# Guide to Performance Metrics and BIM to support Green Building Objectives

APEC Sub-Committee on Standards and Conformance

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# Guide to
# Performance Metrics and BIM
# for Green Building Objectives

Asia-Pacific
Economic Cooperation

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# 1. Introduction

The *Leaders' Declaration* issued by APEC in 2011 stated that APEC members are committed to advancing their shared green growth objectives, with the aspiration to reduce APEC's aggregate energy intensity by 45% by 2035. In a 2014 APEC workshop on the role of standards and conformity assessment in advancing green building goals, Building Information Modeling (BIM) was acknowledged prominently as an effective tool to inform the design, construction, and operation of greener built environments. The need for relevant metrics was a theme underscored by participants. This guide illustrates a systematic approach leading from green building vision to policy and practical implementation steps useful to economies in promoting the use of BIM to further green building goals.

Identifying the current state of BIM adoption and maturity within an economy is an important early step in this process. The *Start-up Guide for Building Information Modeling (BIM)* published in December 2013 by APEC in collaboration with bimSCORE, Inc. provides specific BIM-supportive actions for economies at each of five stages of BIM adoption as described below, ranging from maintaining *Status Quo* (minimal BIM adoption, with no government policies or support) through *Innovation* (novel and transformative approaches to BIM adoption). The *Start-up Guide* provides general advice at each stage of BIM adoption which is also applicable to support Green Building aspirations through BIM (see: http://publications.apec.org/publication-detail.php?pub_id=1510).

| STATUS QUO | PILOTING | POLICY | INDUSTRY | INNOVATION |
|---|---|---|---|---|
| ⇨ Minimal BIM adoption, no government policies or support | ⇨ Exploring value and implications of implementation for the economy | ⇨ Developing support, incentives, and requirements for BIM by Government or Industry Leaders | ⇨ Wide adoption of BIM and ready to spread best practices and benefits | ⇨ Leading development of new capabilities and extending the value of BIM |

BIM–supportive Actions:

| | | | | |
|---|---|---|---|---|
| ⇨ Benchmark current productivity to other economies<br>⇨ Compare the cost of BIM enablement to the cost of maintaining status quo | ⇨ Invest in case studies and pilot projects<br>⇨ Align pilot project targets to strategic goals<br>⇨ Assess each approach and benefit | ⇨ Formalize realistic and enforceable policies at agency and economy-wide levels<br>⇨ Support repeatable and measurable gains | ⇨ Harmonize leadership and grassroots efforts<br>⇨ Encourage with support, rewards, and mandates<br>⇨ Identify and adopt BIM standards and technologies | ⇨ Consider both evolutionary and revolutionary transformation<br>⇨ Establish global strategic partnerships |

This Guide expands and extends the scope of the *Start-up Guide* with special emphasis on the value of BIM to improve Green Building outcomes, and support the standardization and measuring of Green Building accomplishments. It provides further guidance for selection and development of policies, programs, standards, technologies, and tracking mechanisms specific to support Green Building initiatives.

Selection of content for this guide was informed by responses to a recent survey of APEC economies related to BIM and Green Building. Results indicated that the most valuable and effective guidance to improving Green Building outcomes should focus on creating policies for resource use and conservation, establishing education and training programs, and leading pilot or demonstration projects. Economies responding to the survey also identified the five most important Green Building Benefits. These five benefits guided selection of examples, observation, and advice presented in this guide, and provided a secondary framework for analysis presented in several sections. The Icons to the left of each benefit are used to key relevant items throughout this document.

Reduction of Energy Use

Reduction of $CO_2$ Emissions


Reduction of Water Use / Increased use of Recycled Water


Increased use of Recycled and Recyclable Building Materials & Reduction of Waste


Increased use of Renewable Energy

In order to further Green Building achievements, this guide will provide a **conceptual overview and survey** of Green Building and BIM programs to demonstrate the value of aligning strategic objectives, policies, standards, technologies, performance metrics, and educational programs, building a broad base of support among government, business, education, and industry. Implementation examples are used throughout this guide, with additional references and examples in an included appendix, to illustrate concepts and inspire development of individualized responses for each economy.

This guide is organized in sections to serve several purposes:

1. ***Introduction*** – background and explanation of the relationship between the key elements presented in the balance of the guide.
2. ***Objectives & Success Metrics*** – documentation of goals to achieve, how achievement will be measured, and the targets for success. This section includes examples of objectives established by some economies and observations on implementation.
3. ***Policies*** – examples of approaches to achieve goals, by mandate or suggestion, with examples of policies established by some economies and observations on their implementation.
4. ***Standards, Rating Systems, and Guidelines*** – definitions, measurement systems, and processes to bring uniformity and repeatability to Green Building efforts. Standards also facilitate reliable data communication and credible comparison of performance results.
5. ***BIM Applications & Integration*** – a categorized inventory of BIM-related capabilities and applications useful in achieving these outcomes. The importance of data standards and interoperability are also detailed in this section.
6. ***Metrics & Key Performance Indicators*** – references and examples of performance measurement to track and report Green Building and BIM effectiveness and outcomes.
7. ***Education*** – the role of education in successful Green Building and BIM programs, and elements of successful education programs.
8. ***Conclusion*** – a summary outline Key Steps to Achieving Green Building Success and

