a 4-level classification rating of serviceability, condition and remaining service life for each of the occupant groups or functions, as shown in Table 5.

Table 5: Case-study rating of space functional suitability
(source: Szigeti & Davis, 2002a, [ref.41])

Functionality status and rating	General description of suitability
A = OK at present. Close fit for the functionality requirement profile.	Percent of topics without problems of fit is greater than 90%, meets all threshold levels, and there are no problems of degradation nor "immediate" issues.
B = Threshold(s) and/or 10% to 30% of topics miss significantly.	Miss one or more threshold level(s) and/or significant problems of fit on 10 to 30 percent of topics, but there are no problems of degradation nor "immediate" issues.
C = Serious problems, but not immediate.	Need action to protect the asset from serious deterioration, and/or significant problems of fit with more than 30% of topics, but there are no "immediate" issues. Percent of fit is less than 70% and/or need action to protect the asset from serious deterioration or failure. May not meet some threshold levels. There are no "immediate" issues.
D = Immediate action needed, e.g. for health or safety.	There is one or more issues identified for immediate consideration, e.g. health or safety. When all the "D" topics are remedied, then the site will be re-categorized as an A or a B or a C.

The comparison between the building's rating of serviceability and the divisions' functionality requirement clearly indicated that the building was not suitable for the organization and its mission. The assessment identified the physical changes that were needed to make the building suitable and helped the organization made an informed decision about its future use of the building. Use of the ASTM standards also enabled a comparison between the organization's own requirement levels to those of other similar government and private sector organizations.

Szigeti & Davis [41] recommended a selection of half or less of the most important indicators of functionality when classifying a large portfolio for the first time and noted that, when occupant requirement profiles are not available, facilities could be compared to generic requirements profiles of comparable organizations with similar work functions.

The authors also showed how building functionality assessments can be used at several points throughout a building's life-cycle (Figure 9), and recommended periodical reviews of a building's functional suitability (e.g., five years since the last rating for an office building), based on the level of 'wear and tear' of the building, as well as at key events such as changes in occupancy or major renovations [41].

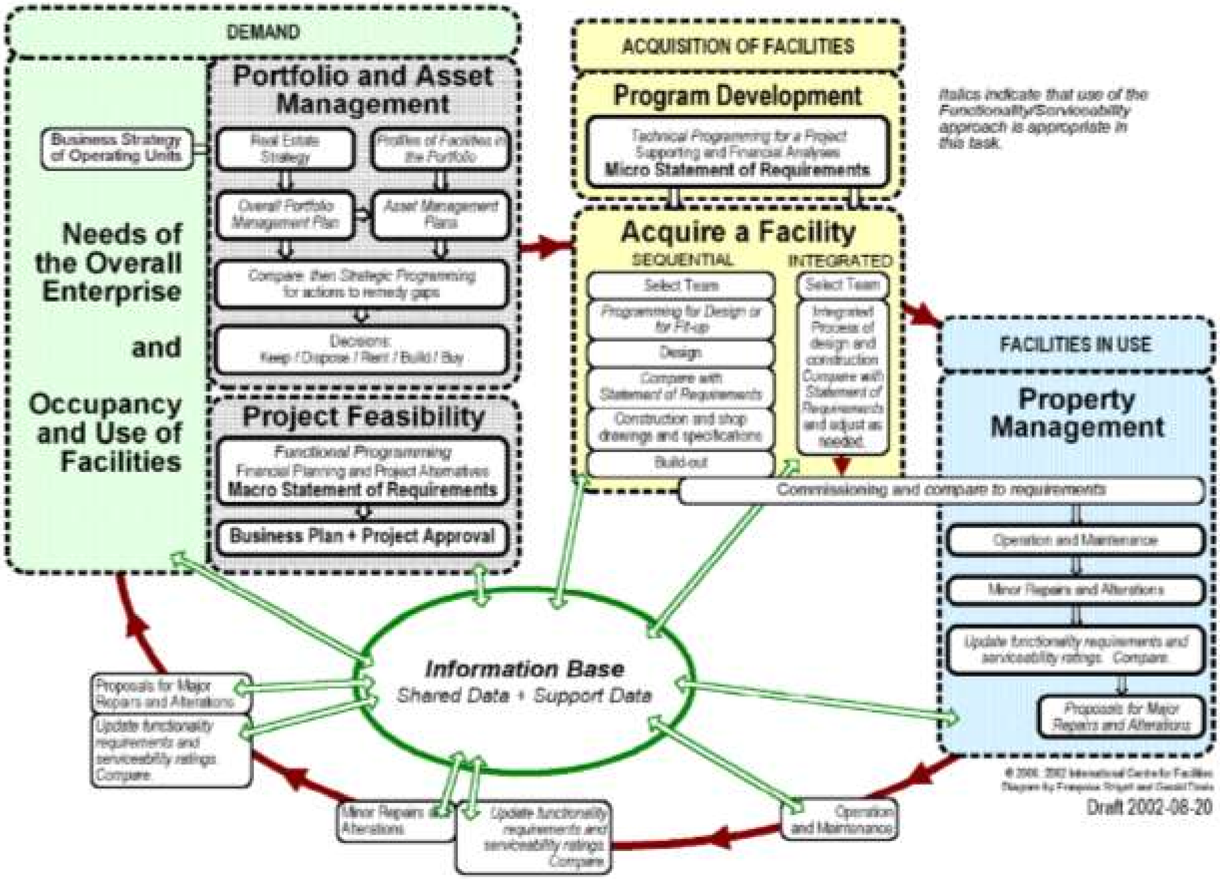

Figure 9: Use of functionality assessments throughout a building's life-cycle

(source: Szigeti and Davis, 2000, [ref.41])

(*Note: text in italics indicates when a suitability assessment would be appropriate*)

Szigeti et al. [42] and Hammod et al. [43] presented an evaluation of the suitability of an U.S. Coast Guard organization occupying several buildings divided into 10 organizational units with different profiles of serviceability. The assessment indicated how each facility matched the requirements in terms of: importance to the mission, building codes and regulations, environmental protection, security, condition and service life, functionality, and utilization. The relative importance of each asset for the mission, as well as the functionality and serviceability profiles, were determined based on interviews with key user representatives and onsite facility assessments.

Figure 10 shows an example of how suitable each organizational unit was in response to the requirements associated with mission (M), security (S), functionality (F), condition and service life (C), and utilization (U). As shown, some facilities exceeded the requirements for functionality, while others were found to be functionally deficient. The results of the assessment, summarized in a simple high-level visual way, made evident which assets were mission-critical and whether each asset was capable of supporting that mission. This information assisted the organization with the allocation of resources based on mission-related priorities.

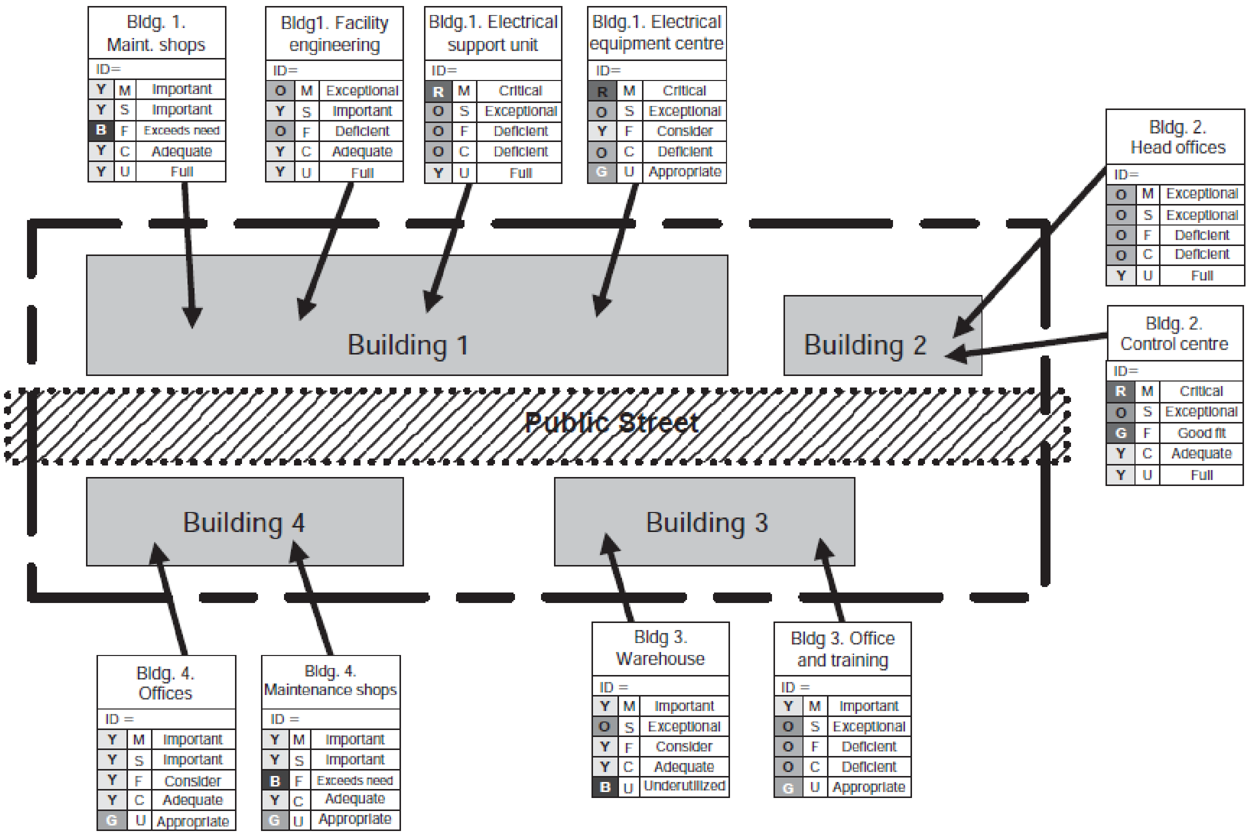

Figure 10: Facility suitability in response to requirements

(source: Szigeti et al. in Presier and Visher, 2005, [ref.10]).

The serviceability methodology used by the ASTM standards has been recognized internationally as the most practical tool to evaluate a building's suitability for a program or mission [44, 45, 70], because of its potential to distinguish between a building's serviceability and a building's performance, where "Serviceability is about whether a building or facility is capable of performing as required", while "Performance means actual behavior in service at a given moment" [46].

Baird et al. [47] can be consulted for techniques and tools that can be used to gather information related to building functionality (developed based on case studies conducted in New Zealand), and Meacham et al. [48] can be referred to for an overall building performance model describing the relationship between the statement of user requirements and the goals and objectives of an organization.

McDougall et al. [49] published a review of leading industry tools for building performance assessment used by practitioners, including the *PROBE - Post Occupancy Studies*[23] and the *ASTM Standards for Whole Building Functionality and Serviceability*. The authors compared the level of measurement each tool provided and highlighted their limitations. The role of the facilities team in the performance measurement was also considered. The PROBE occupant

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[23] http://www.cibse.org/knowledge/probe-post-occupancy-studies

surveys were conducted in occupied offices over a period of ten years and included 43 variables mainly addressing indoor environmental comfort issues such as noise, temperature and glare. These aspects were correlated with management and behavioral issues such as perceived control, response of control systems and perceived productivity. The authors concluded that subjective occupant assessments provide an estimation of the effectiveness of the building systems, however, they mostly reveal information about the user satisfaction with the systems rather than about their functional needs alone. The authors suggested that to support the perception data, a “real world” data collection is needed, and concluded that the methodology used by ASTM standards offers this objectivity, if careful attention is paid to eliminate potential ambiguities caused by personal preferences and interpretations.

6.2 International Organization for Standardization (ISO)

The International Organization for Standardization (ISO) publishes two standards pertaining to building functional performance:

ISO 11863: Building and building-related facilities - Functional and user requirements and performance - Tools for assessment and comparison, which gives guidance on how to determine the levels of functional performance requirements and the levels of serviceability [50].

ISO15686-10: Buildings and constructed assets – Service life planning – Part 10: When to assess functional performance, which establishes when to specify and verify the functional performance requirements during the service life of buildings, and when to check the capability of buildings to meet the identified requirements [51].

6.2.1 ISO 11863:2011

In 2011, Technical Committee ISO/TC 59[24] (Buildings and Civil Engineering Works), Subcommittee SC 3 (Functional/user requirements and performance in building construction) adopted the method used by the ASTM Standards for Whole Building Functionality and Serviceability as ISO 11863: Building and building-related facilities - Functional and user requirements and performance - Tools for assessment and comparison [50].

Furthermore, ISO11863 introduces two additional concepts, “usability” and “user satisfaction”, calling for these two aspects to be explained through the assessment of a building’s functionality to show how they relate to serviceability and capability.

6.2.1.1 Building usability

The concept of usability can be applied to buildings because of their unique physical location and assortment of serviceability features. The term *usability* is defined in the ISO 9241-11 standard to be the “extent to which a product can be used by users to achieve specified goals with effectiveness, efficiency and satisfaction in a specified context of use” [52]. Usability of a product can be measured by analyzing the following indicators: (1) the features of the product required for a particular use; (2) the process of interaction with the product; (3) the effectiveness and efficiency resulting from use of the product, and (4) the satisfaction of the product users. Usability can also depend on software qualities, which “contribute to the quality of the … system in use” [52].

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[24] https://www.iso.org/committee/49070.html; https://www.iso.org/files/live/sites/isoorg/files/news/magazine/ISO%20Focus%20(2004-2009)/2008/ISO%20Focus,%20October%202008.pdf

The usability approach centers on the real purpose of the design of a product, which is to meet the needs of its users, carrying out real tasks, in a real work environment. The concept of usability has been recently adapted to buildings through the work of the International Council for Research and Innovation in Building and Construction[25] - CIB W111: Usability of Workplaces[26]. CIB Publication 330 can be consulted for an overview of methodologies developed to evaluate a building's usability [53]. Additionally, Hansen et al. [54,55] describe in their USEtool Evaluating Usability - Methods Handbook, the process, tools and measurement parameters used to evaluate the usability of existing offices and educational buildings. The methodology can also be adapted for other types of buildings.

6.2.1.2 User satisfaction

ISO11863 cautions about using *user satisfaction* as an indicator of building serviceability, as this indicator may not always provide accurate results when used as a target level of functionality, and may not correctly indicate the order of priority that needs to be allocated to resolving problems within a building. To exemplify, the standard makes reference to a case study where an occupant satisfaction survey conducted by the U.S. General Services Administration (GSA), the provider and building manager of offices for the U.S. government, set a target level for user satisfaction. The study concluded that occupant satisfaction was not indicative of which buildings needed repairs, because of two intervening variables: (1) the occupant satisfaction was "dominated by the perceived responsiveness and helpfulness of the personnel providing building management, rather than by the serviceability of the physical building"; and (2) "respondents mistakenly thought that the building administrators in their own units, to whom they took their complaints, were the building managers, rather than the GSA staff who actually managed their buildings." [50].

Kaiser [56] also noted that the information obtained from user interviews to determine the required level of building functionality needs to accurately distinguish between the objective/quantifiable functional needs for a space and the users' subjective evaluations, "wish lists", or personal preferences.

Nevertheless, occupant satisfaction surveys remain a critical tool in the determination of users' well-being and comfort. Such surveys should be seen as complementary to building functionality evaluations, being indicative of how the occupants feel about the space where they work, as opposed to what they need to do their jobs effectively [57].

6.2.2 ISO15686-10:2010

ISO 15686, Part 10, 2010: "establishes when to specify or verify functional performance requirements during the service life of buildings and building-related facilities, and when to check the capability of buildings and facilities to meet identified requirements." [51].

The standard defines the phases and stages of a building's life-cycle, giving examples of *actions* and *outputs* required for assessing a building's functional performance, as well as examples of typical *actions* and *functions* that may occur during the building management phase. Appendix C of this report shows examples of typical building functions to be assessed for suitability during the property management phase of a building's life-cycle.

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[25] https://www.cibworld.nl/site/home/index.html
[26] https://site.cibworld.nl/db/commission/browserecord.php?-action=browse&-recid=363

6.2.3 Matched terms used for functionality and serviceability assessments

ISO11863 stresses the importance of using the correct terminology when performing building functionality evaluations. Figure 11 shows correctly matched terminology that should be used throughout the process[27].

Demand Considers: uses, needs, requirements, wants, wishes	**Supply** Considers: what is provided in response to demand
Users Occupants, facility managers, building managers, portfolio managers, visitors, other stakeholders such as investors, insurers, municipalities, code officials, etc.	**Constructed assets and other assets** Facilities, properties, buildings, building systems, components, products and materials; infrastructure assets such as bridges, highways, municipal waste systems, etc., and materiel
define, state, or set requirements	provide, assess, rate or evaluate assets
inputs	outputs
ends, results, outcomes	means, solutions
functional statement	performance statement
statement of requirements (SOR)	explicit and implicit performance
functionality	serviceability
functional performance	technical performance
functionality requirement scale	serviceability rating scale
demand scale	supply scale
user functional requirement	capability of asset or facility
functionality profile	serviceability profile
functionality requirement profile	serviceability rating profile
functional element	physical feature
bundle of functions	combination of features
bundle of required functional elements	combination of physical features
description of functional element	indicator of capability
demand for functionality	supply of serviceability
demand for service life	estimated or predicted service life
level of functionality (0 and 1 to 9)	level of serviceability (0 and 1 to 9)
level of demand (0 and 1 to 9)	level of service (0 and 1 to 9)
criteria	unit of measure, verification, test method, etc.

Figure 11: Matched terms relative to functionality (user demand) and serviceability (building supply)

(source: ISO 11863:2011, [ref.50])

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27 ISO11863 terminology is compatible with the Building Performance System Model of the Inter-jurisdictional Regulatory Collaboration Committee (IRCC), http://www.ircc.info/.

7. Existing guidelines including aspects of building functional performance

7.1 Treasury Board of Canada

The following criteria of building functionality are listed in the Treasury Board of Canada, Guide to the Management of Real Property [58], as being indicative of a facility's ability to meet its operational requirements:

Suitability

- Location and configuration of property;
- Adequacy of municipal services;
- Proximity of real property to supporting infrastructure, other operational facilities, and clients/customers;
- Internal configuration of the asset to support uses and permit the flow of people and goods;
- Highest and best use (development potential).

User satisfaction

- Tenants/occupants;
- Proximity to employee services;
- Clients;
- User complaints/suggestions.

Mission (program) criticality

- The degree to which a specific property is required to meet program requirements;
- Business continuity.

Property readiness (PR)

Readiness ratings for property are classified in different categories as follows:

- Fully ready;
- Excess to the program;
- Requires replacement;
- Requirement exceeded;
- Does not support the program.

