The Role of GIS Technology in Sustaining the Built Environment

By Patrick Wallis, AICP, LEED AP, GISP

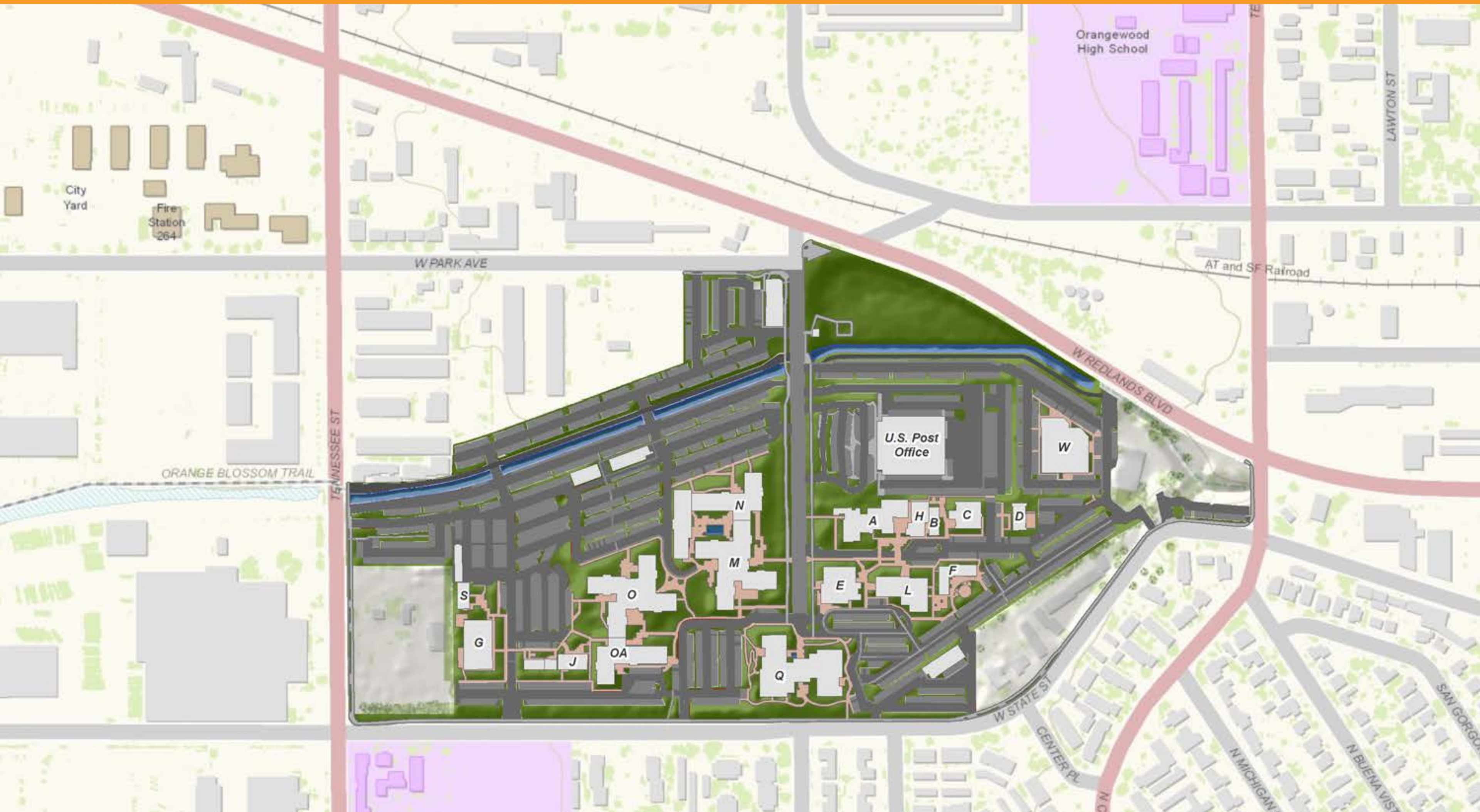


Table of Contents

An Introduction

This white paper was written for those responsible for the form and condition of the built environment—regulators, policy makers, facility designers, owners, and managers. It was produced for two key reasons.

The first was to connect the dots between a number of reports published over the past 14 years on the state of the capital[1] and residential facilities industry in the United States, as well as between our experiences working for and with the industry. Based on our research and experience, decision making is predominantly biased toward a paper-driven paradigm, or one with digital outputs that are not machine readable (e.g., highly customized multicolored Excel spreadsheets with three tiers of column headers). Neither is conducive to running an enterprise where information must flow efficiently and nearly instantaneously, from the highest to lowest levels of the organization. Generally, there was a clear inability by many decision makers to conceptualize the efficiencies gained by fully embracing new technologies enabling tele-present[2] communications and data interoperability" where individuals and systems would be able to identify and access information seamlessly, as well as comprehend and integrate information across multiple systems."[3]

The second reason was to provide a cogent and compelling argument for using geographic information systems (GIS) as the enabling technology for better communication and data interoperability. Trends over the past 30 years have not been favorable for the long-term sustainability of the built and natural environments. We are proposing the use of GIS as a means to achieve required stewardship, sustainability, and savings for the built environment.

GIS technology can be exploited to provide key facility information for decision makers when they need it.

Executive Summary

Over the past 30 years, key practices for shaping and managing the built environment within building and related industries have proved unsustainable. Available evidence demonstrates that these practices were not economically, environmentally, or socially viable in the long run. One barrier to achieving greater sustainability has been the industries' partial, lukewarm embrace of advanced technologies for shaping and managing the built environment. Typical examples include existing difficulties exchanging and integrating data contained in paper or complex spreadsheet formats to provide an intuitively understandable holistic view. GIS is rapidly emerging in a new role as the enabling technology for better communication and data interoperability. Using GIS as a means to achieve required stewardship, sustainability, and savings targets significantly enhances the ability for a triple bottom line approach in expanding, operating, and maintaining the built environment.

At present, industry stakeholders most often use technologies such as building information models (BIM) and other more traditional computer-aided drafting (CAD) systems to design and store data about buildings. Usually, this information is queried and reported building by building. The challenge for facility managers is querying, analyzing, and reporting this information for all buildings across a site or an even broader geographic region. Facility age and the technologies used to design them contribute to this challenge. In many cases, building data is managed within spreadsheets and in hard and soft copy floor plans with no real organized system of data management. By importing and aggregating into a GIS the geometries and tabular data of the multiple BIM and/or CAD files required to accurately represent the built environment, the efficiencies and power of BIM can be leveraged, extended, and connected in geographic space to other relevant site, neighborhood, municipal, and regional data.