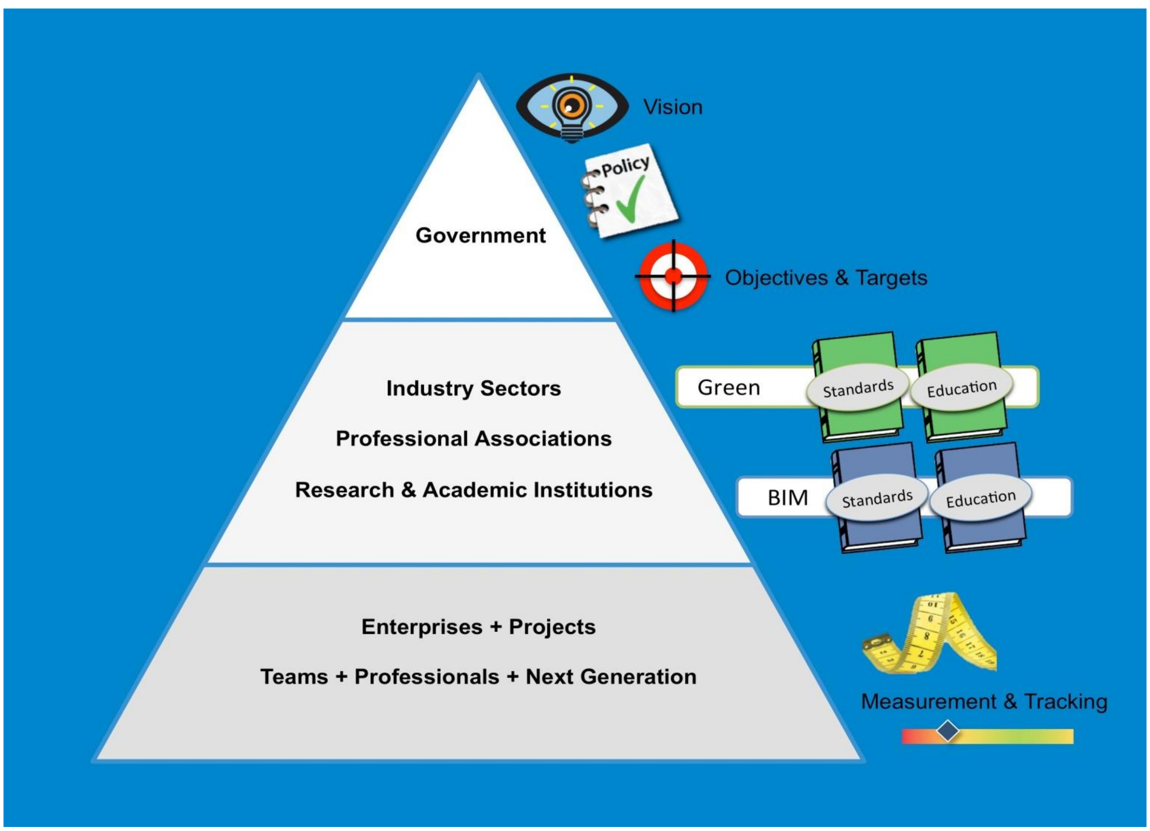
Integration with BIM Technologies.

A successful BIM for Green Building program will begin with a well-articulated **Vision** aligned with the economy's strategic goals. Economy leaders are in the best position to develop and promote visions related to BIM and Green Building, and to support these with **Policies** including measurable and quantifiable **Objectives** with **Targets** indicating expected achievements.

**Standards,** methodologies, and processes are necessary to provide uniform terminology and reference frameworks to facilitate development and implementation of BIM and Green Building efforts. **Educational Programs** established through Industry Sectors, Professional Organizations, and Academic Institutions will promote thoughtful approaches to achieving Green Building goals and will propagate the required skill sets throughout professionals in the industry.

**Measurement and tracking** of actual accomplishments used to report progress toward Green Building Goals will best be accomplished through Enterprises (firms and agencies) and project teams engaged in designing, constructing, and operating built environment.

These components create a pyramid of coordinated actions topped by government leadership, supported by industry and academic leaders, and a broad base of support from enterprises, project teams, and the next generation of trained professionals. Such a holistic ecosystem of support can form the basis to guide, inform, incentivize, regulate, monitor, and manage an integrated approach to leverage BIM for Green Building efforts on an economy-wide scale.



# 2. Objectives & Metrics

Whether driving for ambitious revolutionary approaches or incremental improvement for a greener environment, it is important that objectives be represented by transparent, quantifiable, and consistent success metrics. Defining key performance indicators that can be regularly and reliably tracked is essential to ensure that the achievement of objectives, and success metrics used to track these, are verifiable and reportable.

Key Performance Indicators may be tracked as “leading” and “lagging” indicators. Leading or *process-related* indicators may track planned steps along the way to achieving Green Building outcomes such as adoption of mandatory policies and standards, or diversity in types of BIM-related predictive analyses successfully employed. Leading indicators are frequently used to inform management decisions and improve performance during project execution. Lagging or *outcome-related* indicators may track ultimate results such as total energy consumption or total water use, quantities usually known after implementation of a program or sustained operation of a building.

Some government agencies and project teams choose to report results through publically accessible documents, or website dashboards displaying real-time figures showing energy consumption, renewable energy generation, water usage and collection, CO2 emissions, and other factors relevant to their overall resource and ecology management programs.

The following five examples illustrate how some economies have defined objectives. Each includes discussion of how the objectives may be achieved. While all of the examples are primarily stated in terms of lagging (outcome) indicators, leading (process) indicators could easily be established to track progress with actions intended to contribute to achievement of objectives. For example, tracking development of district heating and biofuel programs in Example 1 could provide leading indicators of progress toward reduction of CO2 Emissions.

| Objective Example | Leading Indicators | Lagging Indicators | Level of Target | Success Metric (Numerical/ Notional) | Target Year to Achieve | Energy Reduction | CO2 Emission Reduction | Water Use Reduction | Recycled & Recyclable Content | Renewable Energy |
|---|---|---|---|---|---|---|---|---|---|---|
| Objective #1 | possible | x | typical | numerical | 2020 | | x | | | |
| Objective #2 | possible | x | typical | numerical | 2030 | x | | | | |
| Objective #3 | possible | x | ambitious | numerical | 2020 | | | | | x |
| Objective #4 | possible | x | aggressive | numerical | 2030 | | | x | | |
| Objective #5 | possible | x | Innovative | numerical | 2020 | | | | x | |

### Green Objective Example 1: Reduction of $CO_2$ Emissions

**Target:** Reduce greenhouse gases emission such as carbon dioxide to 20% by 2020[Typical example]

**Observations:**

- If somewhat advanced approaches are used such as district heating, heat pumps, and biofuels instead of oils by housing and service sector, then a 20% target is achievable.
- If technologies like carbon capture and sequestration are used, then a 30% target is possible.
- A more ambitious objective of fossil fuel-free transport can help achieve a target of 35% to 40% reduction of greenhouse gas emission by 2020 or 2030.