The list above is not exhaustive and could be supplemented with other criteria linked to *environmental performance* (e.g., including indoor air quality, emissions, waste water, solid or hazardous waste management, energy use, etc.), and *space utilization*, which verifies how intensively a building is being used and determines whether the space needs are met efficiently and suit the operational requirements. Indicators of space utilization include:

- *Vacancy rate index:* percentage of unoccupied area versus total building area; a simple calculation of this index does not always distinguish accurately between short and long term vacancies or between real property that supports a mission and property that might be excess to program requirements;

- *Asset utilization index:* ratio between utilized versus total assets; measures asset inventory against program requirements, detecting surplus space;

- *Space utilization index:* calculated by dividing the actual space by authorized space standards (e.g., for specific types of spaces an index of 1.15 indicates excess space while an index of less than 0.95 indicates insufficient space to support an activity);
- *Hours of operation;*
- *Developed land area.*

7.2 **National Research Council Canada**

The National Research Council Canada (NRC) published a Technical Report, *Protocols for building condition assessment* [59], which includes a methodology to verify the functional effectiveness and compliance of office buildings with the national building codes in terms of barrier free access, and acoustical and lighting performance.

The audit methodology calls for user input and building inspections, which together can identify real and potential functionality issues. The main goal is to determine how well the interactions between the people using the building, the activities performed in the building, and the building indoor and outdoor environment measure against established criteria. The functionality assessment considers the environment surrounding the building and its site; the environment of the building and its site; the environment enclosing the workstations or special use function; and the environment immediately surrounding the users.

7.2.1 Assessment of building barrier free access

Under the Canadian Human Rights Act, it is discriminatory for federal organizations to deny persons with disabilities access to federal real property customarily available to the general public. The Treasury Board Accessibility (TBA) Standard for Real Property[28] addresses the basic needs of employees and the public using or receiving services on federal property. The TBA accessibility standard requires the application of most but not all of the aspects included in the Accessible Design for the Built Environment technical standard[29].

A barrier free access evaluation aims to verify whether the building indoor and outdoor environment effectively addresses the needs of all people who use the building (e.g., service providers, service receivers, visitors, staff, or any individuals who may be permanently or temporarily disabled, or are not disabled).

The *key accessibility indicators* included in the NRC Technical Report [59] are shown in Appendix D.

7.2.2 Assessment of building acoustical performance

Acoustic space requirements depend on the specific use of the space. For example, in open-plan offices, the speech privacy between the workstations, and the loudness and spectrum of the background noise might negatively impact the occupants' ability to effectively complete their work responsibilities. In enclosed offices or in conference rooms, speech or audio/video privacy might be required. In conference rooms reverberation may also impede clear communication and should be within an acceptable range.

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[28] CAN/CSA-B651-M95, https://www.tbs-sct.gc.ca/pol/doc-eng.aspx?id=12044

[29] CAN/CSA-B651-04, https://www.tpsgc-pwgsc.gc.ca/biens-property/sngp-npms/bi-rp/tech/accssblt/cb65119952004-eng.html

A building's acoustical evaluation includes:

- a review of the user requirements and characteristics of the user/building interface;
- an investigation of the problematic areas and issues;
- identification of the problems impacting on the acoustical functional effectiveness.

Building acoustical user requirements can be obtained from the records of complaints and by surveying the building users. Such surveys may include a set of possible answers to the following questions:

- Is the noise you hear at your workstation mainly linked to the building services or to the other building occupants (e.g., your neighbors)?
- How noisy is your work environment?
- How often do you hear your neighbors' speech?
- How much do you understand of your neighbors' speech?
- Is communication clear (e.g. in conference rooms)?

Acoustical measurements should be conducted in sample spaces to identify:

- Background sound levels of the Heating, Ventilating and Air Conditioning (HVAC) system, as well as other building services systems;
- Representative noise levels, if sound masking systems are being used;
- Reverberation time in conference rooms;
- Speech security ratings, if any are required.

A building's acoustical speech privacy can be evaluated by means of a "standard talker" (portable tape player plus an omnidirectional speaker with speech tape that simulates speech at a precalibrated reproducible sound power level) placed at the workspace of interest. An evaluator listening in an adjacent space will assess the speech privacy.

Acoustical target levels for facilities are available in the NRC Technical Report [59], as well as other standard publications and guidelines, including:

- Canadian Occupational Safety and Health (COSH) Regulations of the Canada Labour Code (Part VII, Levels of Sound)[30];
- National Building Code[31];
- The American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) Systems Handbook[32];
- ISO 15712-2005, Parts 1 to 4, Estimation of acoustic performance of buildings from the performance of elements[33];
- ASTM E1130-16, Standard Test Method for Objective Measurement of Speech Privacy in Open Plan Spaces Using Articulation Index[34];
- ASTM E2638–10, Standard Test Method for Objective Measurement of the Speech Privacy Provided by a Closed Room[35];

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[30] https://laws-lois.justice.gc.ca/eng/regulations/sor-86-304/index.html
[31] https://www.nrc-cnrc.gc.ca/eng/publications/codes_centre/codes_guides.html
[32] https://www.ashrae.org/technical-resources/ashrae-handbook
[33] https://www.iso.org/standard/37595.html
[34] https://www.astm.org/Standards/E1130.htm
[35] https://www.astm.org/Standards/E2638.htm

- Canadian Acoustical Association - Guide to the Use of Acoustical Standards in Canada[36] [79].

The *key acoustical indicators* for office building environments included in the NRC Technical Report [59] are shown in Appendix D.

7.2.3 Assessment of building lighting performance

Lighting audits provide an assessment of the building environment in terms of electric lighting and daylighting, covering quantitative and qualitative issues mandated by legislative authorities and considered important by building users. Building indoor lighting is typically assessed in terms of luminance and illuminance levels, reflections and glare, color rendition, control, and adaptability.

Lighting design and performance are assessed relative to the Canadian Occupational Safety and Health (COSH) Regulations of the Canada Labour Code (Part IV, Lighting)[27], and the Illuminating Engineering Society of North America (IESNA) Lighting Handbook[37]. These documents provide illuminance recommendations for good visual acuity for different types of spaces, derived from characteristic lighting requirements for typical activities that occur in each space. The user lighting requirements should be obtained from the records of complaints and by surveying the building users. The lighting functional evaluation should include measurements in sample spaces, taking into consideration daily and seasonal variations.

The *key lighting performance indicators* for office building environments included in the NRC-Technical Report [59] are shown in Appendix D.

7.3 **Public Services and Procurement Canada**

The Public Services and Procurement Canada (PSPC) Technical Reference for Office Building Design establishes baseline technical requirements for office buildings owned or operated by PCPC for the Canadian federal government [60]. The document applies to both new building design and building renovations, providing minimum requirements for each major discipline involved in the design, including: functional suitability; building site; architecture and interior design; structural, mechanical, electrical and fire protection engineering; telecommunications systems; security; accessibility; sustainability; heritage conservation; and end user requirements. This technical reference provides a detailed list of codes, standards and legislation related to:

- functional suitability;
- health, safety, universal accessibility, and security;
- sustainable and enduring development;
- creativity, innovation, and technical competence;
- inspiring and attractive work environments;
- financial performance based on life-cycle costing;
- heritage conservation;
- environmental responsibility;
- fulfilment of immediate occupancy needs (as outlined in the functional program) and anticipation of future building uses;

[36] http://caa-aca.ca/wp-content/uploads/2015/05/CAA-Guide-to-Acoustic-Standards-First-edition.pdf
[37] https://www.ies.org/handbook/DiLaura/Introduction%20to%20the%20IES%20Handbook%20PDF.pdf

- adaptability of building systems to changing priorities and building future uses.

Functional suitability is only generically described as aiming to ensure that design solutions are appropriate for their use and consider the performance of assets over their entire life. Design solutions must be flexible and adaptable, and must respond to operational requirements and the site-specific context by taking into account the local urban design and the landscape architecture. No other metrics of building suitability are provided in the PSPC document.

7.4 **U.S. National Institute of Building Sciences**

The Whole Building Design Guide (WBDG) of the U.S. National Institute of Building Sciences (NIBS) provides information and guidance on functional requirements[38] by building type (e.g., ammunition and explosive magazines; archives and record storage buildings; aviation hangars; community services; educational facilities; federal courthouses; health care facilities; land port of entry facilities; libraries; office buildings; parking facilities; research facilities; barracks; warehouses; waterfront facilities)[39], covering the basic principles applicable in the design of new and renovated buildings [70].

The WBDG also specifies the codes, standards, technologies and issues applicable by space type, outlining aspects such as the functional needs supporting specific missions and spaces; spatial requirements for occupant activities and equipment; functional relationships between program spaces; installation, operation, spatial change, reuse, and replacement of equipment; information technology, communication and other building systems equipment; serviceability (clearance) requirements; workspace flexibility and productivity, workspace "hoteling", adaptability for possible change of building needs and function over time, sustainability and green building design, etc. For example, the "Serviceability (clearance) requirements"[40] section lists aspects such as: design for vehicular clearances in the site design (e.g., drives, gates, ramps, parking); design for vehicular clearances in building design (e.g., doors, docks, obstructions); design for proper equipment access for maintenance and removal and replacement of equipment and/or major components, such as filters, boiler tubes or piping; design for equipment and system life-cycle; design for maintainability (including housing of maintenance equipment, etc.

The space types included in the WBDG are: atrium, auditorium, automated data processing facilities, child care centers, clinic/health units, conference rooms, classrooms, courthouse spaces, firing range, food service, general storage, hearing rooms, joint use retail, laboratories, libraries, light industrial facilities, loading docks, lobbies, mail centers, offices, parking spaces, physical fitness (exercise rooms), places of worship, plaza, private toilets, warehouses[41].

The WBDG guide also references the ASTM Standards for Whole Building Functionality and Serviceability, and the work by Szigeti & Davis' on Functionality and Serviceability Standards: Tools for Stating Functional Requirements and for Evaluating Facilities [82]. For example, section "Design for the changing workplace" [42], could be consulted for recommendations related to: design for flexibility / accessibility, support mobility support, enable informal social interaction, design for a variety of meeting sizes and types, support individual concentration,

[38] https://www.wbdg.org/design-objectives/functional-operational/account-functional-needs
[39] https://www.wbdg.org/building-types
[40] https://www.wbdg.org/design-objectives/functional-operational/account-functional-needs
[41] https://www.wbdg.org/space-types/atrium
[42] https://www.wbdg.org/design-objectives/productive/design-changing-workplace

support stress reduction and relaxation. Relevant codes and standards listed under this section are: ANSI/TIA/EIA-569 Telecommunications Pathways and Spaces[43]; ASTM E1663 Serviceability of an Office Facility for Typical Office Information Technology[24]; ASTM E1679 Standard Practice for Setting the Requirements for the Serviceability of a Building or Building-Related Facility, and for Determining What Serviceability is Provided or Proposed [33]; ASTM E1692 Standard Classification for Serviceability of an Office Facility for Change and Churn by Occupants [34]; Department of Defense DG 1110-3-122 Design for Interiors, U.S. Army Corps of Engineers[44].

Furthermore, for a comprehensive list of documents hosted by the WBDG website, pertaining to the planning, design, construction, sustainment, restoration, and modernization of U.S. Military Departments, Defense Agencies, and the Department of Defence (DoD) Field Activities, using the Defence Unified Facilities Criteria (DoD-UFC)[45], consult the DoD Engineering Criteria Status Report[46]. The documents listed in the aforementioned report can be consulted for setting the functional performance requirements for various buildings and space types and for measuring how well the stated requirements are being met. More details are available online at the WBDG website [70].

7.5 **APPA: Leadership in Educational Facilities**

APPA used to stand for the Association of Physical Plant Administrators in the late 1960's through the early 1990's. Today, the association is known as APPA: Leadership in Educational Facilities.

APPA administers annual surveys tracking Facilities Performance Indicators[47] of over 450 educational facilities in the U.S. Reports based on data collected from colleges, universities, K-12 organizations, and other educational entities enable comparisons of average costs for different types of space and institutions, including performance levels for custodial, grounds, maintenance, and other functional areas [61].

APPA's Facilities Management Evaluation Program (FMEP)[48] offers a customized facility evaluation based on a comprehensive set of criteria [62]. APPA's Facilities Condition Assessment document provides "the tools needed to conduct a facilities condition assessment, guidelines to report assessment findings, and advice to present a persuasive case for the need to fund capital renewal and deferred maintenance" [56]. Functionality criteria were developed for various types of academic spaces, research laboratories and student and community support spaces, and are rated using a 5-level rating system for "functionality and adequacy" as follows: 1 =Optimum, 2 = Adequate, 3 = Fair, 4 = Poor, and 5 = Unsatisfactory. An example of functionality criteria recommended for general classrooms is presented in Appendix E.

APPA also developed a *Work Environment Index*, which measures employee's satisfaction with facilities across various areas. The information collected includes demographic data about the respondent, communications, compensation, customer service, decision making, diversity, leadership, morale, performance management, teamwork, training and development, vision,

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[43] http://innovave.com/wp-content/uploads/2016/03/tia-569-c.pdf
[44] https://apps.dtic.mil/dtic/tr/fulltext/u2/a403980.pdf;
[45] https://www.wbdg.org/FFC/DOD/ufc_implementation.pdf
[46] http://www.wbdg.org/FFC/DOD/dod_engineering_criteria_report.pdf;
[47] Facilities Performance Indicators Survey & Report; https://www.appa.org/research/FPI/index.cfm
[48] APPA's Facilities Management Evaluation Program (FMEP); http://www.appa.org/FMEP/

values and business principles and mission. Results from the surveys are rolled up in an aggregate index indicative of occupant satisfaction and performance [8].

7.6 U.S. Department of Education

The Postsecondary Facilities Inventory and Classification Manual of the U.S. Department of Education targets university real estate portfolios and describes "standard practices for initiating, conducting, reporting, and maintaining an institutional facilities inventory …, which will enable an institution to measure the ability of its space to meet its current programs, assess the current operation costs of its facilities (maintenance, utilities, cleaning, etc.), and … plan for future space needs." [63].

Section 5.5.5. of the manual provides a 6-level classification rating of functional suitability as shown in Table 6, which reflects a judgement about how well the design of a space and its features support the requirements of the organization, or organizational unit, the space is assigned to [63].

Table 6: U.S. Department of Education rating of space functional suitability

(based on: Postsecondary Education Facilities Inventory and Classification Manual (FICM): 2006 Edition, [ref.63])

Functionality status and rating	General description of suitability
Highly Suited, Excellent A	Highly suited or optimally matched to the original design intent and configuration of the space. The architectural features of the space support the use/activity. Appropriate building infrastructure and services are easily and readily available to support the use.
Satisfactory B	Suitable for continued use and provides adequate support for program delivery. Although the space is not optimal for the use, minor modification may be desired to improve the suitability.
Conditional C	Requires limited renovation to support the use on a continued basis. The cost of renovation to optimize program delivery would not exceed 25 percent of the replacement cost of the space.
Development Required D	Requires significant renovation to support the assigned use on a continuing basis. The space significantly inhibits program delivery. The cost of renovations to optimize the fit between the assigned use and the space would range between 25 percent and 50 percent of the replacement cost of the space.
Unsatisfactory F	Is unsatisfactory for the assigned use. Renovating the space to fit the use would not be cost-effective. Renovation costs would exceed 50 percent of the replacement value of the space.
Inappropriate I	Not appropriate for current use but may be appropriate for other uses. It may be appropriate to relocate the activity to another location and use this space for more suitable activity.

During the evaluation process, a clear distinction is being made between the suitability of a space for a specific task or activity, and the current physical condition of the space, which assesses the needs for repairs, renovations and upgrades. It is entirely possible for a space to be rated as *highly suited* for its existing (or a future) use but to require major restorations. Likewise, a space in an excellent physical condition may be rated as *unsuitable* for its current use (or a specific future use). The manual calls only for the permanent architectural features of a space and the fixed equipment to be included in the suitability assessment, while aspects such as age, current space configuration, and movable elements (e.g., furniture, equipment) are not to be included.

Section 5.5.7 of the manual provides coding for room or space features that could be used during functional performance assessments [63]. For example, the following categories may be used to indicate the availability of utility services:

- (C) Communication. Special cabling for telecommunications, data distribution, video sources, or media projection.
- (E) Electrical Service. Special electrical services such as 200v, 440v, or filtered electrical supply.
- (G) Gas Service. Gas piping installed to provide compressed air, lab gases (flammable or inert), and vacuum services.
- (S) Special Plumbing Service. Special plumbing services such as acid drains, glassed pipes, distilled water, or ionized water provisions.
- (T) Temperature Control Service. Special temperature and humidity control services, typically for cold or hot rooms.
- (V) Ventilating Service. Special ventilating services such as fume hoods, clean rooms, or special air circulation systems for animal rooms.
- (W) Water Service. Access to water drainage for drinking, washing, or sanitary functions.

7.7 **Queensland Government**

The Building Asset Performance Framework (BAPF) is Queensland Government guideline to providing departments with a best practice "approach to manage the performance of building assets to meet service delivery requirements" [64]. The document describes performance indicators and performance measures for building assessment, and includes a building asset performance template which users can practically use to enter data during an evaluation.

The BAPF can be applied at floor, building, or portfolio level, taking into account social and environmental aspects in addition to functional and financial considerations. The framework specifies the following performance indicators: *appropriateness* (capacity, functionality, locations, condition, remaining life); *financial* (operating cost, maintenance cost, deferred cost), *statutory compliance*, *effective use* (utilization rate), *environmental impact*, and *social significance* (significance in meeting government priorities and community obligations), as shown in Appendix F. Departments are instructed to "use appropriate performance measures that are relevant to their service delivery needs to ensure that the performance data obtained is useful and meaningful for their specific requirements" [64].

Under the *functionality* section, the guide calls for aspects such as size, shape and configuration; services and facilities; suitability of building asset or space for intended purpose; and flexibility, to be assessed and rated using the generic scale shown in Table 7. Performance measures of functionality include percentage of spaces appropriate for purpose, housing overcrowding, and other department-specific measures.

Under the *capacity* section, the guide calls for aspects such as nature of services delivered; space or other standard-based on service delivery requirements; capacity to accommodate people and equipment; and demand projections for services based on demographics, to be assessed and rated. Performance measures of capacity include square meter per person, student workspaces/places, and other department-specific measures. The same generic rating scale used for functionality is also used for the capacity rating (Table 7).

Optional performance indicators include *compatibility of use* of a building asset compared with the design purpose of the asset ('effective use' performance) and *environmental rating*, reflecting achievement in meeting specific criteria of a particular environmental rating system suitable to the type of building asset and department and government priorities ('environmental impact' performance).

Table 7: Queensland Government rating of space functional suitability

(source: Queensland Government Building Asset Performance Framework, [ref.64])

Rating	Performance measure
5	Exceedsservicedeliveryneeds/expectations(e.g.thereispotentialforsharing with other departments).
4	Meetsallservicedeliveryneedsforcurrentandforeseeablefuture(3-5years).
3	Meetsallcurrentservicedeliveryneeds.
2	Belowservicedeliveryrequirements.Someimpactonservicedelivery.Action required.
1	Significantly below service delivery requirements. Significant action required.