GIS technology can be exploited to provide key facility information for decision makers when they need it. In this context, it is used to answer questions regarding the best manner to develop and manage the built environment. This ability is largely a result of the relational database technology underlying it, as well as the capacity for GIS to identify spatially related objects. Spatial relationships allow GIS to merge different worlds of knowledge—it is significant and powerful because it unearths and exposes related patterns that would otherwise go undiscovered. It is a powerful system and enabling technology for shaping and managing the built environment—one that:

- Provides a common and coordinated view, thereby increasing collaboration and understanding while reducing risk and its associated costs.
- Enables visualization, analysis, and comparison of possible alternatives to optimize performance.
- Provides the analytic tools necessary for stakeholders to determine which strategy presents the best short- and long-term solutions to pursue.
- Can provide the support the building industry requires to realize more sustainable development practices and patterns.

Since 1980, average US expenditures on the maintenance and construction of facilities has accounted for nearly 9 percent of the annual US gross domestic product (GDP).[4] At the height of the US construction boom in 2007, the estimated value of all US construction accounted for 12.4 percent of US GDP[5], totaling nearly $1.95 trillion[6]. In 2010 alone, facilities "directly account[ed] for almost 40 percent of primary energy use, 12 percent of water use, and 60 percent of all non-industrial waste. The processes used to produce and deliver energy to facilities for heating, cooling, ventilation, computers, and appliances account[ed] for 40 percent of US greenhouse gas emissions."[7] Indeed, considering only changes in residential construction practice, average home sizes ballooned compared to what was standard in 1980—a capital cost premium of $1.75 trillion,[8] or .5 percent of the US GDP for that same period.[9] Obviously, more energy was consumed to heat and cool this added space—accounting for nearly $2.33 trillion in additional energy costs.[10] So, coupled with rising energy prices, there was an enormous 263 percent increase in residential energy expenditures[11] that was borne by smaller households whose median income had been relatively static.

With the benefit of hindsight, these trends and the cumulative net impact of previous individual actions become clear. Had there been tools available to forecast the short- and long-term impacts of proposed development, the market and consumers would have been better informed regarding available alternatives—such as those to provide the same or better functionality using fewer fiscal, personnel, or material resources. In this manner, it would have been possible for developers and architects to configure more efficient layouts to achieve the same net square feet (NSF) as other alternatives with more gross square feet (GSF) for the purpose of increasing profitability for developers and reducing energy costs for consumers.

Enabling technology, such as GIS, provides industry managers and executives with the tools required to be better stewards of the built environment. The common and coordinated awareness that GIS delivers provides a better understanding of the present. Shared awareness enables stakeholders to visualize and analyze data regarding the built environment and its links to the world at large. This enables better collaboration among stakeholder disciplines, thereby reducing the unknowns and leading to lower project contingencies, risk, and cost.

By spatially organizing and linking the standards, policies, and values that guide the development and ultimate form of the built environment to the analysis required to achieve shared awareness, GIS helps industry stakeholders better understand the future. In this way, GIS provides stakeholders with the predictive capability needed to manage and actualize performance of the built environment. This ability allows decision makers to visualize performance and virtualize scenarios to improve the built environment, thus ensuring its future viability. For example, it allows facility managers to abandon run-to-failure maintenance strategies and instead adopt strategies for preventive and reliability-centered maintenance, which can dramatically lengthen facility service lives as well as reduce operating costs.

As shown in figure 1, a GIS-based system for managing the built environment can provide industry stakeholders with the awareness required to manage it, as well as the technology, tools, and processes required to actualize its potential for optimal performance. GIS for the built environment is powered by the geospatial information model, which serves as the primary data source for all managed facilities throughout the entire facility management (FM) life cycle. Information contained in the geospatial information model can be visualized in geographic space via the GIS, thereby providing users of the system with a common and coordinated view of the built environment. By further linking the geospatial information model to authoritative data sources, stakeholder workflows, needed reports, and relevant standards, GIS provides industry stakeholders with a predictive capability essential for understanding the future, as well as for optimizing it.

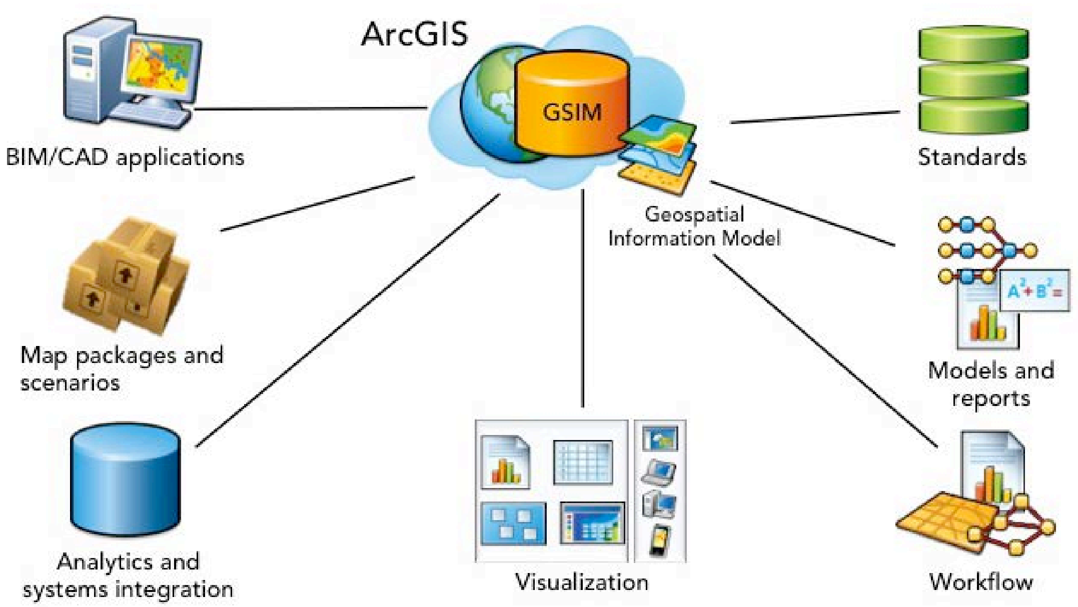


Figure 1: The Geospatial Information Model Framework, a Solution for Management of the Built Environment

A Sustainability Problem

Since 1980, average US expenditures on the maintenance and construction of facilities has accounted for nearly 9 percent annual US GDP (see figure 2).[12] That the industry has been integral to the economy's growth over the past 30 years is undeniable; however, its key practices for shaping and managing the built environment have proved unsustainable. Available evidence demonstrates that while these practices may have in the short term proved lucrative, they are not economically, environmentally, or socially viable in the long run. Juxtaposed against this state of affairs are the precepts of sustainable development, which are based on an understanding that "all the Earth's resources are limited, and that it is less expensive to build in harmony with the environment."[13]

GIS provides industry stakeholders with a predictive capability essential for understanding the future.