### Green Objective Example 2: Reduction of Energy Use

**Target:** 30% reduction in energy consumption by 2030 [Typical example]
**Observations:** The target can be more aggressive, e.g. 40% to 45% reduction in energy consumption by 2030 through the following steps:

- Improve processes to reduce wasted energy (e.g. design, construction, and operation for increased efficiency) and capture recoverable energy while keeping output constant.
- Employ standardized monitoring and verification processes so that the information received can be related back to individual activities to identify opportunities that promote energy efficiency improvements. Several monitoring technologies are ready for commercial and residential implementation.

### Green Objective Example 3: Increased use of Renewable Energy

**Target:** Increase renewable energy share to total energy consumption to 40% by 2020 [Ambitious]
**Observations:** Note that reliance on "renewable" energy compliments, and does not eliminate, policies regarding reduction of total energy use. This ambitious target is achievable through:

- Use of natural renewable energy source(s) on site as much as would be practical (hydroelectric power, wind, solar and geothermal).
- Processing wastes, wood residues, and black liquor to produce electricity.
- Use of biomass and biofuels in district heating schemes and transport sector.

### Green Objective Example 4: Reduction of Water Use / Increased use of Recycled Water

**Target:** 20% of "wastewater" processed for reuse 2030 [Aggressive target]
**Observations:** More aggressive targets are possible:

- In addition to reusing water for agricultural, drinking and household purposes, recycled water can be used in industries through the following measures. This can help in achieving a target of reusing recycled wastewater to 25% by 2030.
    - New heavy and general industrial areas to investigate the installation of a third pipe to distribute recycled water, commonly referred to as "purple pipe system".
    - Where feasible and cost effective, existing heavy industrial areas should be retrofitted to facilitate the use of recycled water.
- The following actions can further elevate the target to 30% reuse of recycled water by 2030:
    - Incorporate water consumption constraints during construction, energy conservation, and industry planning.
    - Integrate energy water infrastructure by running different scenarios to assess how energy sector development strategies change relative to the reference scenario if water is a constraint.
    - Explore brackish and saline water options.
    - Strengthen independent accountability mechanisms of water usage for more transparent performance monitoring.

### Green Objective Example 5: Increased use of Recycled and Recyclable Building Materials & Waste Reduction

**Target:** recycle 50% of municipal waste and 70% of construction waste by 2020 [Ambitious target and innovative steps]
**Observations:** This is an ambitious target, but it can be achieved through a combination of practices:

- Forecast and quantify construction and demolition (C&D) wastes
- Follow the waste hierarchy: 1] prevention, 2] preparing for recycling, 3] reusing, 4] other methods, 5] disposal
- With waste prevention being at the top of the hierarchy, the reduction and reuse of building materials should also be addressed more specifically, through the promotion of increased material efficiency, eco-design of buildings (particularly design to reduce the need for deconstruction), and reuse of building parts.
- Levy taxes on resource extraction that contributes to the price increase of primary raw materials and make recycling more competitive.
- Turn waste into a valuable raw material achieved through quality certification of secondary raw material from C&D waste.
- Encourage the sorting of C&D waste “at source”
- Selective demolition / controlled deconstruction in the systematic removal of contaminants prior to demolition, as well as the sorting of different building materials, should be encouraged and generalized.

# 3. Policies

Policies in sustainable design, green building, and BIM are strongest when expressed in enforceable terms with realistically attainable targets, well-defined success metrics, credible benchmarks, and clear implementation timelines. While policies may be mandatory or advisory in nature, most outlined below are required only when certain conditions apply, as in example 4 where use of BIM--enabled analysis may be required only for government-funded buildings. Funding and incentives are also used to drive policy, as in example 1.

| Policy Example | Mandatory | Coupled with Regulations | Success Metrics | Target Year to Achieve | Energy Reduction | CO2 Emission Reduction | Water Use Reduction | Recycled & Recyclable Content | Renewable Energy |
|---|---|---|---|---|---|---|---|---|---|
| Policy #1 | x | x | numerical | 2020 | | | | | x |
| Policy #2 | x | x | numerical | 2030 | | x | | | |
| Policy #3 | x | x | numerical | 2020 | | x | | | |
| Policy #4 | | x | notional | ongoing | x | | | | x |

### Policy Example #1: Increased use of Renewable Energy

This economy’s policy sets ambitious targets for developing renewable energy resources with a major introduction of laws and incentives. Some of the accomplishments under this policy include achieving targets set for:

- Wind power sector (installed wind power capacity rose from 0.567 GW in 2003 to 91 GW in 2013 and targets to install 200 GW by 2020);

- Solar photovoltaic (PV) power sector (installed solar PV capacity rose from 0.14 GW as of 2009 to over 19 GW in 2013 and targets to install 50 GW by 2020); and
- Hydropower capacity (doubling hydropower capacity to 380 GW by 2020 compared to 200 GW in 2013).

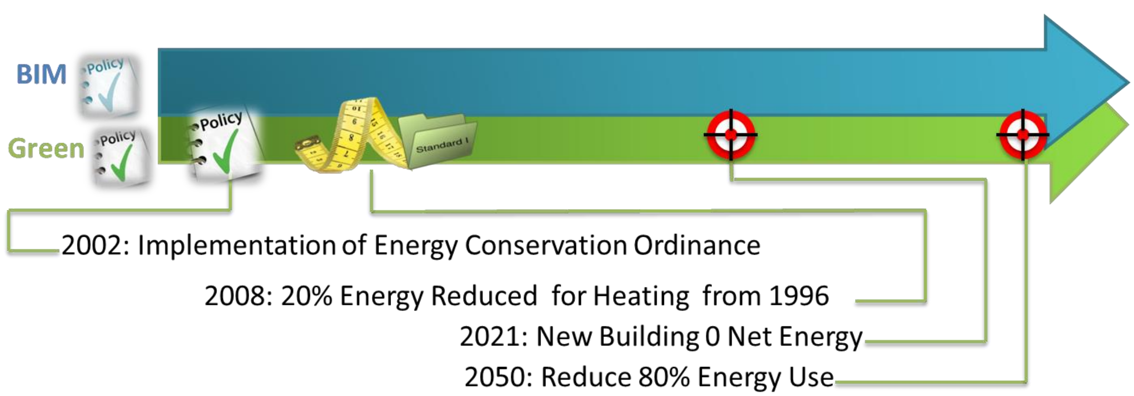
**Discussion:** Although the set targets for renewable energy are being met and exceeded in some cases, not all of the power generated is used to meet energy consumption needs. For example, approximately 18% of wind power capacity was not connected to the power grid in 2013. As a result, the ability to deliver electricity generated through wind power to consumers will depend upon improvements to the power grid.