The guideline also provides a framework for post occupancy evaluations (POE) after at least 12 months of building occupancy [64], assessing the following aspects of performance:

- *Functional Performance*: General planning and design of functional spaces in and around the building; space allocation and fit out; quality and standard of the design and construction of the site and the building, including physical characteristics, circulation and access, safety, operational aspects of the building (including cleaning and maintenance);
- *Technical and Environmental Performance*: Health, safety and security; building services requirements (heating and cooling; lighting and acoustics; plumbing and electrical); equipment; materials and information technology needs;
- *Economic Performance:* Performance of buildings as an investment in resources and whole-of-life issues, including those relating to recurrent costs associated with building occupancy and operations, leasing and lease management, maintenance;
- *Symbolic Performance:* Aesthetic/image characteristics of the building for the community; and integration of art and design.

7.8 **Higher Education Statistics Agency (HESA)**

The Higher Education Statistics Agency (HESA) collects statistical information about the UK higher education sector for estate management planning. Their mandate includes an annual collection of data from higher education providers (HEP) for an estates management record. Mandatory data that HEPs located in England and Northern Ireland are requested to generate includes information on *suitability of spaces* [65]. The following are examples of factors that HEPs are asked to consider when setting the functional suitability grade for their facilities:

- *Environment:* Internal room(s)/area(s) environment in terms of temperature, humidity, fresh air, clean air (if required), lighting levels, daylighting;
- *Layout/Plan:* Layout of room(s)/area(s) relative to equipment used, ancillary and related room functions, furniture, circulation and access;
- *Location:* Physical location of the room(s)/area(s) relative to the activities that need to use the space, and other spaces these activities need to use;
- *Flexibility:* Intrinsic ability of room(s)/area(s) to be altered, amended or changed in terms of size, environment and layout in response to changing demand - this will be a factor of structural and building services design;
- *Servicing Requirements:* Ability of the room(s)/area(s) fittings, furniture and equipment to meet the identified business demands of the users, such as electrical capacity, data points, etc.;
- *User Perception:* Decorative, aesthetic and cosmetic qualities of the room/area from the perspective of users;
- *General External Environment:* Quality of external surroundings and settings. This could include factors such as footpath and lighting quality, security perception, building and site appearance, and signage.

Participating HEPs are asked to calculate the proportion of total Gross Internal Area which lies in each of the following four categories:

- *Grade 1 Excellent:* the room(s)/building(s) fully support current functions. There are no negative impacts upon the functions taking place in the space.
- *Grade 2 Good:* the room(s)/building(s) provides a good environment for the current function in all or most respects. There may be shortfalls in certain areas, but these have only a minor effect upon current functions.
- *Grade 3 Fair:* the room(s)/building(s) provides a reasonable environment for current functions in many respects, but has a number of shortfalls. These shortfalls may be causing mismatches between space and function that is having a more significant effect upon current functions than Grade 2 rooms.
- *Grade 4 Poor:* the room(s)/building(s) fail to support current functions and/or are unsuitable for current use. The operational problems associated with such space are major, and are constraining current functions in the space. Space in this grade may require alternative solutions, rather than straightforward improvements in particular features of the space.

More details about the framework used by HEPs to produce an overall assessment of functional suitability ca be found in the Estate Management System (EMS) data definitions document of the University of Leeds [66].

8. Existing tools including indicators of building functional performance

8.1 **BUILDER Sustainment Management System**

The review of the literature revealed the existence of a novel computerized real property maintenance management software called the BUILDER Sustainment Management System (SMS). BUILDER was developed by the U.S. Army Corps of Engineers, Engineering Research and Development Centre, Construction Engineering Research Laboratory (ERDC-CERL) to help U.S. federal agencies improve the long-term evaluation and maintenance of their building infrastructure[49]. BUILDER can provide standardized data and valuable insights to help organizations with important real estate portfolio (e.g. Government agencies) determine priorities and investments for facilities.

8.1.1 BUILDER description

BUILDER SMS is a web-based software that provides a generalized methodology to assess and measure the functional performance of a building, which in essence is related to its suitability to perform its intended mission. The premise is that BUILDER can facilitate the budgeting and investments process, which allows a reduction over time of the overall costs to asses an organization's building portfolio.

The methodology incorporated in BUILDER to determine a building's functionality is patented[50], however, ERDC-CERL allows users to operate the product online or on closed network (agency's own server) using government-owned software, which supports enhanced security measures [17].

BUILDER follows the ASTM UNIFORMAT II for Building Elements classification[51] (organization of building assemblies by systems and components) but does allow some customization. Using UNIFORMAT II ensures consistency in the evaluation of buildings, permitting comparison between institutions at different hierarchical levels (i.e., Level 1 – Major Group Elements; Level 2-Group Elements; and Level 3 - Individual Elements).

BUILDER's open data architecture permits free communication with other electronic Army facility management systems and data repositories. Communication links between other external systems and BUILDER can be created using web services and Extended Markup Language (XML) exchange features [18].

The SMS uses Knowledge-Based Inspection (KBI), which optimizes sustainment, repair, and restoration, prioritizing resources that are most critical to an organization's mission. BUILDER uses a standard set of criteria for evaluating the condition of a building, including a Building Condition Index (BCI), which is an overall building condition score based on a roll-up of all section condition scores weighted by their replacement value, ranging from 0-100 (with 100 denoting an ideal state with defect-free components), as shown in Table 8 and Figure 12. The highest component level tier within a building, the BCI can be rolled into larger groups of buildings or entire portfolios.

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[49] U.S. Army Engineer Research and Development Center | Construction Engineering Research Laboratory, https://www.erdc.usace.army.mil/Media/Fact-Sheets/Fact-Sheet-Article-View/Article/476728/builder-sustainment-management-system/

[50] US Patent 7734488B2 (2005) - Functionality index (FI), https://patents.google.com/patent/US7734488

[51] ASTM E1557- 09(2015) Standard Classification for Building Elements and Related Sitework—UNIFORMAT II, https://www.astm.org/Standards/E1557.htm

Table 8: BUILDER SMS – Building Condition Index definitions

(source: Grussing, 2012, [ref. 67])

Condition Index	Descriptor
100-85 Good	Slight or no serviceability or reliability reduction
85-70 Satisfactory	Serviceability or reliability is degraded but adequate.
70-55 Fair	Serviceability or reliability is noticeably degraded
55-40 Poor	Significant serviceability or reliability loss.
40-25 Very Poor	Unsatisfactory serviceability or reliability reduction
25-10 Serious	Extreme serviceability or reliability reduction
10-0 Failed	Overall degradation is total.

The BCI is composed of several other metrics, as follows:

- Component-Section Condition Index (CSCI), which reflects the presence, type and level of deficiency that adversely affects the condition of a component section; The theoretical range to complete repair work ranges from a CSCI of 70 to 80 [17];
- Building Component Condition Index (BCCI) [52], which is an aggregate condition index of every section within the building's components;
- System Condition Index (SCI)[53], which measures the condition of a system as a whole. The higher the SCI the better.

BUILDER uses the CSCI indexes to calculate the remaining service life of the building components (the difference between the component's current age and its predicted life). Condition life-cycle trends are estimated for each component based on initial baseline condition assessments, and the expected degradation over time is modeled to identify the optimal point for maintenance work. Users can define a minimum CSCI level to trigger preventive, repair or replacement work based on the minimum desired condition level that supports the assets mission [17].

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[52] BUILDER Glossary. 2015. https://digonsystems.com/articles/14/BUILDER-Glossary.html
[53] same as above

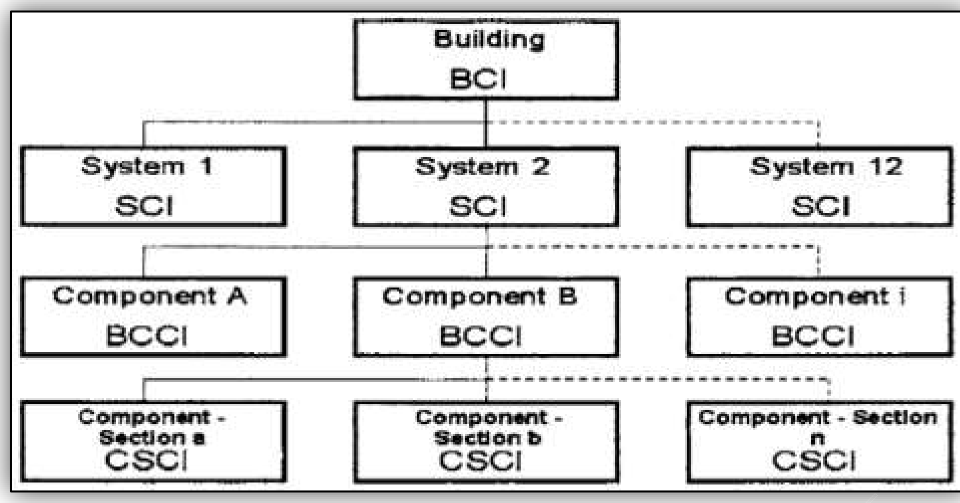

Figure 12: BUILDER SMS - Building Condition Index Metrics
(source: Herrera et al., 2017, [ref.17])

In addition to the building condition indexes (BCI, SCI, BCCI, CSCI), other assessment metrics supported by BUILDER include the following two indices, which allow the measurement of an asset's suitability to the building's function and mission:

- Functionality Index (FI), which measures how well a building can serve its prescribed function;
- Mission Dependency Index (MDI), which is a risk measure that indicates the importance or criticality of a building to an organization's mission.

Similarly to the building condition indexes, the FI of each component ranges from 0 to 100 and can be estimated over a building's life-cycle. This information can be used as a metric for modernization requirements, as shown in Figure 13.

The MDI also ranges from 0 to 100 and is divided into: Mission Critical Facilities, Mission-Dependent Facilities, and Mission Independent Facilities. MDI assesses a facility's relative importance to an organization's missions, prioritizing allocation of funding for facility repair and maintenance work across a facilities portfolio. The failure of a Mission Critical Facility has a significant impact on an organization and would need to be maintained at the highest standard of functionality, whereas the failure of a Mission Independent Facility can be mitigated by moving the facility's function to another facility [17].

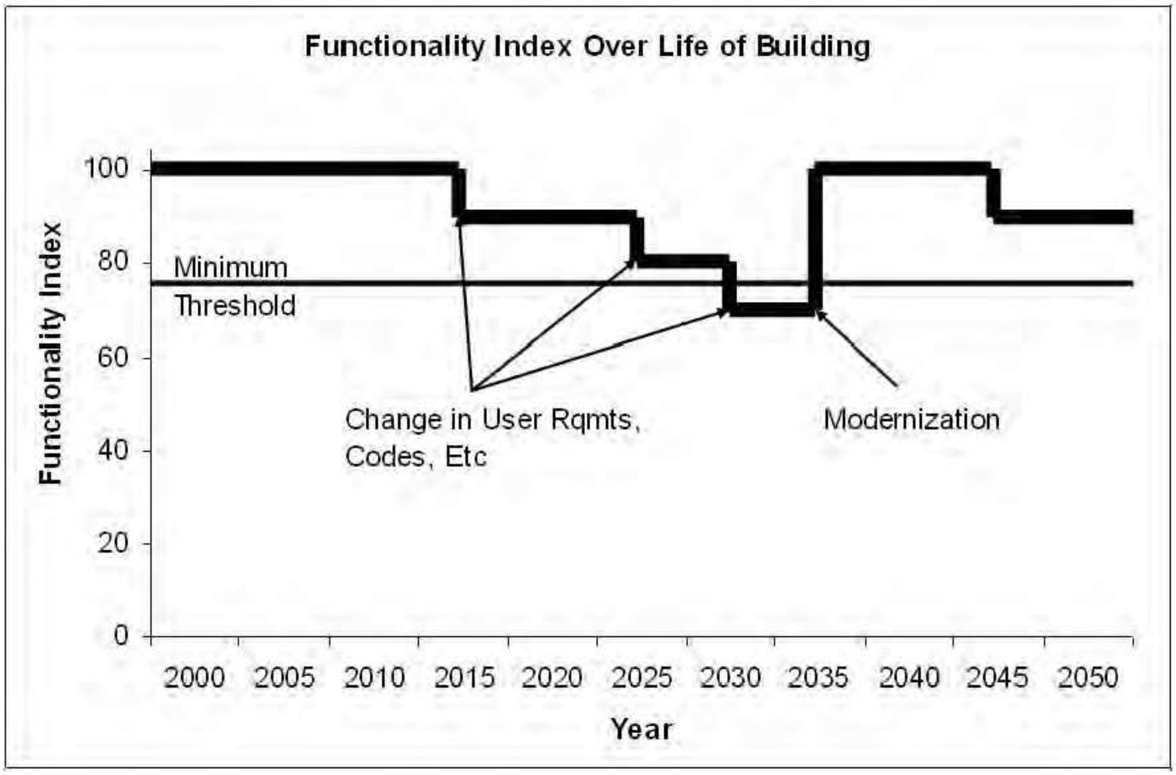

Figure 13: BUILDER SMS - Functionality Index over time

(source: Grussing et al., 2010, [ref.18])

8.1.2 BUILDER framework for functionality assessments

BUILDER's framework is based on research work conducted by the U.S. Army Corps of Engineers, Engineering Research and Development Centre, Construction Engineering Research Laboratory (ERDC-CERL) over 25+ years.

Reddy et al. [68] proposed a set of 17 building characteristics providing an objective assessment of a building's functional capability (Table 9). The 17 building characteristics were classified according to the functionality they provided to the building occupants. Taken together, these indicators offered a tool to: (1) determine the functional suitability of a building to satisfy a mission requirement, and (2) compare the functional capability of different facilities being considered for the same purpose.

Table 9: Building functional attributes

(*source: Reddy et al., 1994, [ref.68]*)

Higher level attributes of functionality	**Lower level attributes of functionality**	**Description**
Functional spaces	Dimensions of functional spaces (quantitative) Layout of functional space	These are spaces needed to *perform* the mission, e.g., office spaces, conference areas, storage areas, shipping and receiving areas, etc. Suitability is measured according to : quantitative criteria (space dimensions, availability), and qualitative criteria (layout, shape, adjacent spaces).
Supporting spaces	Dimensions of supporting spaces (quantitative) Layout of supporting spaces	These are spaces required to *support* (as opposed to perform) the mission. Include restrooms, janitor rooms, personnel lounges, and first-aid rooms. Supporting spaces may be dedicated to activities, personnel, equipment. Suitability is measured according to quantitative and qualitative criteria.
Ceiling height		May be critical to performing required functions or may prevent performance of functions.
Access to material and equipment	Width and height of doors Circulation (corridor width, etc.)	Measures accessibility of spaces, equipment and materials. Corridors and access doors are evaluated for accessibility. Attributes are door dimensions (width and height) and circulation (corridor width).
Handicap access		Evaluates compliance with requirements for access by disabled individuals (e.g., ASTM E2018—15 Standard Guide for Property Condition Assessments: Baseline Property Condition Assessment Process, provides a screening survey/checklist to verify compliance with the 2010 Americans with Disabilities Act (ADA).
Floors	Floor load ratings Floor finishes	Evaluates suitability of floors to perform the required mission. Suitability of floor loads and finishes are evaluated separately.
Health and safety	Fire safety Health hazards (asbestos, radon, indoor air pollution, etc.) Operational safety	Attributes are fire-safety features, health implications of building materials or type of construction, and operational safety. Assessment of the building's compliance with National Fire Protection Association (NFPA) life-safety codes and Army fire-safety requirements. Health hazards from asbestos, chemical fumes, smoke, radon, etc.,. Safety features related to the building's mission are evaluated under operational safety.

Higher level attributes of functionality	Lower level attributes of functionality	Description
Grounds	Parking Accessibility to vehicles Landscaping	Site-related attributes that can affect the use of a building. This attribute does not evaluate the overall location factors, but addresses specific site-related factors. Other attributes are parking availability, access driveways and curbs, and the condition of landscaping at the site.
Sound and visual environment	Acoustics Lighting and glare	Distractions or disruptions due to noise or poor visual environment (too much glare, unattractive paint, etc.).
Electrical service and fixtures	Building power supply Power distribution Adequacy of fixtures	The suitability of the electrical system to support a building's intended mission. Includes power supply, power distribution, adequacy of fixtures. Is the power supply sufficient to perform the functions efficiently? Is the building suitable to perform the required functions using the existing power distribution and fixtures?
Water and plumbing	Water supply Plumbing system	Suitability of the water supply and plumbing system to perform the required functions.
HVAC (heating, ventilating, and air conditioning) system suitability	Temperature and humidity control Ventilation	Suitability of temperature, HVAC controls, humidity to performing a building's required functions. The mechanical condition of the HVAC system itself is not covered under this attribute, but rather the suitability of the indoor environment produced by the system.
Built-in equipment		If built-in equipment is required for a building's mission, it is evaluated under this attribute.
Security		Building security features are evaluated under this attribute.
Communications		Building communication features are evaluated under this attribute
Environmental impact		Environmental impact resulting from the building's functional use is covered under this attribute.
Aesthetics and image	Exterior appearance Appearance of public spaces Appearance of interior spaces.	Building appearance. Some missions require an appealing view from inside, public spaces that project a good image, and attractive work areas and interior spaces.

To characterize the overall adequacy of a building to satisfy mission requirements, Reddy et al. [68] distinguished between a building's: (1) *physical condition* (structure and engineering systems); (2) *location* (land compatibility, zoning, environmental concerns), and (3) *functional condition* (e.g., usability for a specific mission, suitability of the layout, availability of engineering systems to support mission required activities, etc.).

During the building inspection process, each building attribute is considered to have a standard minimum level of functionality (threshold value) provided by Army regulations, standard designs, design guides, industry standards, or specific user requirements, which defines the minimum requirement for an acceptable rating. Building attributes are evaluated and compared with their threshold values, and assigned a numerical score based on an applicable rating scale. Each rating scale is graded into condition scores ranging from excellent to failed. "Excellent" means that the attribute's condition exceeds the target requirement for that attribute. "Failed" means the condition does not meet the threshold value. The rating for any given attribute may fall at either extreme, or anywhere in between. A rating of failed means renovation is required before the attribute meets the mission requirement. Each attribute's score is then multiplied by a weighting factor that takes into account the relative importance of the attribute to the mission. After the condition indexes for all building attributes are computed, an overall functional condition index (FCI) is calculated for the building.

Expanding on previous research efforts, Grussing et al. [18, 69] developed the analytical approach of the building Functionality Index (FI) integrated in BUILDER SMS, as a direct indicator of a building's suitability for the mission.

The premise behind the FI methodology is that during a building's life-cycle, *functional deficiencies* occur due to:

- *Occupant/user requirements* (e.g., a building's capability to provide service to its users is affected when the user requirements change, or when the mission requirements change).
- *Regulatory/code compliance* (e.g., buildings must continuously adapt to changes/updates of building codes, regulations, or organizational policies).
- *Technical obsolescence:* (e.g., existing building components may offer an inferior level of performance compared to newer technologies penetrating the market).