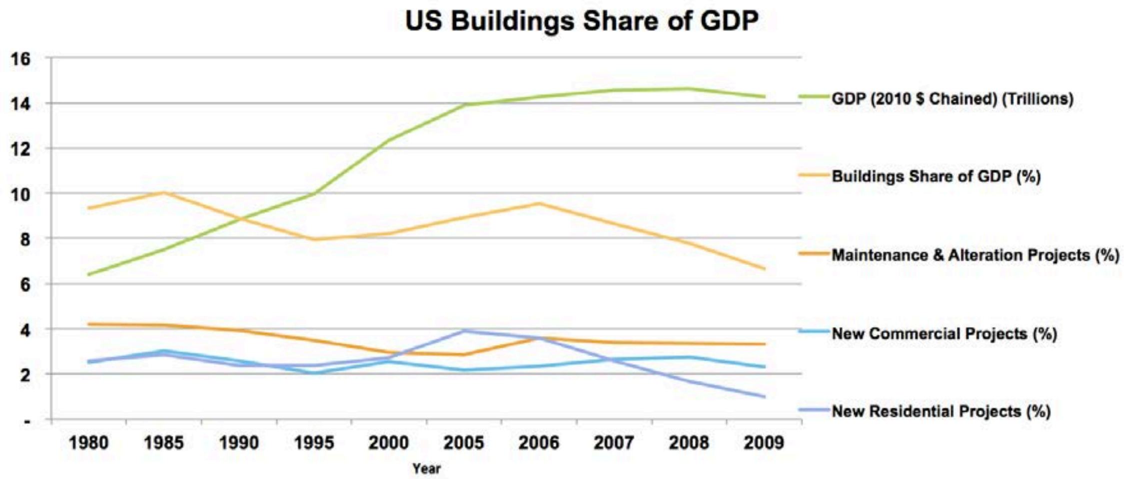


Figure 2: Buildings Share of US GDP

A Communication Breakdown

The global information revolution has, over the past 30 years, radically transformed global computing, networking, communications, and business processes, "[making] it possible to apply information technologies in all phases of the building/facility life cycle, creating the potential for streamlining historically fragmented operations . . . "[14] Despite the availability of such transformational technology, the industry remained slow to embrace and adopt it, the evidence of which can be found stored away in the lead engineering office of any private, public, or commercial organization. What will most likely be found are stacks upon stacks of flat files containing hard-copy as-built and design documentation.

One of the key responsibilities and benefits of using integrated project teams (IPTs) is that realistic, comprehensive project objectives can be established.

The persistence of paper-driven processes has proved to be the bane of the industry. It was obvious by 2002 that a significant technological gap had developed between it and other global industries. That year, the National Institute of Standards and Technology published a report noting this gap and the negative impacts to the industry, writing that other global industries (e.g., aerospace, automotive) had moved forward and taken "the lead in improving the integration of design and manufacturing, harnessing automation technology, and using electronic standards to replace paper [documentation]" and business processes.[15]

Enabling technologies supporting tele-present communications and data interoperability were not widely utilized. The result was that meaningful, timely communication did not occur as part of an established process between industry stakeholders (e.g., owners, developers, planners, cost engineers, architects, suppliers)[16] and those directly responsible for the built environment's form, condition, and management. Consequently, forging a common understanding and attaining a coordinated view became more difficult than necessary—directly impacting the timeliness and effectiveness of project communications and activities.

Integrated Project Teams

The "stove-piping"[17] of stakeholder contributions, within and between disciplines, impeded the formation of effective integrated project teams. One of the key responsibilities and benefits of using integrated project teams (IPTs) is that realistic, comprehensive project objectives can be established. Typical cross-disciplinary IPT objectives include

1. Sustainability, functionality and performance.
2. Making informed decisions about [needed] tradeoffs among resources, materials, mission objectives.
3. Short and long-term building performance.[18]

To support sustainable development goals, industry disciplines must be tightly integrated to eliminate conflicting needs in their processes for shaping and managing the built environment. This level of integration requires leveraging and coordinating fiscal, environmental, personnel, and material resources more precisely "toward the goal of meeting user needs."[19] A primary reason for the industry's ineffective integration was its failure to adopt advanced data interoperability and communication technologies for providing shared awareness and the efficient, near-instantaneous flow of critical information between stakeholders throughout the FM life cycle.

With their absence, valuable fiscal and material resources were spent "validating and/or re-creating facility information that should be readily available."[20] This resulted in "scope creep"[21] between different FM phases (see Figure 3), as well as a lack of clarity regarding the composition (quantity and quality) of the facility assets managed by public and private organizations. At a minimum, fiscal and personnel resources were lost as these organizations tried to better understand the resources they were managing.

At worst, this lack of coordination enabled and empowered industry stakeholders to sacrifice long-term economic, environmental, and functional viability in favor of short-term gains.