**Policy Example #2: Reduction of CO2 Emissions**

One global economy sets targets for green-house gas emissions to be cut by at least 80 % by 2050 compared to levels in 1990, using renewable energy sources to supply the bulk of energy in the future. This economy also set a target for energy consumption to be reduced considerably and energy efficiency increased.

**Observations:**

- Significantly reduced transport-related GHG emissions (by 15.8% in 2000-10) while transport activity increased (decoupled greenhouse gas (GHG) emissions from economic growth)
- The use of renewable energy sources more than tripled in the last decade, and accounted for 10% of primary energy supply.
- Achieved high levels of resource productivity due to structural changes and reduction of domestic extraction of construction materials.
- An effective waste management policy resulted in about three-quarters of total and municipal waste to be pre-treated and sent for recovery, while 63% of municipal waste was recycled.
- The development and diffusion of renewable energy technology are supported by targeted research and development measures. Innovation in wind and solar renewable energy technologies has increased sharply.




| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| 2000 | 2003 | 2006 | 2009 | 2012 | 2015 | 2018 | 2021 | 2024 | 2027 | 2030 & onwards |

**Observations:** Comparing 2008 results to 1996 benchmarks, this economy found 20% reduction in energy consumed for heating in all building types, yet energy consumption for other uses had increased, creating an overall reduction in energy use of 8%. Coupling this policy with initiatives for BIM-empowered analysis to improve the energy performance of the built environment, monitor and report energy use on an ongoing basis, and improve management of resource consumption of buildings during operation, could help improve overall results.

**Policy Example #3: Reduction of CO2 Emissions** plus other environmental concerns

This policy set by a major global economy aims to reduce negative environmental effects, notably in the areas of: greenhouse gas emissions, urban air pollution, climate change, biodiversity, marine environment, and waste management. The policy targets reduction of global greenhouse gas emissions by 30% compared to levels in 1990 by 2020, and to become carbon neutral by 2050.

**Observations:**

- Meeting the 2050 carbon neutral target will be challenging, because both the economy's electricity supply and energy use in buildings are already essentially carbon-free. Hence, the development of technologies for carbon capture and storage (CCS) remains a priority for research and development. Through an innovative approach, 10 million tons of $CO_2$ have been separated in gas production and stored in geological formations 1,000 meters below the seabed.
- Mono-Nitrogen oxides (NOx) Tax: The agreement exempted the main emitters of NOx ($NO$ and $NO_2$) from this tax if they committed to reduce emissions by 30,000 tons to an annual level of 98,000 tons by 2010. NOx emissions have decreased by 10%.
- Developed a technology to capture non-methane volatile organic compounds (NMVOC) emissions from storage vessels and shuttle tankers, with strict regulations requiring use in all vessels.

**Policy Example #4: Reduction of Energy Use** & **Increased use of Renewable Energy**

This policy set by a major global economy aims to reduce energy use. The policy encourages performance of BIM-empowered analysis to inform design of energy efficient buildings for the government portfolio.

**Observations:** This policy is coupled with a broad objective to achieve net-zero building energy performance, buildings which use no more energy than they produce, by 2030, and a plan to more efficiently manage the government's existing building stock.

# 4. Standards, Rating Systems & Guidelines

Standards, Rating Systems, and Guidelines play a vital role in establishing uniform nomenclature, measurement systems, and processes useful in coordinating communication and information sharing, establishing meaningful benchmarks and performance comparisons, and achieving repeatable processes and results. Such standards are essential in verifying conformance with voluntary and mandatory green building requirements. The three standards referenced below treat multiple environmental concerns in a consistent way to aid in analysis, simulation, prediction, and reporting of Green Building achievements. Each example focuses on a different aspect of the process to achieve Green Building goals.

**Example #1: Multiple Environmental Concerns** – A Building **Design guide** focused on means and methods for building analysis, and expected outcomes. This guide provides assessment criteria in determining the level of environmental performance of a building and is applicable to new buildings and related building systems. Some important features of this standard are:

- Requirement to use ventilation simulation modeling and analysis or wind tunnel testing.
- Use of daylight and glare simulation software to optimize day lighting and reduce energy use for artificial light.
- Acoustic analysis to know whether design is meeting the ambient sound levels.
- Simulation analysis of the building cooling load profile to calculate system efficiency.
- Complete building energy analysis.
- Encourage use of innovative energy-efficient features.

**Example #2: Multiple Environmental Concerns** – A Green Building Checklist based on a credit system for specific Green Building functions and remedies. This rating system has become a thriving business paradigm promoting sustainability in the building industry; it provides performance guidelines for the following building types: new construction, existing building, operation and maintenance core and shell, commercial interior, and homes. Comprehensive documentation is required to facilitate communication, support claim for credit compliance, and review and award certification.

- More than 30% of credits can be assessed through BIM and BIM-enabled analysis such as sustainable site selection, public transport access, heat island effect, water use reduction, recyclables handling, minimum indoor air quality, daylighting analysis, and thermal analysis.
- Credits assigned for Innovation to recognize projects for innovative building features and sustainable building practices and strategies.