The principle behind the FI is that loss of functionality can be qualitatively and quantitatively described by identifying the functional deficiencies that make a building perform less than optimally for a specific mission, when compared to a newly constructed building that incorporates all of the mission requirements. The assumption is that each building functional component has: (1) a definition and an explicit visual or technical criteria that can be used by an evaluator during a building inspection to assess the component's actual condition, and (2) a level of severity with which the component affects the building's performance.

The following three aspects are reflected in the building functionality metric:

- Functional deficiencies present in the building;
- Severity factor, which indicates how critically the identified functional deficiency affects the mission (where applicable, severity levels are defined based on codes and regulations requirements);
- Extent the building is affected by the specific functional deficiency (percentage of building area affected by the functional deficiency or density of functional deficiency).

Three levels of severity were defined for functionality attributes and color-coded as follows:

- Green: functionality attribute fully complies with the requirements; does not affect suitability to perform the mission.
- Amber: functionality attribute affects suitability to perform mission but not to a significant degree.

- Red: functionality attribute greatly affects suitability and capability to support the performance of mission. Functional deficiency puts life safety and/or mission accomplishment in jeopardy.

A numerical scale was developed to correlate the FI with qualitative descriptions of functionality, as shown in Figure 14. The FI methodology links this scale with 65 building functionality attributes, grouped under 14 categories, as shown in Figure 15. Appendix G shows the 65 building functionality attributes incorporated in the BUILDER software. Figure 16 shows an example of how BUILDER can be used to forecast the effects of different funding scenarios on the condition of building portfolios.

FI	Rating Definition	Modernization Needs
100	No functionality problems exist in building. All occupant/user requirements are met, no component-sections are obsolete, and the building is in full compliance with all codes and regulations.	None
86–99	One or more, up to a very few, non-critical or critical component-sections suffer from varying degrees of functionality loss; and/or Up to a small number of component-section inventory items suffer from varying degrees of functionality loss; and/or One or	Up to total modernization desired or required for up to a few component-sections or few inventory items (i.e. items that collectively make up a component-section) for given component-sections; or Minor modernization desired or required to certain building
71–85	More than a very few, but not many, non-critical or critical component-sections suffer from varying degrees of functionality loss; or combinations of a few non-critical and critical component-sections suffer from varying degrees of functionality loss, and	
56–70	Many, non-critical and critical component-sections suffer from varying degrees of functionality loss; and/or Large numbers of component-section inventory items are experiencing varying degrees of functionality loss, and/or One or more critical building fu	Up to total modernization required to significant numbers of component-sections or the inventory items for given component-sections; or Significant modernization required to one or more building functional areas; or major modernization required to small b
41–55	One or more critical building functional areas are experiencing significant functional loss and other building functional areas may be experiencing functional loss to a significant or lesser degree; and/or Building, as a whole, is functionally impaired to	
26–40	One or more critical building functional areas are experiencing extensive functional loss and other building functional areas may be experiencing functional loss to an extensive or lesser degree; and/or Building, as a whole, is functionally impaired to an	
11–25	The majority of building functional areas is experiencing a functional loss to some degree with one or more being severe (total or nearly so); or Building, as a whole, is barely able to serve its intended or proposed use.	Major modernization required to large portions of or the entire building; or Building relocation required.
0-10	Building is totally unable to serve its intended or proposed use.	

Figure 14: BUILDER SMS - Building Functionality Index rating scale

(source: Grussing et al., 2010, [ref.67])

Category	Description
Location	Suitability of building location to mission performance
Building Size/Configuration	Suitability of building/area size and layout for the mission required
Structural Adequacy	Capability of structure to support seismic, wind, snow, and mission-related loads
Access	Capability of building/area to support entry, navigation, and egress as required
Accessibility	Level of compliance with the Architectural Barriers Act
AT/FP	Compliance with Antiterrorism/force protection requirements
Building Services	Suitability of power, plumbing, telecom, security, and fuel distribution
Comfort	Suitability of temperature, humidity, noise, and lighting for facility occupants
Efficiency/Obsolescence	Addresses energy efficiency, water conservation, and HVAC zoning issues
Environmental/Life-Safety	Addresses issues such as asbestos abatement, lead paint, air quality, and fire protection
Missing/Improper Components	Availability and suitability of components necessary to support the mission
Aesthetics	Suitability of interior and exterior building appearance
Maintainability	Ease of maintenance for operational equipment
Cultural Resources	Historic significance and integrity issues impacting utilization and modernization

Figure 15: BUILDER SMS - Building Functionality categories

(source: Grussing et al., 2010, [ref.67])

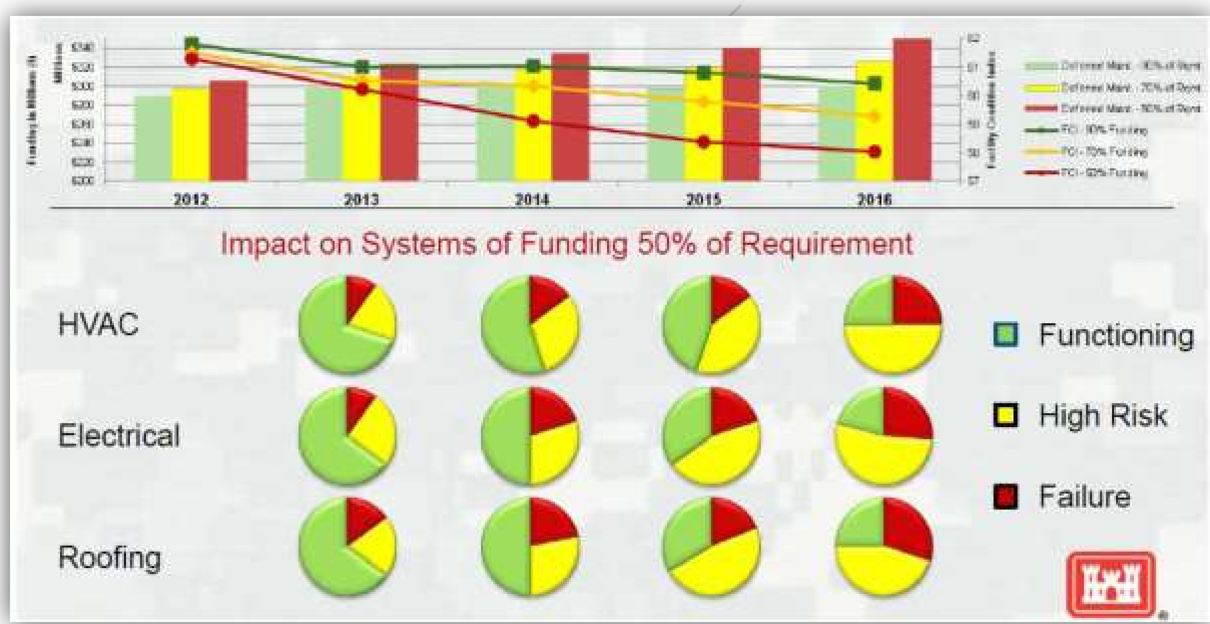

Figure 16: BUILDER SMS - Impact analysis on facility condition for varied funding scenarios

(source: Herrera et al., 2017, [ref.17])

The FI framework incorporated in BUILDER follows the procedure used to calculate the building physical condition index (CI) mandated by the ASTM standards. Coupling the building functionality index (FI) with the building physical condition index (CI), provides a means for justifying building rehabilitation, which includes restoration and modernization, versus demolition and new construction. This supports short- and long-term investment strategies, prioritizing criteria and budget constraints.

In BUILDER, the functionality-related criteria can also be linked with Army-specific criteria based on current Army standards and Army standard designs. In addition, the facility functionality-related criteria from the U.S. Army Installation Status Report for Infrastructure (ISR-I) can also be used as input into the BUILDER functionality assessment framework to calculate the FI value. The ISR-I is the U.S. Army process that installation personnel use to report the condition of facility assets, identifying facility requirements affecting readiness and mission. Grussing et al. [67] describe the process of integrating the BUILDER's condition life-cycle and prediction analysis capabilities with the facility condition assessment information collected from the ISR-I program.

8.1.3 BUILDER adoption

Adoption of a maintenance management software system needs strong buy-in from leadership as well as support from the facilities and infrastructure administrators.

Implementation can be done either by using:

- third-party contractors to conduct BUILDER inventories and assessments;
- trained employees to conduct BUILDER inventories and assessments.

BUILDER offers two approaches to inspecting facilities to determine their condition

- Direct Rating: fast and cost-effective but lacks accuracy;
- Distress Surveys: more up-front time in costs but has the potential to provide additional cost savings in the long term by more accurately predicting future maintenance needs.

Outside of the U.S. federal government, CERL partners with third-party contractors for distributing BUILDER via a Cooperative Research and Development Agreements (CRASAs) and Patent License Agreements (PLAs). The following contractors have PLAs for distributing BUILDER: Atkins Global, Cardno, DIGON Systems, FM Projects, North Pacific Support Services and Tetra Tech. The costs associated with the patent license, including royalties, are negotiated individually with each contractor.

Federal agencies across the U.S. currently implementing BUILDER (including the National Nuclear Security Administration U.S. Department of Agriculture, Agricultural Research Service Department of Defense, Air Force Department of Defense, Navy Department of Defense, Marine Corps Department of Defense, Defense Health Agency Department of Defense, Army Office of the Director of National Intelligence, Department of Commerce, National Institute of Standards and Technology Department of Commerce, National Oceanic and Atmospheric Administration Department of Veterans Affairs) have observed implementation challenges with BUILDER integration [17], as follows:

- Organization buy-in: high up-front costs and existing systems;
- Customization: adding delays and increasing costs;
- Uncertain savings: to-date no cost benefit analysis has been conducted;
- Limited resources: increasing use of contractors;

- Security: server and data migration issues.

For additional information on BUILDER's capabilities and performance, see publication by Herrera et al. [17] who conducted interviews with the 25 U.S. federal agencies and laboratory stakeholders (including facility managers, policymakers, and contractors) who have adopted BUILDER as a tool to evaluate and maintain their building infrastructure.

8.2 **Building user surveys**

Post-occupancy building evaluations (POE) are based on the idea that better spaces can be designed by asking the building users about their needs. POE's can be used to assess the requirements, activities and goals of the users and organizations occupying a facility, gathering information about the building maintenance and operations, occupant performance, satisfaction and productivity, indoor environment (e.g., lighting, air quality, acoustics, adequacy of space), etc. Their findings are relevant when making decisions related to building design, operation and management, because of their potential to identify general building problems, including those related to functional deficiencies and suitability for the activities taking place in the building (e.g., information about a specific building use that may have not been available at the design stage; changes made after occupancy that the building may have not been designed for; users' failure to understand how to operate certain building systems, etc.). Book by Presier & Visher [10] can be consulted for examples of detailed user surveys including aspects of building functionality.

The Center for the Built Environment (CBE), Berkeley, California, USA, provides a web-based survey called the *Occupant Indoor Environmental Quality (IEQ) Survey*[54], which is designed to obtain feedback from building occupants on features related to building indoor environment, services and design. The survey questionnaires are tailored to office and residential buildings (e.g., dorms or multi-unit, single-building projects), healthcare and laboratory facilities, and schools. Currently, the survey includes questions related to acoustic quality, air quality, cleanliness and maintenance, lighting, office furnishings, office layout, thermal comfort, accessibility, building and grounds, commute, conference and training rooms, court work, daylighting, laboratories, maintenance service, office support equipment, operable windows, raised floor and floor diffusers, restrooms, safety and security, wayfinding. For example, the survey measures satisfaction with the thermal environment through questions such as, "How satisfied are you with the temperature in your workspace?" The thermal comfort section also includes branching questions about sources of dissatisfaction

The reports generated by the IEQ Survey tool can be used to evaluate the occupants perceptions of the building, the effectiveness of the building service providers, and the effectiveness of building improvements, providing a means to prioritize the actions needed to improve occupant satisfaction and workplace productivity.

The IEQ Survey can also be used to obtain LEED credits for existing buildings operations and maintenance projects (e.g. for projects using LEED v2009: LEED for Existing Buildings: Operations and Maintenance projects can use the survey to get IEQ Credit 2.1 - Occupant Comfort - Occupant Survey; For projects using LEED v4: All LEED for Building Operations and Maintenance projects can use the survey to get IEQ Credit 10 - Occupant Comfort Survey).

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[54] http://www.cbe.berkeley.edu/research/survey.htm

9. Additional considerations

As stated in the Whole Building Design Guide (WBDG)[55] of the U.S. National Institute for Building Sciences: "Development in the building sciences … has pointed to the need to refocus on programming, designing, constructing, and operating facilities that function well, while *at the same time* incorporating new technologies, and creatively meeting other design objectives*: sustainability, accessibility, safety, aesthetics, cost effectiveness, productivity, and historic preservation*." The WBDG also points out that: "*When the design of a facility satisfies the emotional, cognitive, and cultural needs of the people who use it and the technical requisites of the programs it houses, the project is functionally successful.*" Hence, a building's functionality and suitability, "*must be considered together with other design objectives and within a total project context in order to achieve quality, high-performance buildings*". The ability to evaluate the performance of all of the seven aforementioned interrelated building characteristics supports both a building's functional goals and an organization's productivity. A detailed review these characteristics, each presented in the context of the other, is available at the WBDG website [70].

With this same perspective in mind, a large number of organizations worldwide have adopted various rating systems aiming to certify buildings contributing to users health and well-being, and environmental sustainability. Only a few of these systems are mentioned below for exemplification and a brief review of additional metrics and indicators that could be considered during a building's suitability evaluation, due to their documented potential to affect an organization's efficiency and productivity (e.g., for projects aiming to get accreditation as 'high-performance' or 'net-zero'; reduce environmental foot-print, express a specific image to the public, retain and attract staff, etc.).

9.1 **WELL building standard**

The *WELL* building standard focuses on the health and well-being of building occupants and uses 102 performance metrics related to building design and operation, linked to measures that improve human health and wellness. The standard provides a certification-based process, which verifies requirements for the following indoor environment quality criteria: air, water, nourishment, light, fitness, comfort, mind [71].

For example, the *water* certification criteria requires appropriate water quality for various uses and proper filtration of water contaminants; the *fitness* criteria requires integration of daily exercise and fitness by providing buildings with various physical features that support an active and healthy lifestyle (e.g., bicycle storage, showers, physical activity spaces and equipment, active furnishings such as adjustable standing desks, etc.) ; The *nourishment* criteria requires the availability of fresh and nutritious foods, limiting unhealthy ingredients and encouraging better eating habits; The *mind* criteria requires design strategies that provide cognitive and emotional health (e.g., adaptable spaces, privacy, nature/biophilia, administration of frequent occupant survey; etc.); The *comfort* criteria establishes requirements to create a distraction-free, productive and comfortable indoor environment, and includes acoustic and thermal comfort indicators among other metrics.

The light criteria takes into consideration the fact that light influences the human body in both a visual and a non-visual way. Humans have an internal clock (circadian rhythm), which synchronizes physiological functions and hormones on a 24-hour cycle, as a function of the

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[55] https://www.wbdg.org/design-objectives

level of light that enters the body through the eye. The body requires both periods of brightness and darkness at appropriate times throughout the day to maintain an optimal circadian rhythm. The WELL standard provides illumination guidelines that take into consideration both of these aspects: visual acuity and the body's circadian system.

Air quality in indoor environments is often linked to airborne germs and emissions from the materials used within a building, which contribute to respiratory illnesses such as asthma and allergies. People's reactions to indoor air contaminants vary widely and depend on multiple factors including contaminant concentration and length of exposure. The WELL standard also combines requirements for installation of appropriate materials with protocols for disinfection of targeted areas. Pollution-source removal, proper ventilation and air filtration are typically used to achieve high indoor air quality. The WELL standard for Air uses requirements developed by the following organizations:

- U.S. Environmental Protection Agency[56] (EPA) National Ambient Air Quality Standards (NAAQS), which create exposure limits based on duration and concentration for carbon monoxide, lead, nitrogen dioxide, ozone, particulate matter and sulfur dioxide.
- World Health Organization[57] (WHO), which limits pollutant concentrations.
- American Society of Heating, Refrigerating and Air-Conditioning Engineers[58] (ASHRAE) standards, which include techniques for enhancing air quality in buildings.
- U.S. Green Building Council's LEED program[59], which sets criteria for air filtration and material selection to improve air quality.

For exemplification, Appendix H shows the WELL standard indicators for assessing *lighting* and *air quality* in indoor spaces. The remaining indoor environment quality indicators are not shown in this report, but can be accessed online[60].

The WELL indicators which overlap with LEED.v4 and the Living Building Challenge standard (LBC.v3) certification criteria are also listed online. A comprehensive list of leading organizations that publish standards and best practice guidelines related to healthy buildings and environmental performance can also be retrieved from this source.

9.2 **Living Building Challenge standard**

The Living Building Challenge (LBC)[61] certification program, launched in 2006 by the International Living Future Institute, is considered to the most stringent green building standard in the world[62]. This standard endorses a net-zero or a net-positive impact on "everything the built environment touches". Its requirements for certification, categorized under seven performance areas (sustainability, energy efficiency, water efficiency, materials and resource use, indoor environmental quality, equity and aesthetics) are "a must", unlike those of other rating systems such as Green Globes and LEED, where organizations can choose among

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[56] https://www.epa.gov/
[57] https://www.who.int/
[58] https://www.ashrae.org/
[59] http://leed.usgbc.org/leed.html
[60] Additional WELL Building Standard certification criteria are available here: https://www.wellcertified.com/sites/default/files/resources/WELL%20Building%20Standard%20-%20Oct%202014.pdf;.
[61] https://living-future.org/wp-content/uploads/2016/11/Living-Building-Challenge-Documentation-Requirements.pdf
[62] https://www.buildinggreen.com/living-building-challenge

credits. To earn full LBC certification, building projects must meet all of 20 assigned criteria. For example, the “Healthy Indoor Environment Plan” requires a document that outlines and demonstrates how all the following imperative requirements have been met:

- Cleaning Product List: A list of the project’s cleaning products that comply with the United States Environmental Protection Agency (EPA) Design for the Environment standard[63] or international equivalent.
- HVAC Documentation: A statement confirming compliance with ASHRAE 62[64] or international equivalent and the dedicated exhaust systems requirement, as well as any copies of relevant HVAC drawings.
- A list of all interior building products that have the potential to emit Volatile Organic Compounds (VOCs) and supporting documentation demonstrating each product’s compliance with CDPH v1.1-2010[65] or equivalent standard.
- Indoor Air Quality (IAQ) Testing Results: Results and any steps taken to remedy deficiencies identified by the testing authority.
- Systems Report: Verification of performance for permanently installed equipment used to monitor levels of carbon dioxide, temperature and humidity, including photographs of any hidden systems.