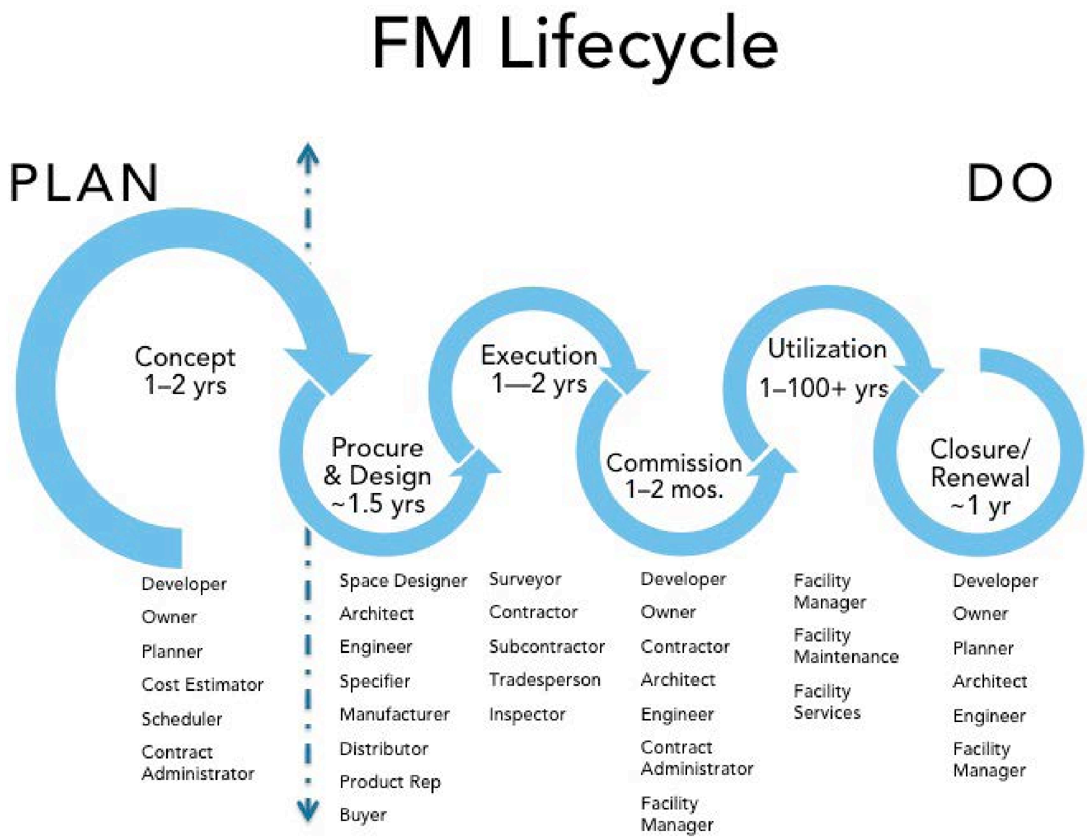


Figure 3: The FM Life Cycle[22]

Without a unified view of benefits and consequences (short- and long-term) of proposed development, industry stakeholders ultimately proved that consideration of first costs was primary, regardless of the long-term impacts. Based on available data,[23] it was inconsequential whether the impacts were fiscal, environmental, or social. The unsustainable practices justified by this myopic world view have changed the face of the built and natural environment in the United States, perhaps irretrievably, creating many negative impacts, some of which will be highlighted in this report.

Value Engineering

At this time, value engineering and life cycle costing in the conceptual planning phase is not standard industry practice. Unfortunately, it is during this phase that decisions having the greatest impact on cost and ultimate sustainability of a facility are made. These include decisions affecting siting, energy, materials, water, indoor environmental quality, and operation and maintenance practices.[24] The earlier in the process that value engineering is employed, the greater the potential benefits for sustainable development and cost savings.[25]

Making value engineering common practice is contingent on making industry business processes more efficient within and between disciplines during all phases of the FM life cycle. The introduction of streamlined communication and data interoperability made possible by computing and information advances is required. Such technologies make it possible to foster utilization of IPTs at an industry-wide scale.

Providing the Evidence

The following section investigates existing research regarding data interoperability within the industry, as well as the characteristics of US commercial and residential facilities, to include physical attributes as well as energy use, exposing the significant costs of failing to embrace advanced technologies. It also builds on this research by relaying the results of new analysis conducted to support the findings of this document.

Data Interoperability

Since the advent of the information revolution, the records used by the industry to design and store data about buildings have been increasingly created digitally instead of by hand. For example, "by the early 1980s, some design professionals and engineers prepared and made decisions on facilities using computer-aided drafting and design."[26] Another example is the use of digital spreadsheets to capture project information for industry stakeholders. By the 1990s, technology advanced to the point where digital spreadsheet and CAD applications were run from desktop computers.[27]

Typically, the facility information contained within these systems is queried and reported building by building. The challenge for facility managers and other industry stakeholders is querying, analyzing, and reporting this information for all buildings across a site or an even broader geographic region. The age of facilities and the technologies used to design them contribute to this challenge. In many cases, building data is managed within spreadsheets and in hard- and soft-copy floor plans with no real organized system of data management.

Since the facility information produced by these systems has no intrinsic structure too often, it is not machine readable or available for use within enterprise systems. This is the case because enterprise data solutions rely on the use of structured data so that the right data can be aggregated or decomposed at the required level to answer end-user queries. Presently, "most correspondence, including project reports and drawings, fall into this category. For these documents, the only way to interpret the contents or to check their quality is for someone to actually read them."[28]

> "Unstructured data of this type cannot be truly interoperable, although it might be compatible with multiple software products. Some human effort will be required to interpret the data for the receiving system. A good example is the work firms do to reach agreement on Computer-Aided Design (CAD) layering for a particular project. This creates the appearance of structure in the CAD files. However, the structure is not intrinsic: a user can place a furniture item on the wall layer."[29]

Value engineering and life cycle costing in the conceptual planning phase is not standard industry practice.

Individual layers within a CAD file have no understanding of how the objects they represent relate to each other, nor do these objects understand that they are indeed discrete." Drafting systems cannot natively detect clashes, missing components, incompatible connections, inconsistencies between drawings, physically impossible configurations, and many other errors that plague design."[30] Consequently,"quantity take-offs from unstructured CAD files have always been subject to error." [31]

It is estimated that in 2002 up to $5.1 billion[32] was lost in the United States just verifying that FM documentation accurately represented existing conditions, and another $742 million[33] was wasted converting and transforming that data into a useful format.[34] Interoperability costs totaling $19.1 billion[35] were accounted for in the capital facilities industry alone, with facility owners bearing 66 percent of the burden. "Architects and engineers had the lowest interoperability costs at [$1.5 billion],"[36] and contractors, fabricators, and suppliers accounted for the rest. "Examples of inefficiencies resulting from inadequate interoperability [e.g., avoidance costs, mitigation costs, and delay costs] include manual reentry of data, duplication of business functions, and the continued reliance on paper-based information management systems."[37]

Interoperability solutions for facility information must be able to provide a structured data environment where a common vocabulary for classifying the built environment exists. A shared semantic structure is critical for ensuring that such data is accessible throughout the FM life cycle by industry stakeholders, regardless of their discipline. Existing, more advanced technologies, such as relational database management systems (RDBMS) and modeling systems, can provide the commonly understood structure needed to meet the industry's interoperability requirements. Such systems "have already replaced drafting systems in [many] complex system projects" yet have not yet been adopted industry-wide.