**Example #3: Multiple Environmental Concerns** – A BIM implementation guide focused on ecological performance

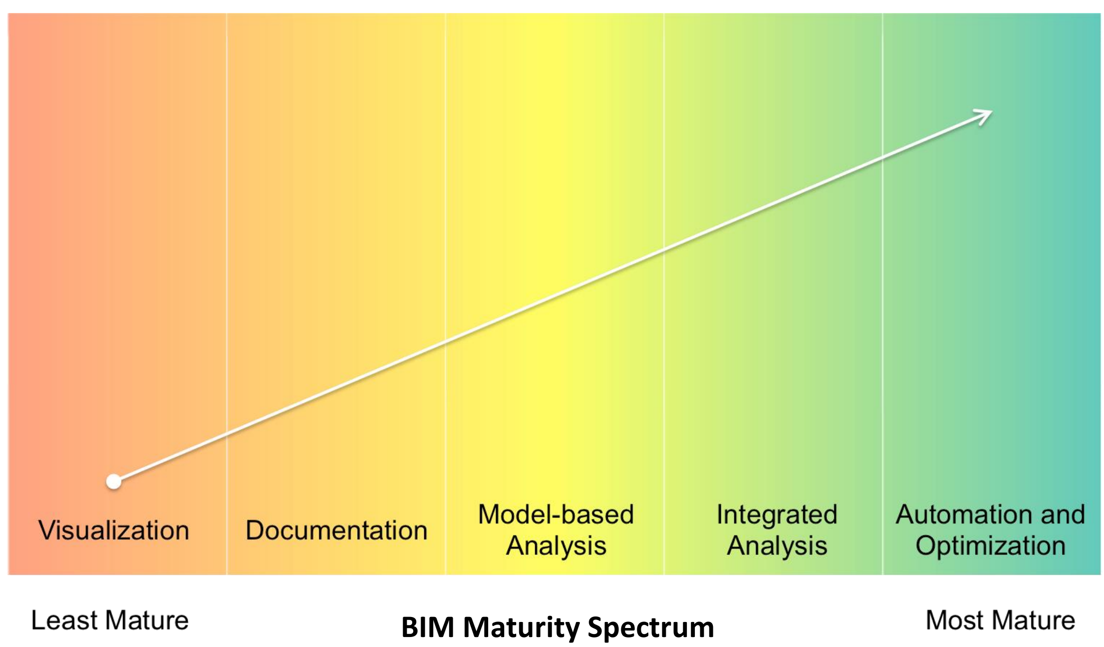
This standard was established to provide processes for facilities to reduce energy usage and achieve a number of energy and water management goals. To meet these goals, the standard explores the use of BIM in energy modeling practices to strengthen the reliability, consistency, and usability of predicted energy use and energy cost results.

- Manages expectations when interpreting the results of energy models and requires different depth of energy analysis during different project phases: concept design, design development, construction documentation, construction, and operation.
- Explores the use of BIM in achieving following goals: reduce annual energy consumption, improve lifecycle analysis, and improve processes to achieve high performance buildings.
- Provide best practices for leveraging BIM data for energy simulations.

# 5. BIM Applications & Integration

Advances in BIM applications and related technologies have empowered policy makers, public officials, owners/operators, urban planners, building designers, contractors, and the public to test numerous approaches in the virtual world where costs are small, and consequences low and easy to mitigate, before committing major resources in the real world, where costs are greater and consequences are manifest and more difficult to manage. Leveraging BIM, economies and project teams can simulate and predict building performance with respect to occupants, energy, water, and materials in compliance with product, system, and BIM standards. Integrated with sensors and meters, performance models can be compared with actual performance during operation, and used to manage buildings do achieve or exceed the expected outcomes and benefits.

The BIM and Virtual Design and Construction (VDC) Scorecard research done by the Center for Integrated Facility Engineering (CIFE) of Stanford University, U.S.A, categorizes BIM applications into five groups based upon key functions and arranged on a **BIM Maturity Spectrum** illustrated below. Functions at the lower end of the spectrum can be quite useful to improve understanding of design, construction, and operations for facilities, and there are many applications available to meet these needs. Functions at the higher end of the spectrum can be even more beneficial in the effort to achieve Green Building goals, yet few applications are currently available to support these functions.




**BIM Maturity Spectrum**

The following **matrix of BIM applications** lists applications under their respective level on the BIM maturity spectrum, and indicates which of the five Green Building Benefits it most directly supports.

Note that some applications can be useful in the consideration of several different Green Building benefits or objectives. It is also true that one objective may require the support of multiple BIM applications. Taking "*Energy Reduction"* and "*CO2 Emission Reduction"* as examples, many applications can be used to plan and design facilities and infrastructures that consume less energy during operation phase, and thus emit less $CO_2$. Additional analyses can inform means to further reduce energy used during construction, and the embodied carbon within the building materials and products, e.g. *Land Cut and Fill Analysis, Model-based Quantity Takeoff and Life Cycle Analysis*.

Additional columns in the chart indicate at which project phases, from initial conception through facility operation, each application will typically be of most use. This information is provided to help plan timing for introduction of each BIM-related application, and also give some understanding of which stakeholders might need to use each application. For example: *Massing Model Studies* are used early in design by Design team, Lifecycle Analysis is used throughout the project for all stakeholders including owners and operators).

| **BIM Applications** | **Green Building Benefits** | | | | | **Project Phases** | | | |
|---|---|---|---|---|---|---|---|---|---|
| | Energy Reduction | $CO^2$ Emission Reduction | Water Use Reduction | Recucled & Recyclable Content | Renewable Energy | Planning & Conception | Design | Construction | Operation |
| **Visualization** | | | | | | | | | |
| Mass Model Study | ● | ● | | | ● | ● | ● | | |
| Preliminary Infrastructure Model (e.g. Utilities) | ● | ● | | | ● | ● | ● | | |
| **Documentation** | | | | | | | | | |
| Quantity Takeoff (Materials & Labor Required) | | ● | ● | ● | ● | ● | ● | ● | |
| Model---based Product Specifications | | ● | | ● | | | ● | ● | |

| BIM Applications | Green Building Benefits | | | | | Project Phases | | | |
|---|---|---|---|---|---|---|---|---|---|
| | Energy Reduction | $CO^2$ Emission Reduction | Water Use Reduction | Recucled & Recyclable Content | Renewable Energy | Planning & Conception | Design | Construction | Operation |
| **Model-based Analyses** | | | | | | | | | |
| Macro and Micro Climate Analyses | ● | ● | | | ● | ● | ● | | |
| Heat Island Analysis (urban / industrial area heat pockets) | ● | ● | | | | ● | ● | | |
| Exterior Shadow & Solar Radiation Analyses | ● | ● | | | ● | ● | ● | | |
| Whole Building Energy Analysis | ● | ● | | | | ● | ● | | ● |
| Detailed Energy Analysis | ● | ● | | | | | ● | | ● |
| Heating and Cooling Load Analysis | ● | ● | | | | | ● | | |
| Interior Thermal Comfort | ● | ● | | | | | ● | | |
| Daylighting & Artificial Lighting Analysis | ● | ● | | | | | ● | | |
| Natural Ventilation Analysis | ● | ● | | | | | ● | | |
| Rainwater Harvesting Analysis* | | | ● | | | | ● | | |
| Storm Water Management Analysis | | | ● | | | | ● | | |
| Water Consumption Analysis* | | | ● | | | | ● | | |
| Landscape Irrigation Analysis* | | | ● | | | | ● | | |
| Land Cut and Fill Analysis | | ● | | | | ● | ● | ● | |