The LBC certification is based on actual performance and projects must be operational for at least 12 months prior to evaluation. The program includes a site visit by an independent auditor confirming compliance with the standard requirements.

9.3 **Sustainable Building Tool (SBTool)**

The Sustainable Building (SB)Tool was developed by the International Initiative for a Sustainable Built Environment (iiSBE)[66], based on collaborative work between 20 countries [72]. The tool uses a comprehensive framework covering issues related to building sustainability assessments during four phases of a building’s life-cycle (pre-design, design, construction, operation). Specific building sustainability criteria are linked to impact categories such as resource depletion, impacts on human health, ecological and climate systems, etc. Separate modules are provided for site and building assessments.

The scope of the assessment can be adjusted from a minimum number of mandatory criteria that cover key issues of building performance, to a medium number of criteria that cover the most important performance issues, or to a maximum scope that includes all the criteria shown in Appendix I [73]. The aspects related to *Indoor Air Quality* are grouped under category D, and the aspects related to *Service Quality* are grouped under category E. The latter includes *building functionality and efficiency* criteria (E2).

9.4 **Other sustainable building rating systems**

Mann [74] provides a visual description of the concept and current practice of building sustainability, while Morelli [75] defines environmental sustainability as “meeting the resource and services needs of current and future generations without compromising the health of the

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[63] https://www.epa.gov/saferchoice/design-environment-programs-initiatives-and-projects
[64] https://www.ashrae.org/technical-resources/bookstore/standards-62-1-62-2
[65] https://www.usgbc.org/resources/california-department-public-health-standard-method-v11%E2%80%932010-ca-section-01350
[66] http://www.iisbe.org/search/node/SBTool

ecosystems that provide them, … and more specifically, as a condition of balance, resilience, and interconnectedness that allows human society to satisfy its needs while neither exceeding the capacity of its supporting ecosystems to continue to regenerate the services necessary to meet those needs nor by our actions diminishing biological diversity”.

Fowler and Rauch [76] completed a review of five Sustainable Building Rating Systems, providing a comparative analysis of the following rating systems:

- BREEAM, including criteria related to adequate ventilation, humidification, lighting, and thermal comfort under the *Health & Well-being* category.
- CASBEE, including aspect of: *Indoor environment* (noise and acoustics, thermal comfort, lighting illumination, air quality); *Quality of services* (functionality and usability, amenities, durability and reliability, flexibility and adaptability); and *Outdoor environment on site* (preservation and creation of biotope, townscape and landscape, outdoor amenities), under the *Building Environmental Quality and Performance* section.
- GBTool (product of the Green Building Challenge international collaboration), including indoor air quality, ventilation, temperature and relative humidity, daylight and illumination, and noise and acoustics under the *indoor environmental quality category*.
- Green Globes U.S. (Green Building Assessment Protocol for Commercial Buildings)[67], including effective ventilation systems, source control of indoor pollutants, lighting design and integration of lighting systems, thermal comfort, acoustic comfort, under the *indoor environment* category.
- LEED, including environmental tobacco smoke control, outdoor air delivery monitoring, increased ventilation, construction indoor air quality, use of low emitting materials, source control, and controllability of thermal and lighting systems, under the *indoor environmental quality* category.

The United States Environmental Protection Agency site can also be consulted for a review of the subject areas and certification/compliance process of Green Building Standards[68], including mandatory legislation and voluntary rating/certification systems such as the International Green Construction Code (IgCC)[69]; National Association of Home Builders' ICC 700 National Green Building Standard (NGBS)[70]; Green Building Initiative's ANSI/GBI 01-2010[71]; Green Globes; LEED, and the LBC standard.

Green Globes Canada includes modules for the assessment of offices, school, hospitals, hotels, academic and industrial facilities, warehouses, laboratories, sports facilities and multi-residential buildings. Similar to LEED and many other systems around the world, the origin of Green Globes was BREEAM. In 1996, the Canadian Standards Association (CSA) published BREEAM Canada, which formed the basis for the development in the year 2000 of the Green Globes for Existing Buildings rating system[72] used by the Building Owners and Managers Association (BOMA) Canada’s national environmental program. Green Globes Canada includes certification

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[67] https://www.thegbi.org/green-globes-certification/
[68] https://www.epa.gov/smartgrowth/comparison-green-building-standards
[69] http://shop.iccsafe.org/2018-international-green-construction-coder-igccr-1.html; https://www.ashrae.org/technical-resources/bookstore/standard-189-1
[70] https://www.nahb.org/en/nahb-priorities/green-building-remodeling-and-development/icc-700-national-green-building-standard.aspx
[71] https://www.thegbi.org/content/misc/GBI_ANSI_01-2010_Standard_04_01_2010.pdf
[72] https://www.greenglobes.com/about.asp

criteria for ventilation, source control and measurement of indoor pollutants, lighting design and systems, thermal comfort, and acoustic comfort.

Bernardi et al. [77] can also be consulted for a comprehensive review of the six most adopted rating systems for assessing the environmental impact of buildings, including BREEAM, LEED, CASBEE, SBTool, the German certification scheme, Deutsche Gesellschaft für Nachhaltiges Bauen (DGNB)[73]; and the French system Haute Qualité Environnementale (HQETM)[74], used also largely in the Canadian province of Quebec[75].

10. Discussion

A literature search was conducted to identify current standards, guidelines and software tools incorporating frameworks and indicators that could be used to assess facilities in terms of their functional suitability for current or future use.

The literature review found that organizations use different criteria, metrics and indicators to conduct functional performance assessments of their facilities, depending on their goals, objectives, functions and activities. A wide range of complexity and selection of metrics was seen between the various tools reviewed. For example, some guidelines call for only the permanent architectural features of a space and the fixed elements to be included in a facility *suitability assessment*; Other organizations determine *functional suitability* by including also aspects related to user comfort (e.g. indoor temperature, humidity, air quality, lighting and daylighting levels, etc.), as well as user perspectives on space aesthetics; Other guidelines aim for the *functional suitability* of building designs to "respond effectively and efficiently to the operational requirements of the project; respond effectively to site-specific context and conditions considering urban design and landscape architecture; meet local urban design and planning guidelines; and be flexible and adaptable" [60]; Yet, other guidelines, describe *suitability* to be an indicator of functionality related to a building's "location and configuration of property, adequacy of municipal services, proximity of real property to supporting infrastructure, other operational facilities, and clients/customers, internal configuration of the asset to support uses and permit the flow of people and goods, and development potential [58]. The list of criteria and metrics grows even larger if one also wants to include other aspects of building performance, such as environmental protection, building sustainability, and occupant satisfaction and well-being (e.g., WELL standard). Identifying the key metrics for DND is fundamental to a successful assessment of building functional suitability.

Building suitability evaluations aim to verify how the building and its spaces, facilities and services relate to the building users' needs, requirements, and well-being. At the building level, comparing the actual performance with documented criteria of expected performance provides information about the level at which a building-in-use allows its current or future occupants to conduct their activities efficiently, productively, and comfortably. The process starts with identifying the user requirements, then stating the requirements in building performance terms, then choosing the qualitative and quantitative criteria/metrics that link the two aspects together. These metrics will subsequently be used to verify the fit between the user demands and the building supply to determine the level of functional suitability.

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[73] https://www.dgnb-system.de/en/index.php
[74] https://www.behqe.com/
[75] http://www.voirvert.ca/communaute/wiki/hqe-haute-qualite-environnementale

Occupant requirements may relate to technical aspects, as well as physiological, psychological, and sociological needs. Typical examples often cited in the literature include: spatial characteristics, indoor environment (temperature, humidity, acoustics, lighting, and air quality), energy efficiency, serviceability, accessibility, health and hygiene, comfort, structural safety, fire safety, security, ease of operation and maintenance, durability and sustainability. However, it is important to keep in mind that: (1) user requirements define conditions to be provided by the building for a specific purpose, regardless of its venue, and (2) occupant requirements may include needs that go beyond the building, for instance they might include a need for proximity to daycare or vehicle parking.

The building and facility needs of a defence organization are specific to the nature of the activities accommodated. Some guides offer specific guidance for some types of buildings (e.g. office spaces, accommodation). Activities housed in other types of building types may require adaptation of existing tools to make the criteria specific to occupant and mission demands (e.g. aircraft hangars). The appendices of this report provide building functions assembled from the literature, that offer an overview of the many possible functions that may be selected for a building suitability evaluation. Theoretically, any of these aspects could be included, and these lists should not be seen as exhaustive. However, the number of aspects studied should depend on the intended building use, as well as on a ranking and prioritization of the requirements. A distinction should also be made between requirements that are mandatory, optional, and ‘nice to have’. The International Council for Research and Innovation in Building suggests that a general list of building performance requirements (such as the ones presented in this report) would help to identify those aspects that are the most relevant to the problem under consideration [80]. As few as three aspects that are fundamental to an organization could be selected at first. However, when the time and the budget permit, a comprehensive performance analysis could include 25 or more aspects that could be examined in detail. Case studies were found in the literature where a small number of topics of functionality/serviceability were used by some organizations to assess their entire portfolio, while other organizations used 50 topics for typical projects.

Furthermore, when a group of buildings are evaluated, such as in portfolio management, the number of performance aspects may depend on the need to find a common framework of requirements, so that various buildings can be compared and cross-analyzed.

The building functions selected will also depend on the stage of the building life-cycle (i.e., design, operation, disposal), as some aspects can only be assessed for suitability only after they have been designed or constructed (e.g., physical size, usability, functional appropriateness, etc.), while a different profile of requirements may need to be considered after refurbishment or changes in functional use (operational phase) compared to the requirement profile of future occupants or buyers (disposal phase)[76].

The translation of user needs into performance requirements generally starts at the level of the entire building, followed by requirements for spaces, parts of spaces, systems and materials. User needs are typically formulated in non-technical terms, which will then need to be translated into technical criteria and metrics that can be measured and evaluated quantitatively or qualitatively.

The verification step consists of an onsite assessment performed by a competent assessor who examines the actual state of the building relative to the desired state and reports the findings in

[76] See ISO15686-10, 2010 [51], for more information.

detail. Commonly, a multiple choice questionnaire or “tick-sheet” process is used, in which both the building users and the evaluators can provide their feedback about each building-related aspect under investigation. The comparison between the building’s desired state and the building’s actual state reflects the gap between the users’ demand and the building’s supply. This gap is a direct indicator of a building’s suitability for its program or mission, (1) assessing how well a proposed design, or an existing facility (either occupied, or to be leased/bought) meets the specific needs of the organizational unit occupying the building; and (2) highlighting the issues that require attention and the facilities that are at risk and require urgent action.

Information about a building’s functionality can be combined with other building data (e.g., importance to mission, physical condition, compliance with codes and regulations, environmental protection, space utilization) to give a holistic overview of real property assets in relation to their requirements.

Existing frameworks that provide an overview of the many possible user requirements and related building performance aspects are the ASTM Standard on Whole Building Functionality and Serviceability (ASTM WBFS); voluntary building certification rating schemes such as BREEAM, LEED, CASBEE, Green Globes and LBC, which include building functions with a focus on sustainability and environmental concerns; and the WELL standard, which focuses on the health and well-being of the building users. The inclusion of organizational productivity metrics as a component of building functional suitability can be, and has been, used to justify investment in building technologies.

11. Recommendations

The literature review identified two comprehensive frameworks that can be readily applied to assess the functional suitability of building assets: the ASTM Standards for Whole Building Functionality and Serviceability (ASTM WBFS) and the BUILDER Sustainment Management System (BUILDER SMS).

The ASTM WBFS standards use an internationally recognized methodology that can be used by real property managers to set priorities for budget allocation throughout all phases of a building’s life-cycle. The 19 individual standards included in this publication cover over 100 topics of building serviceability and 340 building features, each with levels of service calibrated from 0 (not present, does not have, not applicable) to 9 (indicator of the highest level of functional capability). For each topic of serviceability, the evaluation criteria reflects the minimum requirements, and other measures and aspects may need to be considered. Likewise, the levels of functionality requirements are also calibrated on a scale from 0 (not required, not applicable) to 9 (functionality most needed). Subsequent to onsite evaluations comparing the two scales, a computerized database and a bar chart profile can be used to visually describe how well a building’s services meet each functional requirement.

The focus of the ASTM WBFS standards is on office buildings but the scales provided can be easily adapted for other types of facilities. Furthermore, new scales for other topics of functionality/serviceability can be developed following the steps provided in both the ASTM WBFS and ISO 11863 (2011) standards. Additionally, ISO 15686-10 (2010) can be consulted for events and timelines on when to specify and verify a building’s functional performance requirements during its service life-cycle.

Appendices A and B of this report present the functionality criteria incorporated in the ASTM WBFS standards. The 19 standards listed in Appendix A can be accessed online either individually via paid subscription (at the date of this writing at a cost of about 50 $USD/standard[77]), or purchased together as part Volume 04.11[78] of the 2019 Annual Book of ASTM Standards (at the date of this writing at a cost of about 500 $USD/printed volume)[79]. Note that the ASTM E2320-04 (2018) Standard Classification for Serviceability of an Office Facility for Thermal Environment and Indoor Air Conditions is the only WBFS standard not included in Volume 04.11. It can be purchased individually[80] or part of Volume 04.12[81] of the 2019 Annual Book of ASTM Standards.

The BUILDER Sustainment Management System is a software application which provides a generalized methodology for assessing and measuring a building's functional performance. The methodology was developed by the U.S. Army Corps of Engineers Engineering Research and Development Centre, Construction Engineering Research Laboratory (ERDC-CERL) to assist federal agencies to improve the long-term evaluation and maintenance of their building infrastructure. The software can be operated online or on closed networks (own servers) using government-owned software, which supports enhanced security measures. BUILDER follows the ASTM UNIFORMAT II for Building Elements classification and its open data architecture permits free communication with other electronic Army facility management systems and data repositories. Communication links between those systems and BUILDER can be created using web services and Extended Markup Language (XML) exchange features.

BUILDER SMS uses a Knowledge-Based Inspection (KBI) methodology, which prioritizes the resources that are most critical to a mission. A standard set of criteria for evaluating the condition of a building is used to generate a Building Condition Index (BCI) ranging between 0-100, index which can subsequently be rolled up into larger groups of buildings or entire portfolios. The software also computes a Functionality Index (FI), which measures how well a building serves its prescribed function, as well as a Mission Dependency Index (MDI), which indicates the criticality of a building to an organization's mission. These two indices measure a building's suitability based on both function and mission. The FI can be estimated over a building's life-cycle and can be used as a metric for modernization requirements.

The principle behind the functionality index (FI) is that loss of functionality can be qualitatively and quantitatively described by identifying the functional deficiencies that make a building perform less than optimally for a specific mission, when compared to a newly constructed building that incorporates all of the mission requirements. The following three aspects are reflected in the building functionality metric: functional deficiencies present in the building; a severity factor, which indicates how critically the identified functional deficiency affects the mission (where applicable, severity levels are defined based on codes and regulations requirements); the extent the building is affected by the specific functional deficiency (percentage of building area affected by the functional deficiency).

The FI index framework follows the procedure used to calculate the building physical condition index (CI) mandated by the ASTM standards. Coupling the building functionality index (FI) with the building physical condition index (CI), provides a means for justifying building rehabilitation, which includes restoration and modernization, versus demolition and new construction. This supports short- and long-term investment strategies, prioritizing criteria and budget constraints.

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[77] https://www.astm.org/Standards/E1664.htm
[78] https://www.astm.org/BOOKSTORE/BOS/TOCS_2018/04.11.html
[79] https://www.astm.org/BOOKSTORE/BOS/0411.htm
[80] ASTM Standard E2320-04(2018); https://www.astm.org/Standards/E2320.htm
[81] https://www.astm.org/BOOKSTORE/BOS/TOCS_2018/04.12.html

Appendix G of this report presents the 65 functionality criteria incorporated in BUILDER SMS.

For adoption of the BUILDER SMS software outside of the U.S. federal government, ERDC-CERL partners with third-party contractors for distributing BUILDER via a Cooperative Research and Development Agreements (CRASAs) and Patent License Agreements (PLAs). The following contractors have PLAs for distributing BUILDER: Atkins Global[82], Cardno[83], DIGON Systems[84], FM Projects[85], North Pacific Support Services[86] and Tetra Tech[87]. The costs associated with the patent license are negotiated individually with each contractor.

In July 2017, a Tetra Tech press release[88] announced a five-year contract valued at 150 million $USD aiming to assist the U.S. Department of Defense implement BUILDER to support mission readiness and building infrastructure investments for the U.S. Army, and to prepare facility budget forecasts for presentation to the U.S. Congress. In August 2018, Gordian, the leading provider of facility and construction cost data, also announced that its RSMeans database can now be integrated into the BUILDER catalog to provide up-to-date reference construction cost data at the material or task level[89]. This recent development addresses an earlier challenge reported with BUILDER implementation (i.e., out-of-date cost books data) to accurately estimate replacement costs versus new construction in budgeting plans [17].

Development of new tools will take significantly more time compared to adaptation of existing tools. Nevertheless, the need to meet federal government targets for energy and carbon reduction within its building stock by relatively close target dates could motivate decision-makers to select one method over another, irrespective of whether the solution is the optimal one.

A clear scope of the objectives of a building functional suitability tool for the Canadian military should be clearly expressed prior to the selection or development of a tool. A starting point could be to create an inventory of the current stock to see the number and diversity of buildings requiring evaluation, categorize them by building type, and then define the functional priorities for each generic type.

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82 https://www.atkinsglobal.com/en-GB/angles/all-angles/builder-planning-power-in-asset-management
83 https://www.cardno.com/projects/builder-sms-implementation/
84 https://digonsystems.com/
85 http://www.fmprojects.com/index.php/2013-03-11-14-00-59/2013-03-11-14-07-37
86 http://www.norpacss.com/builder_sms.html
87 http://www.tetratech.com/en/projects/infrastructure-assessments-at-multiple-us-air-force-bases
88 https://www.businesswire.com/news/home/20170719005208/en/USACE-Awards-Tetra-Tech-150-Million-Architecture
89 https://www.businesswire.com/news/home/20180802005027/en/CERL-Gordian-Partner-Bring-RSMeans-data-BUILDER

12. Recommended further reading

Development of Army Building Functionality Assessment Criteria and Procedures (Grussing et al. 2010, [ref.18]), for a comprehensive overview of the process for identifying the functionality criteria and the functional capability of Army facility real property, incorporated in the BUILDER Sustainment Management System.

A Review of the BUILDER Application for Assessing Federal Laboratory Facilities (Herrera et al., 2017, [ref.17]), for a comprehensive review of BUILDER software implementation by 25 U.S. federal agencies and laboratory stakeholders.

Performance Based Building: Conceptual Framework (Szigeti F., Davis G. 2006, [ref.78]), for a comprehensive description of the building performance based approach and guidance on how to prepare the statement of requirements during the different phases of a building's life-cycle.