US Commercial Facilities

Over the past 30 years, US commercial facilities have become much more inefficient. Based on available data, carbon emissions grew by 59 percent,[38] and energy consumption rose by 81—so much that it now accounts for 19 percent of all US and 4 percent of all global energy consumption.[39] This should not be a surprise, as the number of commercial buildings has increased by 1.45 million, a 39 percent growth,[40] and the total floor space has grown by 31.2 billion square feet, a 62 percent increase.[41] The rise in the number and size of commercial facilities since 1980 has very much been pushed along by the large, simultaneous growth of the US economy, which is up to $14.8 trillion—a 127 percent increase.[42] The largest commercial facility growth was in the mercantile, office, warehouse, educational, and lodging sectors—increasing in size by 75, 73, 62, 50, and 117 percent, respectively. Figure 4 details the change in the US commercial building stock. The significant rise in the amount of available floor space was a direct cause of the simultaneous and also significant rise in energy consumption by commercial facilities. This change in commercial energy consumption is depicted in figure 5.

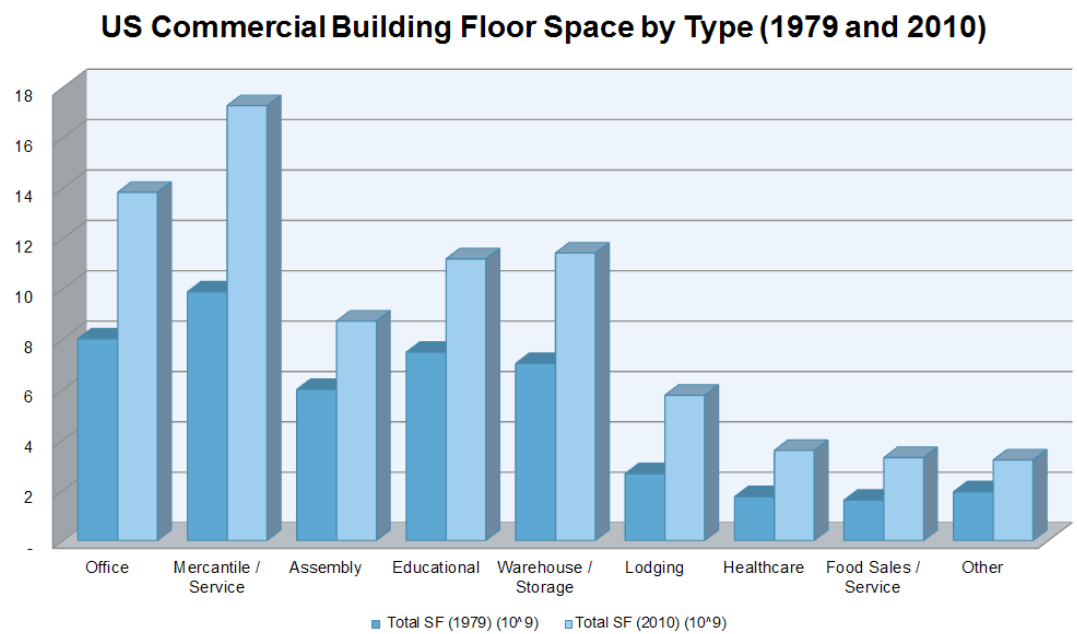


Figure 4: Commercial Building Floor Space by Type (1979 and 2010)[43]

In far too many instances, the lack of advanced communication, RDBMS, and modeling technology frustrates attempts by industry stakeholders to understand the structure, size, and quality of what they are responsible for managing—eventually hampering attempts to stem or reverse trends toward increasing energy consumption. Over periods of months, years, and decades, facility occupants often wind up being assigned space based on what makes the most sense from a tactical day-to-day perspective. While this may be the logical result of tactical decision making, the story from a strategic vantage point is very different. When managers first apply a coherent structure to their facility information, it is common that its aggregation reveals striking imbalances, inefficiencies, and deficiencies. Before the application of this structure, the risk to current operations was unknown. With it, strategic understanding of the current situation can be realized and used to reduce the risk to current and future operations.

When facility utilization statistics are aggregated at the floor level, inefficiencies in departmental functional adjacencies can be revealed. These inefficiencies can lead to redundancies in departmental common areas, administrative support spaces, and equipment and storage spaces. When this data is aggregated at the building level, there is frequently noticeable over- or underutilization that could have otherwise been resolved through the use of space available on a different floor. Additionally, in many cases, the present predominant use of the facility turns out to be different from what the facility was originally designed for (e.g., a warehouse used as an administrative facility or an office complex used for medical purposes). When this happens, it is very difficult to achieve an efficient layout for building occupants, and it generally costs more to improve, alter, and repair spaces with mismatched uses. At the campus level and higher, aggregated facility information can reveal clusters of under- and overutilized spaces, floors, and buildings.

At the strategic investment level, this type of information can be crucial in formulating capital improvement plans that make the most use of the existing infrastructure. However, when delivery of a strategic view is impeded by a lack of advanced communication, RDBMS, and modeling technology, ill-advised investment decisions are made. For example, it is frequently the case that plans are made to acquire new facilities when the same functionality could have been provided within the existing facility inventory. Generally, and depending on its location and condition, the costs to alter, improve, and modernize an existing facility are half the cost to build a new one with equivalent functionality. Plans to eliminate over- and underutilization can be designed and executed by first identifying swing space in the existing inventory so that current occupants can temporarily relocate while their old spaces are altered, improved, and modernized to efficiently meet the demands of their current intended use.