| BIM Applications | Green Building Benefits | | | | | Project Phases | | | |
|---|---|---|---|---|---|---|---|---|---|
| | Energy Reduction | $CO^2$ Emission Reduction | Water Use Reduction | Recucled & Recyclable Content | Renewable Energy | Planning & Conception | Design | Construction | Operation |
| **Integrated Analyses** | | | | | | | | | |
| Integrated Infrastructure Planning | ● | ● | | | ● | ● | ● | | |
| Lifecycle Analysis (Cradle to Cradle) | | ● | | ● | | ● | ● | ● | ● |
| Passive System Analysis | ● | ● | | | ● | ● | ● | | |
| Green Building Certification, Energy Code Compliance | ● | ● | | ● | ● | ● | ● | ● | |
| **Automation & Optimization** | | | | | | | | | |
| Automatic Mechanical System Balancing & Sizing | ● | ● | | | | | ● | | |
| Building Automation & Monitoring Systems | ● | ● | | | | | | ● | ● |
| BIM-enabled Off-site Fabrication | | ● | | ● | | | ● | ● | |
| Smart Building/Smart Metering | ● | ● | ● | | ● | | | ● | ● |
| Multi-Disciplinary Design Optimization (MDO) | ● | ● | ● | | ● | ● | ● | | |

** Few or no software applications directly harness model-based workflows for these BIM applications.*

Employing BIM applications and technologies during appropriate project phases will result in greater gains in performance outcomes, for example:

- During **Planning and Conception**:
    - Explore various combinations of orientations, densities, shapes and functional arrangements through mass model studies in BIM (use of low level of detail models representing the basic shape and volume of the building to analyze energy performance).
- During **Design**:
    - Inform the assessment of design options with model-based analyses results, such as Overall Building Energy and Micro Climate analyses, and guide the design direction with the green benefits in mind.
- During **Construction**:
    - Use BIM-based sequencing and resource management applications to optimize construction resources while reducing waste and re-work.
    - Enhance models with accurate as-delivered information for BIM-enabled facility maintenance systems.
- During **Operatio**n:
    - Use BIM-enabled facility management systems to monitor performance, assure proper maintenance of building and equipment, and operate the facility at peak efficiency.
    - Publish building performance metrics through online dashboards for continual monitoring.

**Interoperability** is the ability to coordinate efforts and share data between various analysis, simulation, and automation tools, and is key to leveraging BIM for the attainment of Green Building objectives. Interoperability between BIM authoring, performance analysis, and facility operation tools, especially interoperability achieved through use of open standards, supports the use and re-use of information throughout the building life cycle, and also guards against reliance on a single proprietary system to access important information.

Although **several workable international standards exist** to support application interoperability, such as Industry Foundation Class (IFC), Extensible Markup Language (XML), Green Building Markup Language (gbXML) and others, industry has not yet fully adopted and implemented these standards. As a result, frequent instances of data inaccessibility, corrective re-work, and lost opportunities are experienced during project design, delivery and operation.

**The use of international standards facilitates trade and economies that are WTO members are obligated to use relevant international standards where they exist.** Government representatives may also participate in bodies which are developing open standards in this area. There are several examples worldwide of governments individually and in alliance with one another developing policies, standards, and mandates requiring the use of open data standards to streamline workflows and protect long-term accessibility of data.

# 6. Metrics & Key Performance Indicators

Given the vast number of proven and emerging BIM technologies, workflows, and applications to support green building objectives, economies and policy makers should carefully evaluate the investments and benefits of BIM-based approaches before advocating or standardizing their adoption. Defining metrics and key performance indicators that can be accurately and reliably tracked provides objective insight into the performance of BIM processes, and gives a means of verifying that investments in BIM are achieving positive return in supporting overarching green building objectives.

Similar to the overall objectives and metrics for green building, BIM-specific metrics may be tracked as "leading" and "lagging" indicators, and depending on the level of automation in collecting data and evaluating BIM processes, may also be displayed and made accessible in performance dashboards providing an executive overview of BIM performance.

Below are proposed BIM metrics to aid in assessing the value of BIM-based tools and processes to each of the major green building objectives described throughout this document. These metrics and their measured performance can be collected via industry surveys, and will inform economy and policy-level decisions regarding BIM adoption and standardization efforts. Similar to the evaluation of Green Objectives, Success Metrics, and Policies as outlined in prior sections, economies shall ensure that their BIM metrics are measurable and built upon benchmarks that are attainable in their local contexts.

**Green Objective Example 1: Reduction of greenhouse emissions**

| Metric | Example Target | Indicator Type | Data Collection Method | Frequency of Evaluation |
|---|---|---|---|---|
| # of Design Alternatives Evaluated for Carbon Footprint | 5 per project | Leading | Manual tracking | Once per project |
| % Objects with Attributes for Carbon Footprint Analysis | 75% of BIM objects | Leading | Collect/track in model object schedule | At major design milestones, more frequent during early design |
| % Reduction in Estimated Carbon Footprint from Baseline Design | 15% | Lagging | Software output | At major design milestones, more frequently during early design |

**Green Objective Example 2: Reduction of energy use**

*and*

**Green Objective Example 3: Increased use of renewable energy**

| Metric | Example Target | Indicator Type | Data Collection Method | Frequency of Evaluation |
|---|---|---|---|---|
| # Alternatives Evaluated for Energy Use | 5 per project | Leading | Manual tracking | Once per project |
| % of Objects with Attributes for Energy Analysis | 75% of BIM objects | Leading | Collect/track in model object schedule | At major design milestones |
| % Reduction from baseline estimate for Energy Use | 15% reduction | Lagging | Software output | During facility use |
| Time Required for Energy Use Analysis | Less than 15 min. | Lagging | Software output | For typical/average analysis |
| Accuracy of Energy Use Prediction | +/- 20% | Lagging | Software output and actual facility energy use | Average over 3-5 years of building operation |