National Institute of Building Science - Whole Building Design Guide [70], for an understanding of the basic processes, techniques, and language by which functional and operational building decisions are made in the United States.

Building Performance Analysis (Pieter de Wilde, 2018, [ref.1]) for a comprehensive review on building performance analysis, including needs, functions and requirements, building performance metrics, indicators and measures, performance criteria and quantification.

Assessing Building Performance (Preiser and Vischer, 2005, [ref.10]) for a comprehensive review of building post-occupancy evaluation and user surveys.

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[23] ASTM E1662-95a(2018), Standard Classification for Serviceability of an Office Building for Sound and Visual Environment, https://www.astm.org/Standards/E1662.htm

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Appendix A - **ASTM Standards for Whole Building Functionality and Serviceability**

Aspect of serviceability	Topic of serviceability
ASTM E1660-95a(2018) Standard Classification for Serviceability of an Office Building for **Support for Office Work**	*A.1 Support for Office Work* A1.1 Photocopying and office printers A1.2 Training rooms, general A1.3 Training rooms for computer skills A1.4 Interview rooms A1.5 Storage and floor loading A1.6 Shipping and receiving
ASTM E1661-95a(2018) Standard Classification for Serviceability of an Office Building for **Meetings and Group Effectiveness**	*A.2 Meetings and Group Effectiveness* A.2.1 Meeting and conference rooms A.2.2 Informal meetings and interaction A.2.3 Group layout and territory A.2.4 Group workrooms
ASTM E1662-95a(2018) Standard Classification for Serviceability of an Office Building for **Sound and Visual Environment**	*A.3 Sound and Visual Environment* A.3.1 Privacy and speech intelligibility A.3.2 Distraction and disturbance A.3.3 Vibration A.3.4 Lighting and glare A.3.5 Adjustment of lighting by occupants A.3.6 Distant and outside views
ASTM E1663-03(2010) Standard Classification for Serviceability of an Office Building for **Typical Office Information Technolog**y	*A.5 Typical Office Information Technology* A.5.1 Office computers and related equipment A.5.2 Power at workplace A.5.3 Building power A.5.4 Telecommunications core A.5.5 Cable plant A.5.6 Cooling
ASTM E1664-95a(2018) Standard Classification for Serviceability of an Office Building for **Layout and Building Features**	*A.7 Layout and Building Features* A.7.1 Influence of HVAC on layout A.7.2 Influence of sound and visual features on layout A.7.3 Influence of building loss features on space needs
ASTM E1665-95a(2018) Standard Classification for Serviceability of an Office Building for **Building Protection**	*A.9 Building Protection* A.9.1 Protection around building A.9.2 Protection from unauthorized access to site and parking A.9.3 Protective surveillance of site A.9.4 Perimeter of building A.9.5 Public zone of building A.9.6 Building protection services
ASTM E1666-95a(2018) Standard Classification for Serviceability of an Office Building for **Work Outside Normal Hours or Conditions**	*A.10 Work Outside Normal Hours or Conditions* A.10.1 Operation outside normal hours A.10.2 Support after-hours A.10.3 Temporary loss of external services A.10.4 Continuity of work (during breakdowns)
ASTM E1667-95a(2018) Standard Classification for Serviceability of an Office Building for **Image to the Public and Occupants**	*A.11 Image to the Public and Occupants* A.11.1 Exterior appearance A.11.2 Public lobby of building A.11.3 Public spaces within building A.11.4 Appearance and spaciousness of office spaces A.11.5 Finishes and materials in office spaces A.11.6 Identify outside building A.11.7 Neighborhood and site A.11.8 Historic significance

Aspect of serviceability	Topic of serviceability
ASTM E1668-95a(2018) Standard Classification for Serviceability of an Office Building for **Amenities to Attract and Retain Staff**	*A.12 Amenities to Attract and Retain Staff* A.12.1 Food A.12.2 Shops A.12.3 Daycare A.12.4 Exercise room A.12.5 Bicycle racks for staff A.12.6 Seating away from work areas
ASTM E1669-95a(2018) Standard Classification for Serviceability of an Office Building for **Location, Access and Wayfinding**	*A.14 Location, Access and Wayfinding* A.14.1 Public transportation (urban sites) A.14.2 Staff visits to other offices A.14.3 Vehicular entry and parking A.14.4 Wayfinding to building and lobby A.14.5 Capacity of internal movement systems A.14.6 Public circulation and wayfinding in building
ASTM E1670-95a(2018) Standard Classification for Serviceability of an Office Building for **Management of Operations and Maintenance**	*B.3 Management of Operations and Maintenance* B.3.1 Strategy and program for operations and maintenance B.3.2 Competences of in-house staff B.3.3 Occupant satisfaction B.3.4 Information on unit costs and consumption
ASTM E1671-95a(2018) Standard Classification for Serviceability of an Office Building for **Cleanliness**	*B.4 Cleanliness* B.4.1 Exterior and public areas B.4.2 Office areas (interior) B.4.3 Toilets and washrooms B.4.4 Special cleaning B.4.5 Waste disposal for building
ASTM E1679-13 (2013) Standard Practice for Setting the Requirements for the **Serviceability of a Building or Building-Related Building, and for Determining What Serviceability is Provided or Proposed**	"This document is a definitive procedure to (1) ascertain the profile of required levels of functionality (functional support) for a specific occupant group, (2) ascertain the profile of levels of serviceability (functional capability) that are provided in an existing building, or called for in the design for a building, and (3) compare what is provided to what is required."
ASTM E1692-95a(2018) Standard Classification for Serviceability of an Office Building for **Change and Churn by Occupants**	*A.6 Change and Churn by Occupants* A.6.1 Disruption due to physical change A.6.2 Illumination, HVAC and sprinklers A.6.3 Minor changes to layout A.6.4 Partition wall relocations A.6.5 Lead time for facilities group
ASTM E1693-95(2018) Standard Classification for Serviceability of an Office Building for **Protection of Occupant Assets**	*A.8 Protection of Occupant Assets* A.8.1 Control of access from building public zone to occupant reception zone Interior zones of security A.8.2 Vaults and secure rooms A.8.3 Security of cleaning service systems A.8.4Security of maintenance service systems A.8.5 Security of renovations outside active hours A.8.6 Systems for secure garbage A.8.7 Security of key and card control systems

Aspect of serviceability	Topic of serviceability
ASTM E1694-95a(2018) Standard Classification for Serviceability of an Office Building for **Special Facilities and Technologies**	*A.13 Special Facilities and Technologies* A.13.1 Group or shared conference centre A.13.2 Video teleconference facilities A.13.3 Simultaneous translation A.13.4 Satellite and microwave links A.13.5 Mainframe computer centre A.13.6 Telecommunications centre
ASTM E1700-16 Standard Classification for Serviceability of an Office Building for **Structure and Building Envelope**	*B.1 Structure and Building Envelope* B.1.1 Typical office floors B.1.2 External walls and projections B.1.3 External windows and doors B.1.4 Roof B.1.5 Basement B.1.6 Grounds
ASTM E1701-95(2018) Standard Classification for Serviceability of an Office Building for **Manageability**	*B.2 Manageability* B.2.1 Reliability of external supply B.2.2 Anticipated remaining service life B.2.3 Ease of operation B.2.4 Ease of maintenance B.2.5 Ease of cleaning B.2.6 Janitors' facilities B.2.7 Energy consumption B.2.8 Energy management and controls
ASTM E2320-04(2018) Standard Classification for Serviceability of an Office Building for **Thermal Environment and Indoor Air Conditions**	*A.4 Thermal Environment and Indoor Air Conditions* A.4.1 Temperature and humidity A.4.2 Indoor air quality A.4.3 Ventilation (air supply) A.4.4 Local adjustment by occupants A.4.5 Ventilation with openable windows

Appendix B - **ASTM Standards for Whole Building Functionality and Serviceability: Overview of building functions and related aspects**

(source: Pieter de Wilde, Building Performance Analysis, 2018, [ref.1])

Function	Aspects
Support office work	Provide rooms, training facilities, generic space, storage space, interview rooms; space for printers and copiers; space for shipping and receiving goods and mail
Enable meetings and group effectiveness	Provide meeting and conference space, room for informal meetings and interaction and space for groups
Provide suitable sound and visual environment	Maintain privacy and speech intelligibility; minimize distraction and disturbance; control vibration; provide lighting while controlling glare; allow adjustment of lighting by occupants; provide distant and outside views
Provide suitable thermal comfort and indoor air	Control temperature, humidity, indoor air quality, fresh air supply; offer occupant control; provide operable windows
Enable typical office ICT equipment	Provide space for computers and related equipment as well as power, telecommunication network access and cooling
Allow changeability by occupants	Enable partition wall relocation; minimize disruption in case of change; provide illumination, HVAC and sprinklers in a way that enables change
Integrate building features in layout	Integrate HVAC, lighting and sound in space layout; minimize space loss
Protect occupants and assets	Control access, provide internal secure zones, provide vaults and secure rooms; ensure cleaning systems are secure in terms of cleaning and maintenance at all times; keep garbage secure; provide key or card access
Protect facility	Protect zone around the building, site and parking from unauthorized access; provide surveillance; protect perimeter and public zones; enable protection services
Enable work outside normal hours or conditions	Enable operation after hours or outside normal hours, during loss of external service, and enable continuity of work during breakdown of services
Provide image and identity	Provide good exterior appearance, lobby, internal spaces, image of spaciousness, good finishes and materials, identity, relation with neighbourhood, historic significance
Offer amenities for staff	Provide food, shopping, day care, exercise, bicycle racks and seating
Provide special facilities and technologies	Offer conference facilities, translation, satellite connection, computing, telecom centre
Enable access and wayfinding	Provide access to public transport, enable visitors, vehicular entry, wayfinding, internal movement, circulation
Provide key structures	Provide floors, walls, windows, doors, roof, basement, grounds
Be manageable	Be reliable, easy to operate, easy to maintain, easy to clean; have a low-energy use; provide controls; have a suitable service life
Enable operations and maintenance	Ensure occupant satisfaction; provide operations and maintenance strategy as well as info on resource consumption
Support cleanliness	Enable cleaning of exterior and public areas, cleaning of offices, cleaning of toilets and washrooms, special cleaning, waste disposal

Appendix C - **Phases and Stages of a Building's Life-Cycle**

(source: ISO 15686-10:2010, [ref.51])

Phase		Stage no.	Name
Portfolio management	Portfolio operations	0.1	Portfolio strategy
		0.2	Portfolio requirements
		0.3	Project initiation
	Pre-project stages	1	Conception of need
		2	Feasibility
		3.1	Authorization
		3.2	First procurement
Project delivery		4	Initial or outline conceptual design
		5	Preliminary design
		6.1	Detailed (coordinated) design
		6.2	Construction procurement
		7	Production information
		8.1	Construction
		8.2	Commissioning
Property management		9.1	Asset operations
		9.2	Maintenance and condition management
		9.3	Occupants' facility administration
		9.4	Refurbishment, adaptation, alteration, change of use
		9.5	Change of functional use by occupant
Disposal	Status change	10.1	Disposal preparation
		10.2	Transfer
		10.3	Reinstatement
	End of life	10.4	Decommissioning
		10.5	Deconstruction
		10.6	Recycling
		10.7	Demolition

Appendix C (continued) - **Example of actions and outputs required for assessing a building's functional performance during the property management phase**

(source: ISO 15686-10:2010, [ref.51])

Phase	**Stage no.**	**Name**	**Main tasks of stage**	**Actions required by ISO 15686-10:2010**	**Outputs called for by other parts of ISO 15686**
Property management	9.1	Asset operations	• Operate during initial warranty period • Operate during continued use (includes management of outsourced services)	Periodically, e.g. at five year intervals or before a planned change of occupants, verify that the building still meets the functional requirement levels, and report significance of any gaps.	15686-3: secondary audit of implementation and adequacy of service-life care 15686-5: analyses of whole-life costing/life-cycle costing 15686-6: analysis of consistency with environmental goals and requirements 15686-7: performance surveys to determine estimated service life 15686-8: selection of reference service-life data and estimation of service life 15686-9: assessment of service-life data
Property management	9.2	Maintenance and condition management	• Maintain during use • Monitor condition • Conduct condition related projects and other actions	If levels of demand and supply of maintenance and of condition are to be assessed, the same methodology as for assessment and gap analysis for functionality shall be considered.	15686-3: secondary audit of implementation and adequacy of service-life care 15686-5: analyses of whole-life costing/life-cycle costing 15686-6: analysis of consistency with environmental goals and requirements 15686-7: performance surveys to determine estimated service life 15686-8: selection of reference service-life data and estimation of service life 15686-9: assessment of service-life data
Property management	9.3	Occupants' building administration	Occupants administer and use their facilities	Demand and supply profiles, and significance of gaps, shall be available to the building administrator	15686-3: secondary audit of conformance to building management plan

Phase	Stage no.	Name	Main tasks of stage	Actions required by ISO 15686-10:2010	Outputs called for by other parts of ISO 15686
Property management	9.4	Refurbishment, adaptation, alteration, change of use	Provide major repairs, replacements and adaptations or alterations	Client's functional brief shall include a main demand profile and any variants for each potential solution. Verify whether this needs to be updated from initial briefs for the building.	15686-3: secondary audit of conformance to (changed) brief for the works, and implementation 15686-5: analyses for (changed) whole-life costing/life-cycle costing 15686-6: analysis of consistency with environmental goals and requirements 15686-7: performance surveys to determine estimated service life 15686-8: selection of reference service-life data and estimation of service life 15686-9: assessment of service-life data
Property management	9.5	Change of functional use by occupant	Respond to client's changes in function or functional needs	When a change of functional use by occupant(s) is recognized, whether the functional performance requirements for the building have changed, and whether the supply profile(s) meet(s) that new demand profile, shall be verified, and significance of any gaps shall be reported.	15686-5: analyses of (changed) whole-life costing/life-cycle costing 15686-6: analysis of consistency with (changed) environmental goals and requirements 15686-7: performance surveys to determine estimated service life 15686-8: selection of reference service-life data and estimation of service life 15686-9: assessment of service-life data

Appendix C (continued) - **Example of typical actions and functions which may occur during the property management phase**

(source: ISO 15686-10:2010, [ref.51])

Stage no.	**Name**	**Task of stage**	**Typical actions and functions at each stage**
9.1	Asset operations	• Operate during initial warranty period • Operate during continued use (includes management of outsourced services)	a) Collaborate in the commissioning process b) The process of commissioning starts at project inception and includes ensuring preparation for the entire service life c) Initial start-up, testing and first operation d) Building management during move-in process e) Day-to-day operations f) Management of building operations g) Operating supplies and services h) Measurement on key performance indicators i) Procurement and contracting j) Quality assurance with key indicators k) Periodic market testing or retendering of selected services l) Create and maintain current, validated data about the portfolio, including: 1) external context and drivers of demand 2) functional requirement levels for each category of functions and each occupant group 3) relative importance of each functional requirement 4) any mandatory or minimum levels of functionality for a function or a user group 5) functional requirement levels for each asset 6) relative importance of each requirement for an asset 7) any mandatory or minimum levels of functionality for an asset 8) importance of each asset for mission, derived from the importance for mission of the function it supports and the users it supports 9) functional capability of each asset, and gaps in required capability 10) 2-D, 3-D and GIS information 11) space utilization of each asset 12) condition of each asset 13) hold appropriate data in an interoperable BIM 14) ensure BIM is current
9.2	Maintenance and condition management	• Maintain during use • Monitor condition • Conduct condition related projects and other actions	a) Routine maintenance at scheduled intervals b) Maintenance special tasks and work orders c) Predictive modelling of condition d) Condition monitoring by inspection e) Maintain data on current and projected condition of major systems and components of each built asset f) Ensure BIM is current
9.3	Occupants' building administration	Occupants administer and use their facilities	a) Occupant administration of its facilities b) Occupant negotiation with building managers
9.4	Refurbishment, adaptation, alteration, change of use	Provide major repairs, replacements and adaptations or alterations	a) Planning and budgeting for major repairs and alterations throughout the service life b) Draft priorities for pending major repairs and alterations c) Draft strategic statement of requirements and business case for priority projects d) Draft and first budget for major repairs and alterations e) Briefing for major repairs and alterations f) Prioritizing potential projects g) Conduct each major repair or alteration as a project having Stage 1 to Stage 8, as above h) Ensure BIM is current

Stage no.	Name	Task of stage	Typical actions and functions at each stage
9.5	Change of functional use by occupant	Respond to client's changes in function or functional needs	a) Periodically (typically, at the time of mission or organization change, or by default at five-year cycle) ascertain, if required, levels of functionality have changed. For example: 1) client functions or operations change 2) client demand profile changes in response to changes in functions or operations 3) client develops new ways of working, with need for changed support from facilities b) Ensure BIM is current

Appendix D - **National Research Council - Protocols for Building Function Condition Assessments**

D.1 Indicators of building barrier free access (source: NRC-IRC Technical Report [ref.59])

Accessibility Aspects	Indicators
Vehicular approach to the building site by bus, para- transport, car and taxi, including relationships of entrances to bus stops, taxi and car drop-offs, outdoor parking, indoor parking, public and private designated parking for disabled people, appropriateness of number, size and location of parking spaces	general use workstations spatial correlations safety flexibility universal accessibility health productivity.
Pedestrian approach to the building from off-site and on-site, including approaches from the street, shopping mall, skywalks, parking facilities	
Major features of the building and its site, the general use of the building, the organizational departments, the relationship to the users and uses	
Orientation and wayfinding systems, including building identification, street identification, directories, information and reception centres, focal and other visual, tactile, and audible wayfinding elements	
Public and private entrances including adequacy of ramp slopes, stair design, landing sizes, handrails, clear openings at doors and passageways, vestibule space for wheelchair maneuvering, ease of door opening, hazards for visually impaired and blind people	
Public use areas including lobbies, reception areas, waiting areas, horizontal circulation, vertical circulation (stairs, ramps, elevators, lifts, escalators)	
Support areas such as washrooms, lounges, meeting rooms, conference rooms, kitchens, mail rooms, filing and storage rooms, areas of refuge	
Semi-private and private use areas such as offices, printing rooms, laboratories	
Secured areas such as vaults, secured storage, mechanical and electrical rooms	
Space separators, including use of partitions, plants, pools, fountains, open space, artifacts, sight and sound baffles	
Communication systems including tactile systems For blind people, visual systems for visually) impaired people, telephone communication for the deaf (tdd), and emergency signaling systems for disabled people	
Systems and procedures such as emergency evacuation for the eleven categories of users, cleaning operations, trash removal, mail distribution, health monitoring, safety precautions and other.	