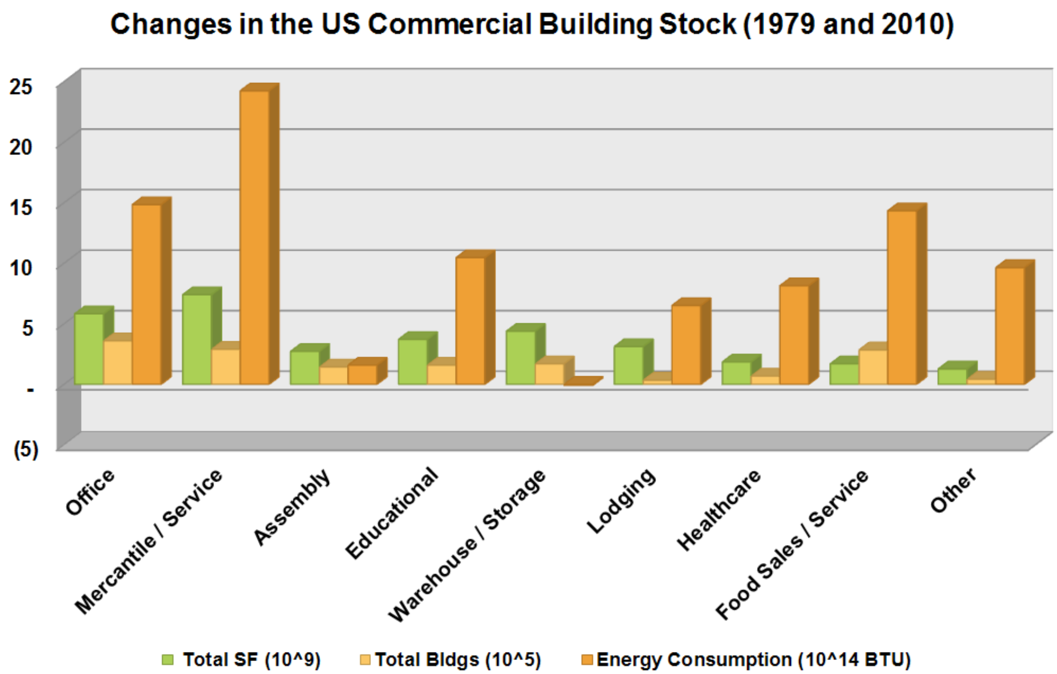


Figure 5: Changes in the US Commercial Building Stock (1979 and 2010)

US Residential Facilities

During the same period, the US population grew only 36 percent, and the average household size dropped by 6 percent to 2.7 persons.[44] Counterintuitive to this, in 2010, the average floor space of all new single-family homes constructed increased by 730 square feet (42%) over the 1980 average of 1,740 square feet.[45] In total, this represents a cumulative capital cost premium of $1.75 trillion,[46] about half of 1 percent of the US GDP for that same period.[47]

Looking closer at these phenomena, what's striking is that over the past 30 years, the average size for all new housing units (single-family, multifamily, and mobile) grew by 95 percent. Counterbalancing this increase was the fact that the energy efficiency of these new units had actually increased, so that on a per-household basis, the average home in 2010 had become 3.2 percent more energy efficient.[48] Yet, due to the large growth in the number of homes and their size,[49] total energy consumption for US households increased significantly (40%).[50] In fact, the total amount of energy lost in 2010 due to these trends was equivalent to 11.3 quadrillion British thermal units (BTUs).[51] This was enough energy to raise the temperature of Lake Superior, the largest of the Great Lakes, by half a degree Fahrenheit, and since 1980, it was enough to raise the temperature of all the Great Lakes by 4.4 degrees Fahrenheit.

As with commercial facilities, attempts to stay or reverse trends toward increasing costs and energy consumption are frustrated by the infrequent use of advanced technologies to improve communication among stakeholders or structure and analyze facility information. Without these tools, it becomes more difficult for developers and architects to improve home design and efficiency. Designers cannot easily configure more efficient layouts to achieve the same net square feet as other alternatives with more gross square feet for the purpose of increasing profitability for developers and reducing energy costs for consumers. It is harder to identify and provide specifications for more efficient building materials to decrease operating costs. It is also more difficult to understand how proximity to mass transit nodes, transportation corridors, utility networks, and markets impact needed quantities of parking and storage space for new homes, and it is hard to measure the eventual up-front capital and recurring costs for these spaces.