**Green Objective Example 4: Reduction of water use and increased use of recycled water**

| Metric | Example Target | Indicator Type | Data Collection Method | Frequency of Evaluation |
|---|---|---|---|---|
| # of Design Alternatives Evaluated for Water Use | 5 per project | Leading | Manual tracking | Once per project |
| % of Objects with Required Attributes for Automated Water Use Calculation | 75% of BIM objects | Leading | Collect/track in model object schedule | Once per project |
| Accuracy of Water Use Prediction | + / - 20% | Lagging | Calculate prediction form model object attribute schedule and compare to actual water use | Average of 3-5 years of building operation |

**Green Objective Example 5: Increased use of Recycled and Recyclable Building Materials & Waste Reduction**

| Metric | Example Target | Indicator Type | Data Collection Method | Frequency of Evaluation |
|---|---|---|---|---|
| % of Objects have Attributes for Recycled/Reused Material Quantity Takeoff | 75% of BIM objects | Leading | Collect/track in model object attribute schedule | At major design milestones |
| % Compliance with Green Building Material Use Requirements | 100% | Leading/ Lagging | Collect/track in model object attribute schedule | At major design milestones and after completion |
| Accuracy of Green Building Material Quantity Takeoff | +/- 20% from actual material installed | Lagging | Manual or automated comparison | Once per project (compare predicted material quantity to installed quantity) |

# 7. Education

Successful education programs play a critical role in achieving Green Building objectives, and are required to function on many levels:

- Promoting Green Building awareness and cultural change
- Informing policy makers and managers
- Developing human capital to professionally leverage BIM processes and achieve Green Building requirements with a balance of theoretical background and proven global best practices
- Maintaining a reliably deployable and scalable program throughout the economy that is appropriate to local context

Programs must include components relevant for a wide range of individuals and organizations with differing modes of engagement with Green Building and BIM programs. For every audience, the educational program must provide a background for environmental issues, the risks and problems to be mitigated, and the benefits Green Building and BIM programs will bring to the economy. The objectives, success targets, and steps that will be taken to achieve these must be clearly articulated, and expressed in terms comprehensible and meaningful to each audience segment. Components proven successful in education programs include holistic coverage of strategic and tactical material for many audiences:

For the General Public:

- Explanation of observed environmental concerns and risks, and the expected benefits from Green Building initiatives. Material must be concise enough for easy understanding, yet provide enough detail to be informational and credible. Some economies provide official briefings as well as written reports, and establish special student programs.

For Policy Makers:

- Survey of policies, standards, and programs for Green Building and BIM already in place and under development worldwide, with explanation of the achievements and shortcomings of each and their potential applicability within the target economy

For Enterprise Decision Makers and Business Leaders:

- A sound grounding in the issues and concerns leading to Green Building policies, and the objectives and strategic importance of Green Building policies and initiatives for the economy
- Expected investments, benefits of success, and risks of inaction from Green Building programs.
- The role of Standards, Metrics, Data, Analysis, and BIM in achieving Green Building Programs, and action items for adoption and implementation.

For Building Professionals, Designers and Program Managers:

- Background of the root causes and factors contributing to environmental concerns, and how Green Building initiatives can mitigate risks and reverse environmental damage.
- Proven and experimental strategies to improve the green performance of the built environment.
- Professional development and training including means, methods, and hands-on experience to build technical skills necessary for all project phases
- Management-level training to promote better understanding among those who will oversee efforts.

For Facility Operators:

- BIM-empowered practices to enhance building performance, maintenance, and productivity.
- Tactical training on asset and facility management and operation systems.

For Higher Education

- Integration of Green Building and BIM topics with engineering, design, and project management curriculums, rather than isolation of these topics as elective studies.

# 8. Conclusion

Key Steps to Achieving Green Building Success and Integration with BIM Technologies:

- Align the economy's **Vision** for Green Building **and Policies with measurable** objectives, attainable targets, specific timelines, and programs to promote adoption and measure performance success.
- **Develop Standards** to facilitate Green Building programs, provide for interoperable data exchange, create a shared reference framework for collaboration, and assure consistent processes and procedures for compliance with voluntary and mandatory requirements.
- **Define Metrics** and Key Performance Indicators to enable constant and meaningful tracking and reporting Green Building achievements, and in assuring conformance with Green Building mandates.

- **Promote BIM** and related technologies to inform design, construction, and operation of facilities, improve predictability, expand the number of alternatives evaluated, and reduce construction waste. BIM can be usefully employed at **all stages of facility life** from conception thru operation to enhance performance and contribution to Green Building objectives.
- **Support interoperability** to standards and requirements to maximize performance of BIM and related technologies and preserve data accessibility.
- **Education** programs designed to inform audiences in a variety of contexts of Green Building and BIM programs. Successful programs include grounding in background theory as well as tactical and instrumental knowledge necessary for practical execution. Education is necessary to **promote knowledgeable adoption** and execution of Green Building and BIM-empowered policies and practices.
- **Establish synergistic Green Building and BIM adoption programs,** with the goal of integrating their activities to create a powerful BIM-informed approach to achieving Green Building goals.