D.2 Indicators of acoustical performance (source: NRC-IRC Technical Report [ref.59])

Components and Characteristics to be Assessed	Evaluation Criteria	Functionality report to include
Masking noise system, lights, transformers, plumbing, HVAC system (including mechanical room) for background noise	Background noise limits for HVAC system or lights Absorption requirements for suspended ceiling system Average planned workstation area or workstation separation for open-plan areas Sound absorption and/or sound transmission loss for office screens Sound absorption for vertical surface treatment in open-plan area Speech privacy requirement for enclosed offices or conference room (Treasury Board performance standard for Secure Discussion Area) Noise reduction for enclosed space intended to house noisy office equipment such as copiers or building services (washrooms, cafeteria, etc.) Intrusion of Outdoor Noise	Comparison of speech privacy objective performance for system vs design specifications Comparison of conference room objective data (background levels, reverberation) with user perception Comparison of objective background levels from building services (dba and octaves) with user perception, with special focus on low frequency noise/rumble Comparison of open-plan occupant and sensory inspection perception of speech privacy with design criteria and actual components Indication of the need to adjust HVAC or masking systems; replace or adjust separation, background noise, boundary wall, room surface or sound system components Where possible, an indication of probable causes of deficiencies Indication of any implications for the
Screens, partitions, doors, suspended ceiling system including space above, HVAC ducts and diffusers for sound transmission limiting speech privacy		
Room surfaces (suspended ceiling and floor in open-plan and conference rooms, window coverings) and screens for unsuitable absorption		
Partitions, doors, suspended ceiling system, to prevent noise spread from spaces designated for specific noisy office equipment or building services (cafeteria, washrooms, etc.).		

Components and Characteristics to be Assessed	Evaluation Criteria	Functionality report to include
		performance of other building aspects (building envelope, fire safety, function, lighting, structure, ventilation) Indication of flexibility to respond to changing building occupancy requirements.

D.3 Indicators of lighting performance (source: NRC-IRC Technical Report [ref.59])

Components and Characteristics to be Assessed	Evaluation Criteria	Functionality report to include
Planned activities within the building	Perceived adequacy of quantity and quality of lighting Adequacy of system response to occupant needs (i.e., type, level and location of controls) Presence of annoying glare, deep shadows, light flickering and ballast noise Absence of, or desire for, window access Colour rendering problems Thermal problems Infrared or ultraviolet degradation Colour recognition	Existing conditions of work spaces and work surfaces Situations where daylight has been successfully utilized or where it has contributed to problems in the visual field Spot measurements of luminance and illuminance Detailed study of problem areas as indicated on building drawings, noting the type of complaint if necessary Placement, zoning and switching of luminaires Classification of building uses from a visual requirement perspective Working areas of common visual requirements Switching arrangements and operation to meet local needs Problem areas due to unusual furniture type and layout, or tenants needs or lighting grid limitations Illumination levels compliance with legislative standard and guidelines Luminance patterns that are too dark or too bright Very low or very bright reflective surfaces Any form of glare Environmental complaints directly or indirectly related to lighting (e.g., poor posture due to glare conditions).
Type and use of spaces required by clients with possible information on future requirements or changes		
Specific functional requirements		
Desirable features for both functional and aesthetic requirements		
Population type and density, occupancy schedules and planned expansions		
Hardware and software requirements		
Building systems integration		
Manual/automatic control, monitoring functions		
Daylighting requirements		

Appendix E - **APPA Leadership in Educational Facilities: Functionality Condition Assessments**

Functionality criteria - General Classrooms (source: Kaiser, 2015, [ref.56])

Space type	**Baseline Functionality Criteria**
1. Functional adequacy	Classroom configuration and the size and arrangement of student and instructional stations satisfies instructional requirements, and provides adequate sight lines.
2. Accessibility	Spaces shall meet ADA standards wherever required to meet program accessibility requirements.
3. Room finishes	Floors shall be covered in an appropriate, easily cleaned material that will permit the room to be maintained in a neat and orderly condition. Walls and ceilings shall be finished in appropriate, easily cleaned materials. Color schemes and finish materials shall present a pleasing appearance conducive to teaching and learning.
4. Acoustics and sound control	Floor covering, wall surface, and ceiling materials shall have appropriate sound absorption and reflective qualities, and insulation against outside noise shall be sufficient to provide a teaching, learning, study, or work environment free of distracting noise levels.
5. Climate control	Heating and cooling systems, together with adequate control systems, shall be installed that will permit the maintenance of a comfortable teaching, learning, study, or work environment at all seasons of the year.
6. Lighting	The installed lighting system shall provide an adequate quality and level of lighting for the teaching, learning, study, or work environment, and shall be provided with controls to vary or adjust the lighting level as required for specific needs. Appropriate classroom window coverings shall be provided to permit unimpaired use of A/V or other teaching equipment.
7. Electrical service	Adequate electrical capacity and outlets shall be provided in the room to accommodate teaching equipment, laptop computers, office equipment, etc.
8. Instructional support	As required, classrooms shall be equipped to support instruction, including: - Connectivity to campus data networks and the Internet - Chalkboards, whiteboards, projection screens, or other teaching accessories - A full range of audio-visual equipment
9. Furniture and fixtures	Classroom fixed seating, when installed, shall be ergonomically correct, maintainable, provided with adequate tablet arms or table space for note-taking, and shall provide an unobstructed view.
10. Information technology	All office spaces shall have appropriate connectivity to campus data networks and the Internet.
11. Storage space	An adequate amount of storage space for equipment and files appropriate to the function shall be provided.

Appendix F - **Queensland Government Buildings: Performance Indicators and Performance Measures**

(source: Building Asset Performance Framework – A best practice guideline for the performance assessment of Queensland Government buildings, 2017, [ref.64])

	Performance indicator	Performance measure
Appropriateness	Capacity	Forexample,squaremetreperperson,studentworkspaces/ places, prisoner numbers, other department-specific measure, orgenericratingscaleasprovidedinAppendixA(section 2.1—Capacity).
	Functionality	For example, percentage of spaces appropriate for purpose, housing overcrowding, other department-specific measure, orgenericratingscaleasprovidedinAppendixA(section 2.2—Functionality).
	Location	For example, percentage of occupants/clients satisfied with dwellingproximitytoservices,centralitywithincatchmentarea, other department-specific measure, or generic rating scale as providedinAppendixA(section2.3—Location).
	Condition	*Maintenance Management Framework's* Condition Index or FacilityConditionIndex(FCI).TheFCIiscalculatedbydividing the costofdeferredmaintenancebytheAsset Replacement Value ofthebuildingasset,expressedasapercentage—thehigher the percentage,thepoorertheconditionofthebuildingasset.
	Remaining life	Estimatedyearstoendofusefuloreconomiclife.
Financial	Operating cost	For example, cost per square metre of gross floor area or other department-specific measure.
	Maintenancecost	For example, cost per square metre of gross floor area, expenditureasapercentageofgrossbookvalueofthebuilding asset or other department-specific measure.
	Deferred maintenance cost	Forexample,estimatedcostofdeferredmaintenance asa percentage of gross book value of asset or other department-specific measure.
	Netreturnonassetvalue (Note: optional indicator)	Netrevenueasapercentageofgrossbookvalueofasset.
Statutory compliance risk	Extent of non-compliance	Qualitative assessment of any gaps in compliance based on department-specific measures, including an estimate of the costtoremedythenon-compliance.
Effective use	Utilisationrate	Forexample,levelofutilisationasapercentageofavailable capacity,percentageofoccupiedstudentworkstationsto capacity ofworkstations,studentnumberstoavailableteaching spaces, vacant square metre of floor area to net lettable area or other department-specific measure.
	Compatibility ofuse (Note: optional indicator)	RatingscaleprovidedinAppendixA(section5.2—Compatibility of use).
Environmental impact	Impactofbuildingasset on environment	Qualitative and quantitative assessment based on department-specific measures. Measurement of this indicatorcan besplit betweenpresenceofhazardousmaterials/site contamination issuesandconsumptionofenergyandwater.
	Environmentalrating system assessment (Note: optional indicator)	Descriptionofenvironmentalratingsystemusedtoevaluate the environmentalimpactsofthebuildingassetandtherating achieved.
Social significance	Significance in meeting government priorities or community obligations	Qualitative assessment based on department-specific measures.

Appendix G - **BUILDER Sustainment Management System: Building Level Functionality Aspects**

(source: Grussing at al., 2010, [ref.18])

ID	Functional Category	Functionality Sub Issue
101	Location	Is the building located on a floodplain?
102	Location	Is the building located within an airfield safety clearance?
103	Location	Is the building located within the explosive arc distance?
104	Location	Is the building located near sources of excessive noise?
105	Location	Is the building adequately located to support the mission?
201	Size/Configuration	Does the building encourage an appropriate level of occupant interaction?
202	Size/Configuration	Is the building overcrowded?
203	Size/Configuration	Is the building configuration adequate?
301	Structural Adequacy	Is the building structurally adequate for seismic conditions?
302	Structural Adequacy	Is the building structurally adequate for all loading conditions?
401	Access	Is entry into the building quick and easy?
402	Access	Is directional, informational, and room signage in and around the building adequate?
403	Access	Is exit (egress) from the building quick and easy?
501	Accessibility	Is the building ABA compliant?
601	AT/FP	Does the building meet ATFP requirements and recommendations?
701	Building Services	Does the building require and internal power supply, and if so, is it adequate?
702	Building Services	Does the building require an uninterruptible power supply, and if so, is it adequate?
703	Building Services	Does the building require a water supply, and if so, is it adequate?
704	Building Services	Does the building require a hot water supply, and if so, is it adequate?
705	Building Services	Does the building require a specialty water supply, and if so, is it adequate?
706	Building Services	Does the building require plumbing fixtures, and if so, is are they adequate?
707	Building Services	Does the building require an stand-alone wastewater removal system, and if so, is it adequate?
708	Building Services	Does the building require an industrial waste removal system, and if so, is it adequate?
709	Building Services	Does the building require an information technology system, and if so, is it adequate?
710	Building Services	Does the building require a fuel distribution system, and if so, is it adequate?
711	Building Services	Does the building require an oxygen (or other gas) system, and if so, is it adequate?
712	Building Services	Does the building require a compressed air system, and if so, is it adequate?
713	Building Services	Does the building require a security system, and if so, is it adequate?

ID	Functional Category	Functionality Sub Issue
714	Building Services	Does the building require a telephone system, and if so, is it adequate?
715	Building Services	Is the capacity of the electrical system adequate?
716	Building Services	Is the electrical system grounded adequately?
717	Building Services	Are the electrical outlets adequate?
801	Comfort	Does the building have the HVAC capacity to be heated adequately?
802	Comfort	Does the building have the HVAC capacity to be cooled adequately?
803	Comfort	Does the building have the HVAC capacity to be dehumidified adequately?
804	Comfort	Does the building have the HVAC capacity to be humidified adequately?
805	Comfort	Does the building have the HVAC capacity to be ventilated adequately?
806	Comfort	Are the HVAC controls adequate?
807	Comfort	Is there disruptive noise in the building?
808	Comfort	Is the building adequately lit?
809	Comfort	Are the lighting controls adequate?
901	Efficiency/Obsolescence	Is the equipment energy efficient?
902	Efficiency/Obsolescence	Is the building adequately zoned for HVAC?
903	Efficiency/Obsolescence	Are efficient lighting controls in use and adequate where applicable?
904	Efficiency/Obsolescence	Are efficient light fixtures in use and adequate where applicable?
905	Efficiency/Obsolescence	Are water conservation mechanisms in use and adequate where applicable?
906	Efficiency/Obsolescence	Are energy efficient windows and doors in use and adequate where applicable?
907	Efficiency/Obsolescence	Does the insulation meet building requirements?
1001	Environment/Life Safety	Is the lightning protection adequate?
1002	Environment/Life Safety	Is asbestos present in the building?
1003	Environment/Life Safety	Is the indoor air quality of the building adequate?
1004	Environment/Life Safety	Is lead paint present in the building?
1005	Environment/Life Safety	Is lead present in the building's water?
1006	Environment/Life Safety	Are PCBs present in the building?
1007	Environment/Life Safety	Is radon present in the building?
1008	Environment/Life Safety	Is the fire and smoke detection/warning system adequate?
1009	Environment/Life Safety	Are flammable and combustible materials adequately stored?
1010	Environment/Life Safety	Is the fire suppression equipment adequate?
1101	Missing/Improper Comps	Are all the necessary components present?
1102	Missing/Improper Comps	Is the correct type of each component present?
1201	Aesthetics	Does the quality and appearance of the exterior create a positive impression on the public and building occupants?
1202	Aesthetics	Does the quality and appearance of the interior create a positive impression on the public and building occupants?
1301	Maintainability	Does the design of or placement of equipment allow for easy maintenance?
1401	Cultural Resources	Does this building have any cultural resources (historical significance)?

Appendix H - **WELL Standard Certification: Matrix for Indoor Light and Air Quality**

(source: WELL Standard, [ref. 71])

Aspect	Assessment Criteria
LIGHTING	
53. Visual lighting design	1. Visual Acuity for Working 2. Task Lighting
54. Circadian lighting design	1: Melanopic Light Intensity in Work Areas
55. Electric light glare control	1: Lamp Shielding
56. Solar glare control	1: View Window Shading in Workspaces 2: Daylight Management in Work Areas
57. Low-glare workstation design	1: Workstation Orientation
58. Color quality	1: Color Rendering Index
59. Surface design	1: Work Area Wall and Ceiling Lightness
60. Automated shading and dimming controls	1: Automated Sunlight Control 2: Responsive Light Control
61. Right to light	1: Lease Depth 2: Windows and Workspaces
62. Daylight modelling	1: Healthy Sunlight Exposure
63. Daylighting fenestration	1: Window Sizes for Workspaces 2: Window Transmittance in Work Areas 3: Uniform Color Transmittance
AIR	
01. Air quality standards	1: Standards for Volatile Substances 2: Standards for Particulate Matter and Inorganic Gases 3: Below-Grade Air Quality Standards
02. Smoking ban	1: Indoor Smoking Ban 2: Outdoor Smoking Ban
03. Ventilation effectiveness	1: Ventilation Design 2: Demand Controlled Ventilation 3: System Balancing
04. VOC reduction	1: Interior Paints and Coatings 2: Interior Adhesives and Sealants 3: Flooring 4: Insulation 5: Furniture and Furnishings
05. Air filtration	1: Filter Accommodation 2: Particle Filtration 3: Air Filtration Maintenance
06. Microbe and mold control	1: Cooling Coil Mold Reduction 2: Mold Inspections
07. Construction pollution management	1: Duct Protection 2: Filter Replacement 3: VOC Adsorption Management 4: Construction Equipment 5: Dust Containment and Removal
08. Healthy entrance	1: Permanent Entryway Walk-Off Systems 2: Entryway Air Seal
09. Cleaning protocol	1: Cleaning Plan for Occupied Spaces
10. Pesticide management	1: Pesticide Use
11. Fundamental material safety	1: Asbestos and Lead Restriction 2: Lead Abatement 3: Asbestos Abatement 4: Polychlorinated Biphenyls Abatement
12. Moisture management	1: Bulk Water – Exterior Management 2: Interior Bulk Water Damage Management 3: Capillary Water Management 4: Wetting by Convection and Condensation
13. Air flush	1: Air Flush
14. Air infiltration management	1: Air Leakage Testing

Aspect	Assessment Criteria
15. Increased ventilation	1: Increased Fresh Air Supply
16. Humidity control	1: Relative Humidity
17. Direct source ventilation	1: Pollution Isolation and Exhaust
18. Air quality monitoring and feedback	1: Indoor Air Monitoring 2: Air Data Record Keeping and Response 3: Environmental Measures Display
19. Operable windows	1: Full Control 2: Outdoor Air Measurement 3: Window Operation Management
20. Outdoor air systems	1: Dedicated Outdoor Air Systems
21. Displacement ventilation	1: Displacement Ventilation Design and Application 2: System Performance
22. Pest control	1: Pest Reduction 2: Pest Inspection
23. Advanced air purification	1: Carbon Filtration 2: Air Sanitization 3: Air Quality Maintenance
24. Combustion minimization	1: Appliance and Heater Combustion Ban 2: Low-Emission Combustion Sources 3: Engine Exhaust Reduction
25. Toxic material reduction	1: Perfluorinated Compound Limitation 2: Flame Retardant Limitation 3: Phthalate (Plasticizers) Limitation 4: Isocyanate-Based Polyurethane Limitation 5: Urea-Formaldehyde Restriction
26. Enhanced material safety	1: Precautionary Material Selection
27. Antimicrobial surfaces	1: High-Touch Surface Coating
28. Cleanable environment	1: Material Properties 2: Cleanability
29. Cleaning equipment	1: Equipment and Cleaning Agents 2: Chemical Storage

Appendix I - **SBTool: Building Sustainability Criteria**

(source: International Initiative for a Sustainable Built Environment (iiSBE), [ref.73])

Category	Issue
S Location, Services and Site Characteristics	
S1 Site Location and Context	
S1.1	Location of site relative to zones of flood risk.
S1.2	Location of site relative to zones of fire risk.
S1.3	Proximity of a site with potential residential occupancy to centres of employment or vice versa.
S1.4	Proximity to public transportation access points.
S1.5	Proximity to emergency services.
S1.6	Proximity to health care facilities.
S1.7	Proximity to public primary educational facilities.
S1.8	Proximity to public secondary educational facilities.
S1.9	Proximity to public, social and recreation facilities.
S1.10	Proximity to small retail commercial facilities.
S1.11	Proximity to large retail commercial facilities.
S1.12	Proximity to other facilities of local importance.
S2 Off-site services available	
S2.1	Frequency of service of local public transportation systems.
S2.2	Availability of renewable energy sources in the district.
S2.3	Access to a public electrical supply network.
S2.4	Access to a public broadband communications network.
S2.5	Access to a public potable water supply and distribution service.
S2.6	Access to a public sanitary sewage collection and treatment service.
S2.7	Access to a solid waste collection and disposal service.
S2.8	Availability within the urban area of recycled materials and products.
S2.9	Availability within the urban area of materials and products that can be re-used in new structures.
S3 Site Characteristics	
S3.1	Pre-development ecological sensitivity or value.
S3.2	Pre-development agricultural value.
S3.3	Pre-development contamination status of land.
S3.4	Ambient air quality conditions - particulates.
S3.5	Ambient air quality conditions - carbon monoxide.
S3.6	Ambient air quality conditions - other.
S3.7	Ambient noise conditions.
S3.8	Availability of existing structure(s) on the site suited to new functional requirements.
S3.9	Impact of orientation and topography of the site on the passive solar potential of buildings.
S3.10	Feasibility for the use of renewable energy systems on the site.
S3.11	Impact of size and shape of the land parcel on the economic viability of the development.
S3.12	Regulations applicable to the site pertinent to heritage conservation.
S3.13	Regulations applicable to the site pertinent to mixed use and medium-rise development.
S3.14	Regulations applicable to the site pertinent to the use of private vehicles.
Assessment of project and building performance	
A Site Regeneration and Development, Urban Design and Infrastructure	
A1 Site Regeneration and Development	
A1.1	Protection and restoration of wetlands.
A1.2	Protection and restoration of coastal environments.
A1.3	Reforestation for carbon sequestration, soil stability and biodiversity.