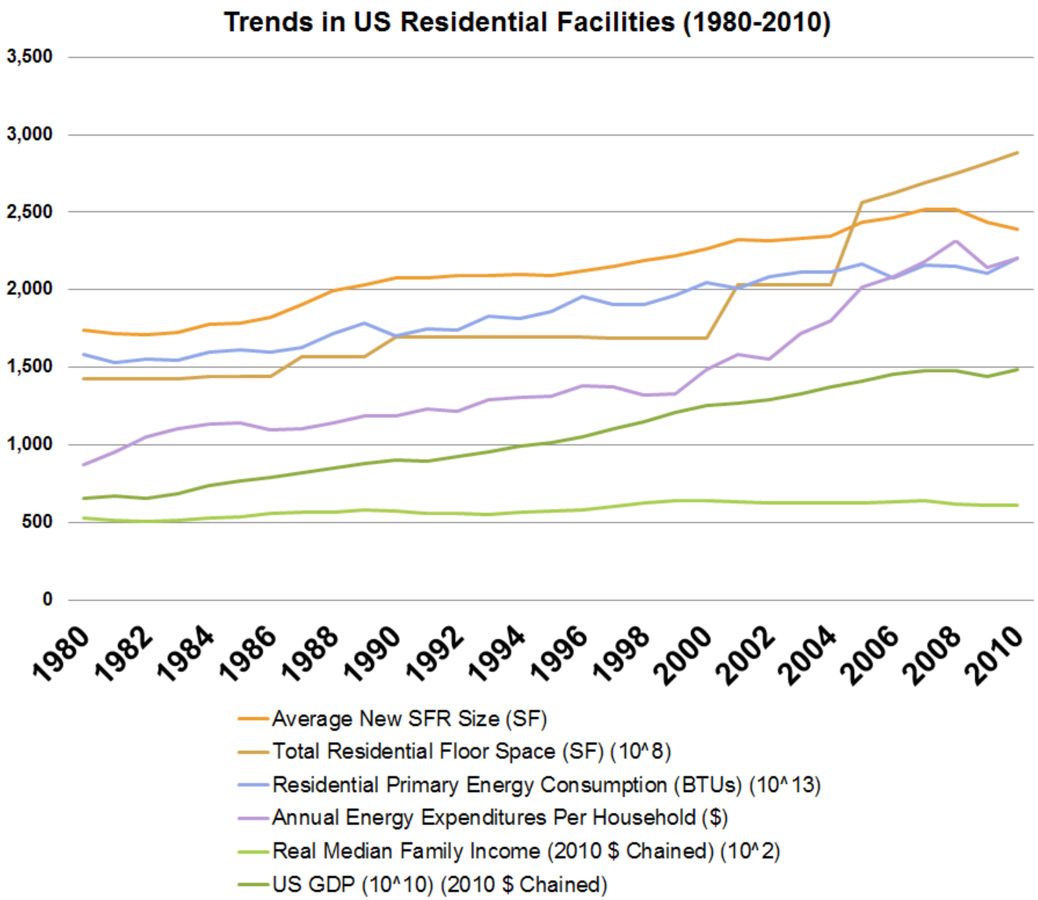


Figure 6: Trends in Residential Facilities (1980–2010)[52]

The Value of Value Engineering

As noted, implementation of value engineering prior to commissioning enables comparison of short- and long-term costs between different alternatives, as well as consideration of what effect changes in the design program will have in "maintaining or improving on desired levels of capability and performance."[53] To support sustainable development, value engineering can also evaluate a range of options during the conceptual planning, design, and construction phases of acquisition.

By way of example, a relatively simple exercise was conducted. Its purpose was to highlight the power of value engineering in exposing these types of deleterious results early and avoiding scenarios where they are realized. The exercise compared differences in net present value (NPV[54]) between various alternatives for residential development in Redlands, California.

In one alternative, the average home size in 2010 was used, and in the other, the average home size in 1980 was used. The cost per unit of measure was derived from historical Housing and Urban Development (HUD) housing affordability reports,[55] and the study period was for 30 years for each alternative. Up-front capital costs and annual operations and maintenance costs were considered. As is demonstrated in figure 8, the opportunity cost for not reducing the average home size is phenomenal, given that the 1980-sized home is only 70 percent the cost of the 2010-sized home.

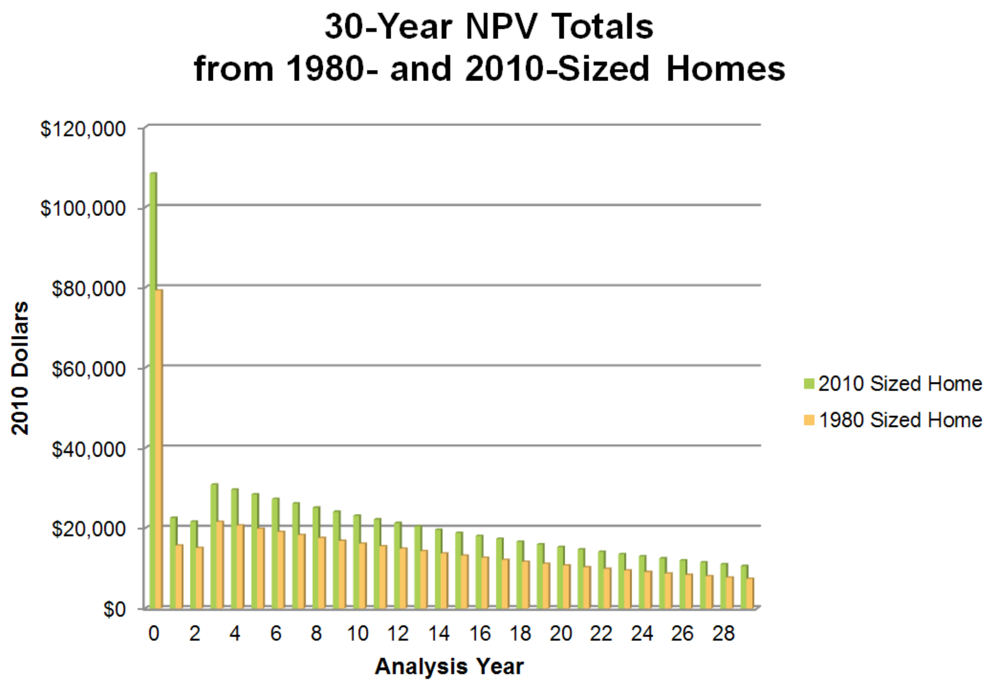


Figure 7: 30-Year NPV Totals for 1980- and 2010-Sized Homes

ALTERNATIVE		Total NPV
1	2010 Sized Home	$666,900
2	1980 Sized Home	$469,300

Figure 8: 30-Year NPV Totals for 1980- and 2010-Sized Homes

Problem Synopsis

Data recording the pulse, outline, and trajectory of the industry over the last 30 years shows that the desire for larger homes cost US households nearly $2.33 trillion in additional energy costs and $1.75 trillion in additional capital costs. These enormous sums account for nearly 1.23 percent of the entire US GDP from 1980 to 2010. It is evidence with a consistent and conflicted narrative thread.

While it is clear that these changes were, on the whole, relatively ill conceived and unsustainable, they are obviously not what industry stakeholders had intended. It is a story of industry professionals working to produce a quality product for their clients. US households and US businesses had grown significantly in number and had outgrown the available housing stock and commercial facilities. But it is also a story of how a whole industry sector, in clear favor of short-term capital gains, was allowed to generally ignore or pay little serious attention to the long-term impacts of proposed development to meet these needs.

The unintended consequences of failing to adopt available advanced technologies may have appeared reasonable at individual project scale, but the net cumulative impacts were deleterious for the environment. By adopting these technologies, these trends could most likely have been pushed toward a more sustainable path. With them, formation of IPTs and industry-wide application of value engineering principles would have been practical. Thus, the most harmful changes could have been identified before project implementation and designs changed to minimize negative impacts as well as maximize opportunities for improved efficiency.