# 9. References

**Case Studies**

*Policies & Standards:*

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2. **Office of Governor of California**, Governor Edmund Brown Jr. issued an Executive Order B-18-12 directing "*all state agencies, departments, and other state entities to reduce energy purchases from the grid by 20% by 2018 (compared to a 2003 baseline)*". A website also tracks their progress and makes information available to the public. (US) http://gov.ca.gov/s_energy.php
3. **The Energy Performance Buildings Directive (EPBD)** aims to reduce energy consumption of buildings in the European Union. However many EU countries had difficulty in introducing national laws to meet EU requirements. Therefore the European Commission launched the **Concerted Action (CA) EPBD to promote dialogue and exchange of best practice between EU countries (**http://www.epbd-ca.eu/). It is the consortium of designated organizations from all 27 EU Member States, plus Norway and Croatia. It has eight themes:
    a. Certification,
    b. Inspection,
    c. Training,
    d. Cost Optimum,
    e. Nearly Zero-Energy Buildings,
    f. Compliance of Regulations,
    g. Compliance in Inspections,
    h. Support Initiatives
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*Applications & Projects:*

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2. **Edith Green-Wendell Wyatt Federal Building Modernization (US)** http://www.aiatopten.org/node/354
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4. **HOK Net-Zero Energy Design Competition Winner: solar (US)** http://www.hok.com/about/news/2014/11/26/hok-net-zero-energy-design-competition-winner-solar/
5. **A zero energy house developed by the research center on zero emission buildings and design office snøhetta (Norway)** http://www.designboom.com/architecture/snohetta-zeb-pilot-house-12-16-2014/

**Standards, Rating Systems, and Guidelines**

1. Construction-Operations Building Information Exchange (COBie) (US) http://www.wbdg.org/resources/cobie.php
2. The *OmniClass* Construction Classification System (known as OmniClass™ or OCCS) is a classification system for the construction industry. (international) http://www.omniclass.org/
3. LEED v4 Rating System (US) Rating system for Building Design and Construction http://www.usgbc.org/resources/leed-v4-building-design-and-construction-current-version
4. BCA Green Mark Assessment Criteria and Online application (Singapore) http://www.bca.gov.sg/GreenMark/green_mark_criteria.html
5. BREEAM (international) BREEAM is the world's foremost environmental assessment method and rating system for buildings, with 425,000 buildings with certified BREEAM assessment ratings and two million registered for assessment since it was first launched in 1990. http://www.breeam.org/about.jsp?id=66
6. Comprehensive Assessment System for Built Environment Efficiency (CASBEE) (Japan) http://www.ibec.or.jp/CASBEE/english/statistics.htm
7. Green Star (Australia) https://www.gbca.org.au/green-star/
8. Pearl Rating System (United Arab Emirates) http://estidama.upc.gov.ae/pearl-rating-system-v10.aspx?lang=en-US
9. National BIM Standard-United States http://www.nationalbimstandard.org/

*BIM Standards, Guidelines and relevant documentations of APEC members:*

1. National BIM Guide (Australia) http://bim.natspec.org/index.php/natspec-bim-documents/national-bim-guide
2. National Guidelines for Digital Modelling (Australia) http://www.construction-innovation.info/images/pdfs/BIM_Guidelines_Book_191109_lores.pdf
3. National Building Information Modelling Initiative (Australia) http://buildingsmart.org.au/wp-content/uploads/2014/03/NationalBIMIniativeReport_6June2012.pdf

4. AEC (CAN) BIM Protocol (Canada) http://s3.amazonaws.com/canbim-production/vol/www/apps/canbim_production/releases/20121021065404/en/public/documents/documents/original_63.pdf?1352735902
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**Organizations:**

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4. UK Green Building Council http://www.ukgbc.org/
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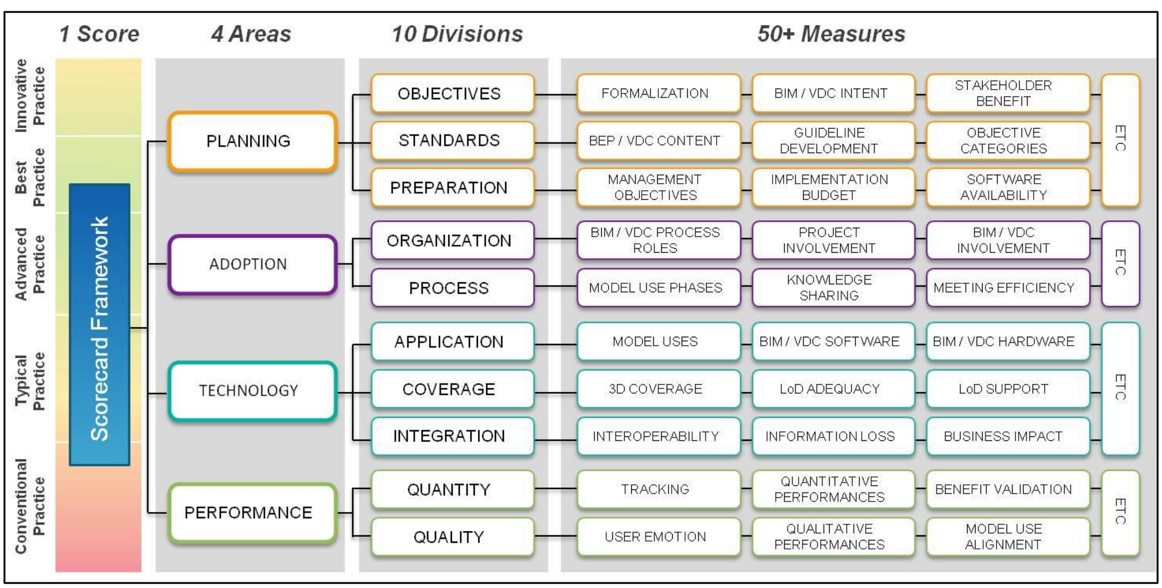
7. German Sustainable Building Council (DGNB) http://www.dgnb.de/en/council/dgnb/
8. Singapore Green Building Council (SGBC) http://www.sgbc.sg/
9. Norwegian Green Building Council http://ngbc.no/english

**VDC Scorecard Framework for assessment of BIM/VDC Maturity:**

BIM and VDC Scorecard evaluations assess current BIM implementations, benchmark to industry practice, and identify opportunities for improvement in light of project and enterprise-wide objectives. Benchmarking is based on Stanford University CIFE VDC Scorecard Research with more than 50 measures of BIM/VDC maturity and backed by more than 100 project applications from 13 countries. The method supports an executive overview and overall score allowing executives and project managers to quickly identify areas with opportunity for improvement. Results are further detailed with four primary areas of evaluation: Planning—addressing objectives, standards, and preparation to meet goals; Adoption—the organization and process used in following the plan; Technology—the maturity, coverage, and integration of tools used to accomplish projects; and finally Performance—the quantitative and qualitative measures of success for outcomes.

These four areas, and further divisions, contribute to a detailed score, and more importantly lead to general advice and specific action items promoting adoption best practices to maximize BIM benefits.



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