Category	Issue
A1.4	Development or maintenance of wildlife corridors.
A1.5	Remediation of contaminated soil, groundwater or surface water.
A1.6	Shading of building(s) by deciduous trees.
A1.7	Use of vegetation to provide ambient outdoor cooling.
A1.8	Reducing irrigation requirements through the use of native plantings.
A1.9	Provision of public open space(s).
A1.10	Provision and quality of children's play area(s).
A1.11	Facilities for small-scale food production for residential occupants.
A1.12	Provision and quality of bicycle pathways and parking.
A1.13	Provision and quality of walkways for pedestrian use.
A2 Urban Design	
A2.1	Maximizing efficiency of land use through development density.
A2.2	Reducing need for commuting transport through provision of mixed uses.
A2.3	Impact of orientation on the passive solar potential of building(s).
A2.4	Building morphology, aggregate measure.
A2.5	Impact of site and building orientation on natural ventilation of building(s) during warm season(s).
A2.6	Impact of site and building orientation on natural ventilation of building(s) during cold season(s).
A3 Project Infrastructure and Services	
A3.1	Supply, storage and distribution of surplus thermal energy amongst groups of buildings.
A3.2	Supply, storage and distribution of surplus photovoltaic energy amongst groups of buildings.
A3.3	Supply, storage and distribution of surplus hot water amongst groups of buildings.
A3.4	Supply, storage and distribution of surplus rainwater and greywater amongst groups of buildings.
A3.5	Provision of building to produce energy from solid waste.
A3.6	Provision of solid waste collection and sorting services.
A3.7	Composting and re-use of organic sludge.
A3.8	Provision of split grey / potable water services.
A3.9	Provision of surface water management system.
A3.10	On-site treatment of rainwater, storm water and greywater.
A3.11	On-site treatment of liquid sanitary waste.
A3.12	Provision of on-site communal transportation system(s).
A3.13	Provision of on-site parking facilities for private vehicles.
A3.14	Connectivity of roadways.
A3.15	Provision of access roads and facilities for freight or delivery.
A3.16	Provision and quality of exterior lighting.
B Energy and Resource Consumption	
B1 Total Life Cycle Non-Renewable Energy	
B1.1	Embodied non-renewable energy in original construction materials.
B1.2	Embodied non-renewable energy in construction materials for maintenance or replacement(s).
B1.3	Consumption of non-renewable energy for all building operations.
B1.4	Consumption of non-renewable energy for project-related transport.
B1.5	Consumption of non-renewable energy for demolition or dismantling process.
B2 Electrical peak demand	
B2.1	Electrical peak demand for building operations.
B2.2	Scheduling of building operations to reduce peak loads on generating facilities.
B3 Use of Materials	
B3.1	Degree of re-use of suitable existing structure(s) where available.
B3.2	Protection of materials during construction phase.

Category	Issue
B3.3	Material efficiency of structural and building envelope components.
B3.4	Use of virgin non-renewable materials.
B3.5	Efficient use of finishing materials.
B3.6	Ease of disassembly, re-use or recycling.
B4 Use of potable water, storm water and greywater	
B4.1	Embodied water in original construction materials.
B4.2	Use of water for occupant needs during operations.
B4.3	Use of water for irrigation purposes.
B4.4	Use of water for building systems.
C Environmental Loadings	
C1 Greenhouse Gas Emissions	
C1.1	GHG emissions from energy embodied in original construction materials.
C1.2	GHG emissions from energy embodied in construction materials used for maintenance or replacement(s).
C1.3	GHG emissions from primary energy used for all purposes in building operations.
C1.4	GHG emissions from primary energy used for project-related transport
C2 Other Atmospheric Emissions	
C2.1	Emissions of ozone-depleting substances during building operations.
C2.2	Emissions of acidifying emissions during building operations.
C2.3	Emissions leading to photo-oxidants during building operations.
C3 Solid and Liquid Wastes	
C3.1	Solid waste from the construction and demolition process retained on the site.
C3.2	Solid non-hazardous waste from building operations sent off the site.
C3.3	Risk of non-radioactive hazardous waste resulting from building operations.
C3.4	Radioactive waste resulting from building operations.
C3.5	Liquid effluents from building operations that are sent off the site.
C4 Impacts on Project Site	
C4.1	Impact of construction process on natural features of the site.
C4.2	Impact of construction process or landscaping on soil stability or erosion.
C4.3	Recharge of groundwater through permeable paving or landscaping.
C4.4	Changes in biodiversity on the site.
C4.5	Adverse wind conditions at grade around tall buildings.
C5 Other Local and Regional Impacts	
C5.1	Impact on access to daylight or solar energy potential of adjacent property
C5.2	Impact of construction process on local residents and commercial building users.
C5.3	Impact of building user population on peak load capacity of public transport system.
C5.4	Impact of private vehicles used by building population on peak load capacity of local road system.
C5.5	Potential for project operations to contaminate nearby bodies of water.
C5.6	Cumulative (annual) thermal changes to lake water or sub-surface aquifers.
C5.7	Contribution to Heat Island Effect from roofing, landscaping and paved areas.
C5.8	Degree of atmospheric light pollution caused by project exterior lighting systems.
D Indoor Environmental Quality	
D1 Indoor Air Quality and Ventilation	
D1.1	Pollutant migration between occupancies.
D1.2	Pollutants generated by building maintenance.
D1.3	Mold concentration in indoor air.
D1.4	Volatile organic compounds concentration in indoor air.
D1.5	CO2 concentrations in indoor air.
D1.6	Effectiveness of ventilation in naturally ventilated occupancies during cooling seasons.

Category	Issue
D1.7	Effectiveness of ventilation in naturally ventilated occupancies during intermediate seasons.
D1.8	Effectiveness of ventilation in naturally ventilated occupancies during heating seasons.
D1.9	Air movement in mechanically ventilated occupancies.
D1.10	Effectiveness of ventilation in mechanically ventilated occupancies.
D2 Air Temperature and Relative Humidity	
D2.1	Appropriate air temperature and relative humidity in mechanically cooled occupancies.
D2.2	Appropriate air temperature in naturally ventilated occupancies.
D3 Daylighting and Illumination	
D3.1	Appropriate daylighting in primary occupancy areas.
D3.2	Control of glare from daylighting.
D3.3	Appropriate illumination levels and quality of lighting in non-residential occupancies.
D4 Noise and Acoustics	
D4.1	Noise attenuation through the exterior envelope.
D4.2	Transmission of building equipment noise to primary occupancies.
D4.3	Noise attenuation between primary occupancy areas.
D4.4	Appropriate acoustic performance within primary occupancy areas.
D5 Control of electromagnetic emissions	
D5.1	Electromagnetic emissions
E Service Quality	
E1 Safety and Security	
E1.1	Construction safety.
E1.2	Risk to occupants and facilities from fire.
E1.3	Risk to occupants and facilities from flooding.
E1.4	Risk to occupants and facilities from windstorms.
E1.5	Risk to occupants and facilities from earthquake.
E1.6	Risk to occupants and facilities from use of explosive devices.
E1.7	Risk to occupants from incidents involving biological or chemical substances.
E1.8	Occupant egress from tall buildings under emergency conditions.
E1.9	Maintenance of core building functions during power outages.
E1.10	Personal security for building users during normal operations.
E2 Functionality and efficiency	
E2.1	Appropriateness of type of facilities provided for tenant or occupant needs.
E2.2	Functionality of layout(s) for required functions.
E2.3	Appropriateness of space provided for required functions.
E2.4	Appropriateness of fixed equipment for required functions.
E2.5	Provision of exterior access and unloading facilities for freight or delivery.
E2.6	Efficiency of vertical transportation system.
E2.7	Spatial efficiency.
E2.8	Volumetric efficiency.
E3 Controllability	
E3.1	Effectiveness of building management control system.
E3.2	Capability for partial operation of building technical systems.
E3.3	Degree of local control of lighting systems.
E3.4	Degree of personal control of technical systems by occupants.
E4 Flexibility and Adaptability	
E4.1	Ability for building operator or tenant to modify building technical systems.
E4.2	Potential for horizontal or vertical extension of structure.

Category	Issue
E4.3	Adaptability constraints imposed by structure or floor-to-floor heights.
E4.4	Adaptability constraints imposed by building envelope and technical systems.
E4.5	Adaptability to future changes in type of energy supply.
E5 Optimization and Maintenance of Operating Performance	
E5.1	Operating functionality and efficiency of key building systems.
E5.2	Adequacy of the building envelope for maintenance of long-term performance.
E5.3	Durability of key materials
E5.4	Existence and implementation of a maintenance management plan.
E5.5	On-going monitoring and verification of performance.
E5.6	Retention of as-built documentation.
E5.7	Provision and maintenance of a building log.
E5.8	Provision of performance incentives in leases or sales agreements.
E5.9	Level of skills and knowledge of operating staff.
F Social, Cultural and Perceptual Aspects	
F1 Social Aspects	
F1.1	Universal access on site and within the building.
F1.2	Access to direct sunlight from living areas of dwelling units.
F1.3	Visual privacy in principal areas of dwelling units.
F1.4	Access to private open space from dwelling units.
F1.5	Involvement of residents in project management.
F2 Culture and Heritage	
F2.1	Compatibility of urban design with local cultural values.
F2.2	Provision of public open space compatible with local cultural values.
F2.3	Impact of the design on existing streetscapes.
F2.4	Use of traditional local materials and techniques
F2.5	Maintenance of the heritage value of the exterior of an existing building.
F2.6	Maintenance of the heritage value of the interior of an existing building.
F3 Perceptual	
F3.1	Impact of tall structure(s) on existing view corridors.
F3.2	Quality of views from tall structures.
F3.3	Sway of tall buildings in high wind conditions.
F3.4	Perceptual quality of site development.
F3.5	Aesthetic quality of building exterior.
F3.6	Aesthetic quality of building interior.
F3.7	Access to exterior views from interior.
G Cost and Economic Aspects	
G1 Cost and Economics	

Appendix J - **Overview of Building Functionality and Performance Aspects**

(source: deWilde., 2018, [ref.1])

Building performance aspects and verbs that can be used to turn each performance aspect into a building functionality requirement. The list also shows the type of performance requirement would be asked for, if the respective function was required from a building (e.g., quality, workload capacity, readiness, etc.).

Aspect	Verb (aspect ▸ function)	Performance requirement
1. Occupant satisfaction	provide	quality
2. Continuity of service	provide	quality
3. Thermal comfort	maintain	quality
(a) Air temperature	control	quality
(b) Radiant temperature	control	quality
(c) Air velocity	control	quality
(d) Relative humidity	control	quality
(e) Air speed	control	quality
(f) Overheating	prevent	quality
(g) Undercooling	prevent	quality
(h) Wind chill	prevent	quality
4. Acoustical comfort	maintain	quality
(a) Speech intelligibility	provide	quality
(b) Reverberation times	control	quality
5. Visual comfort	maintain	quality
(a) Glare	prevent	quality
(b) Flickering	prevent	quality
6. Olfactory comfort	maintain	quality
(a) Odour	control	quality
7. Indoor air quality	maintain	quality
(a) Smoke, fumes, stale air	dispose of	quality
(b) Fresh air	provide	quality
8. Structural integrity	maintain	quality

Continued on next page

Aspect	Verb (aspect ▶ function)	Performance requirement
9. View to the outside	provide	quality
(a) Outside world	provide connection with	quality
(b) Circadian rhythm	support	quality
10. Identity	provide	quality
11. Privacy	provide	quality
12. Inclusivity	support	quality
13. Relative humidity	control	quality
14. Vibration	protect from/limit	quality
15. Noise	protect from/limit	quality
16. Glare	protect from/limit	quality
17. Precipitation	keep out	quality
18. Ground/surface water	keep out	quality
19. Unwanted visitors/vermin	keep out	quality
20. Outdoor pollutants	keep out	quality
21. Electricity/gas/water	provide uninterrupted supply	quality
22. Drainage/sewerage	provide safe and adequate	quality
23. Wayfinding	support	quality
24. Wind flow around building	control	quality
25. Condensation	prevent	quality
26. Contamination	prevent	quality
27. Complaints	minimize number of	quality
28. Fire ignition	prevent	quality
29. Fire spread	prevent	quality
30. Congestion, crowding	prevent	quality
31. Community	provide sense of	quality
32. Historical significance	have	quality
33. Local and national heritage	contribute to	quality
34. Income/revenue	generate	workload capacity
35. Key processes/work	enable	workload capacity
36. Productivity	enable	workload capacity
37. Ease of movement/ circulation	provide	workload capacity
38. Structural loading	carry	workload capacity
(a) Dead load (own weight)	resist	workload capacity
(b) Live load (occupants, furniture)	resist	workload capacity
(c) Live load (wind, precipitation)	resist	workload capacity
(d) Cycling loads (fatigue)	resist	workload capacity
39. Heating/cooling	provide	workload capacity

Continued on next page

Aspect	Verb (aspect ▶ function)	Performance requirement
40. Ventilation/fresh air	provide	workload capacity
41. Daylight/sunlight	provide	workload capacity
42. Hot and cold water	supply	workload capacity
43. Artificial lighting	provide	workload capacity
44. ICT connectivity	provide	workload capacity
45. Safety	ensure	resource saving
(a) Falling risk	mitigate	resource saving
(b) Cutting risk	mitigate	resource saving
(c) Risk from machines	mitigate	resource saving
(d) Electrocution risk	mitigate	resource saving
46. Energy	make efficient use of	resource saving
47. Water	make efficient use of	resource saving
48. Material	make efficient use of	resource saving
49. Renewable energy	generate	resource saving
50. Rainwater	harvest	resource saving
51. Waste	minimize	resource saving
52. Local ecosystem	protect	resource saving
53. Rare and endangered species	protect	resource saving
54. Wear and tear	resist	resource saving
55. Decay and rot	resist	resource saving
56. Corrosion	resist	resource saving
57. Construction costs	control	resource saving
58. Construction time	control	resource saving
59. Operational costs	control	resource saving
60. Cleanability	provide	resource saving
61. Maintenance and repair	efficiently provide	resource saving
62. Greenhouse gas emissions	limit	resource saving
63. Access control	provide	responsiveness
64. HVAC control	provide	responsiveness
65. Lighting control	provide	responsiveness
66. Darkness	provide	responsiveness
67. Solar radiation	control	responsiveness
68. Urban context	respond to	responsiveness
69. Site conditions	respond to	responsiveness
70. Outside hours access	allow	responsiveness
71. Modifications to building	allow	responsiveness
72. Service life	manage	responsiveness
73. Fire/smoke alarm	raise	readiness
74. Intrusion alarm	raise	readiness
75. Evacuation	allow	readiness
(a) Evacuation route	provide	readiness
(b) Evacuation time	allow	readiness
(c) Survival time in refuges	guarantee	readiness

Continued on next page

Aspect	Verb (aspect ▸ function)	Performance requirement
76. Burglary	resist	readiness
77. Vandalism	resist	readiness
78. Extreme events	resist	readiness
(a) Fire (smoke and heat)	minimize impact of	readiness
(b) Explosion	minimize impact of	readiness
(c) Radioactivity spread	minimize impact of	readiness
(d) Poisonous substance spread	minimize impact of	readiness
(e) Heat waves	cope with	readiness
(f) Cold spells	cope with	readiness
(g) Natural disasters	resist	readiness
(h) Human-made disasters	resist	readiness
79. Disease and infection	stop spreading of	readiness
80. Buildability	provide	readiness
81. Flexibility	possess	readiness
82. Disposability	provide	readiness
83. Aesthetics	consider	aesthetics
(a) Architectural statement	make	aesthetics
(b) Creativity	demonstrate	aesthetics
(c) Interpretation	require	aesthetics
(d) Communication	engage in	aesthetics
(e) Embodiment	represent	aesthetics
(f) Image	portray	aesthetics
(g) Eloquence in composition	demonstrate	aesthetics
(h) Enchantment	instil	aesthetics
(i) Movement	suggest	aesthetics
(j) Structural elegance	express	aesthetics

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A literature review was conducted to identify methodologies that could be used to evaluate the functional suitability of the Department of National Defence real property assets. Suitability indicators communicate how well a building contributes to its occupants' efficiency to achieve their work objectives and goals, by identifying the gap between a building's desired state (as defined by the user requirements) and its actual state. The literature review found that organizations use various criteria and indicators when conducting suitability assessments of their facilities, which depend on their missions and goals. This report provides an overview of the many possible building functions that may be selected, supporting the identification, ranking and prioritization of those aspects that are the most relevant for an organization. The report also describes two existing methodologies that can be readily applied and consulted for guidance when evaluating a building's functional suitability, and when establishing the functional priorities and budget allocations for modernization over a building's life-cycle. These methodologies are: (1) the American Society for Testing and Materials (ASTM) Standards for Whole Building Functionality and Serviceability, which cover a broad range of user requirements and related building functions and services; and (2) the BUILDER Sustainment Management System, a software tool developed by the U.S. Army Corps of Engineers, which can be used to identify a building's functional deficiencies based on user and mission requirements.

On a procédé à une analyse documentaire afin de déterminer les méthodes qui pourraient être utilisées pour évaluer la fonctionnalité des biens immobiliers du ministère de la Défense nationale. Les indicateurs de fonctionnalité montrent dans quelle mesure un immeuble permet à ses occupants d'atteindre leurs objectifs de travail en déterminant l'écart entre l'état souhaité d'un immeuble (selon les besoins de l'utilisateur) et son état réel. L'analyse documentaire a révélé que les organisations utilisent divers critères et indicateurs pour évaluer la fonctionnalité de leurs installations, en fonction de leurs missions et de leurs objectifs. Le présent rapport donne un aperçu des nombreuses fonctions possibles des immeubles qui peuvent être sélectionnées, à l'appui de la détermination, du classement et de la hiérarchisation des aspects les plus pertinents pour une organisation. Le rapport décrit également deux méthodes existantes qui peuvent être facilement appliquées et consultées aux fins d'orientation dans le cadre de l'évaluation de la fonctionnalité d'un immeuble, ainsi que dans le cadre de l'établissement des priorités fonctionnelles et des affectations budgétaires aux fins de modernisation au cours du cycle de vie d'un immeuble. Ces méthodes sont les suivantes : 1) les normes de l'American Society for Testing and Materials (ASTM) en matière de fonctionnalité des bâtiments, qui couvrent une vaste gamme de besoins des utilisateurs et de fonctions et services connexes de construction; et 2) le système de maintien en puissance BUILDER, un outil logiciel mis au point par le U.S. Army Corps of Engineers, qui peut être utilisé pour cibler les lacunes fonctionnelles d'un bâtiment en fonction des besoins des utilisateurs et des exigences de mission.