Sustainability Solutions: Enabling Technologies

Building Information Models

It really is only in the last five years that noticeable progress has been made in resolving the industry's data interoperability problems. This progress has largely been accomplished by the National Institute of Building Sciences (NIBS) buildingSMART alliance (bSa). With a mission to "improve all aspects of the facility and infrastructure lifecycle by promoting collaboration, technology, integrated practices and open standards,"[56] bSa has focused on enabling BIM technology. To that end, bSa published the first US National BIM Standard (NBIMS US) in 2007 and just recently revised and updated it in 2011.[57]

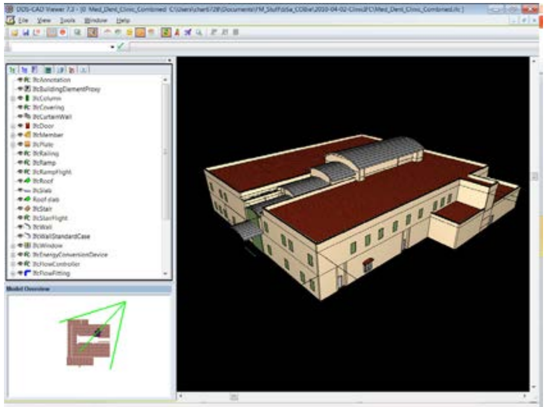


Figure 9: BIM Representation of a Medical Clinic

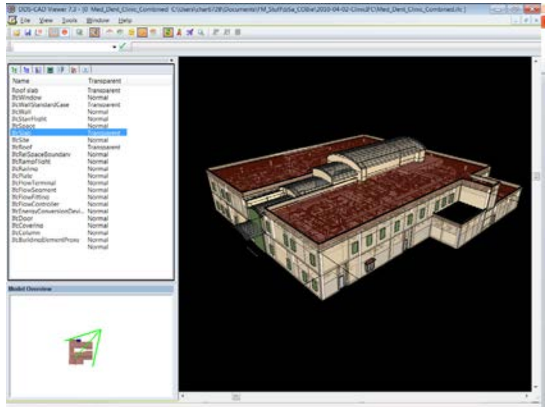


Figure 10: BIM Representation of the Same Clinic Revealing Building Elements

BIM technology encompasses many aspects and ideas, but in short, it "is a digital representation of the physical and functional characteristics of the built environment."[58] It is "a shared knowledge resource for information about a facility,"[59] purposefully designed to form "a reliable basis for [FM] decisions during its lifecycle, from inception onward. A basic premise of BIM is collaboration by different stakeholders at different phases of the lifecycle of a facility to insert, extract, update, or modify information in the BIM to support and reflect the roles of that stakeholder. The BIM is [also] a shared digital representation founded on open standards for interoperability."[60]

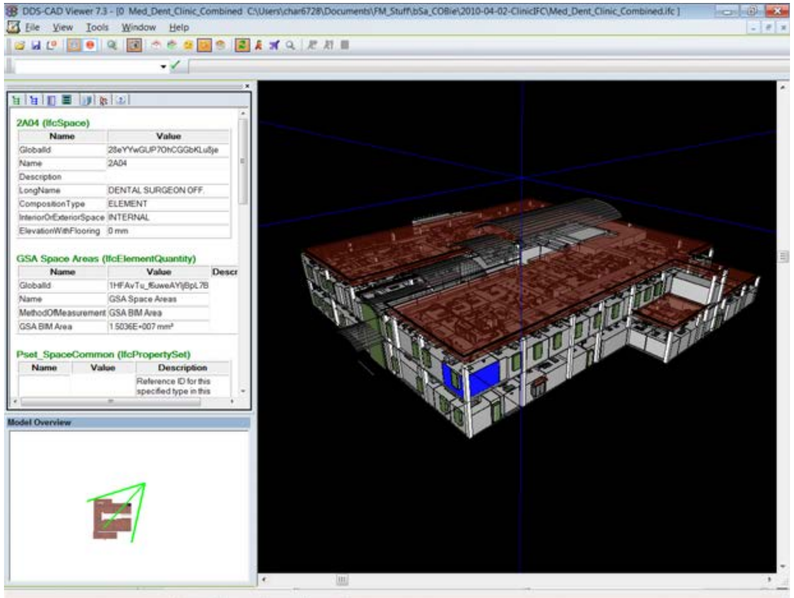


Figure 11: Further Decomposition of the Same BIM, Depicting Associated Tabular Attributes

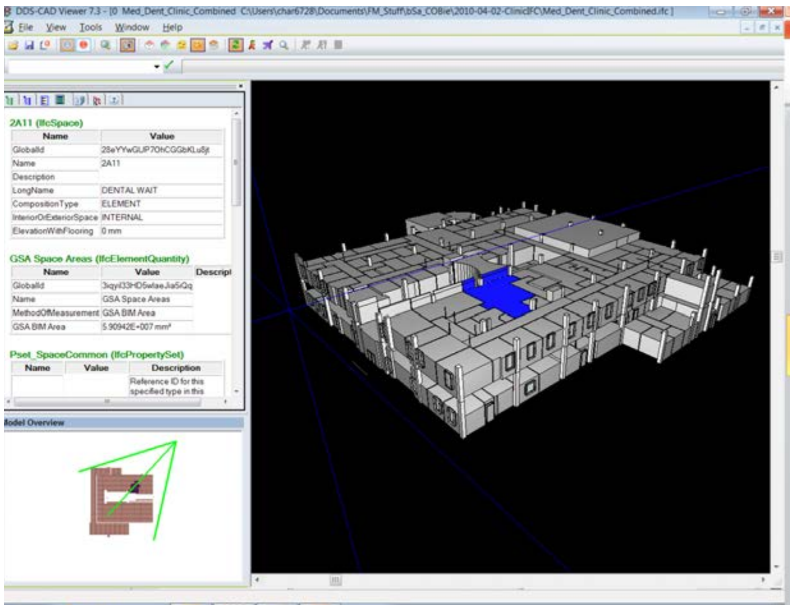


Figure 12: Further Decomposition of the Same BIM, Depicting Spaces within the Model

GIS for the Built Environment

By importing and aggregating into a GIS the geometries and tabular data of the multiple BIM and/or CAD files required to accurately represent the built environment, the efficiencies and power of BIM can be leveraged, extended, and connected in geographic space to other relevant site, neighborhood, municipal, and regional data. The infrastructure and asset management capabilities of existing BIM and CAD systems are greatly expanded by using the geospatially enabled databases and rich analytic and visualization tools provided by a GIS. By geospatially enabling their current systems for managing the built environment, industry stakeholders, such as portfolio managers, gain holistic access to relevant facility information, which in turn supports faster, more accurate decision making. Consequently, many

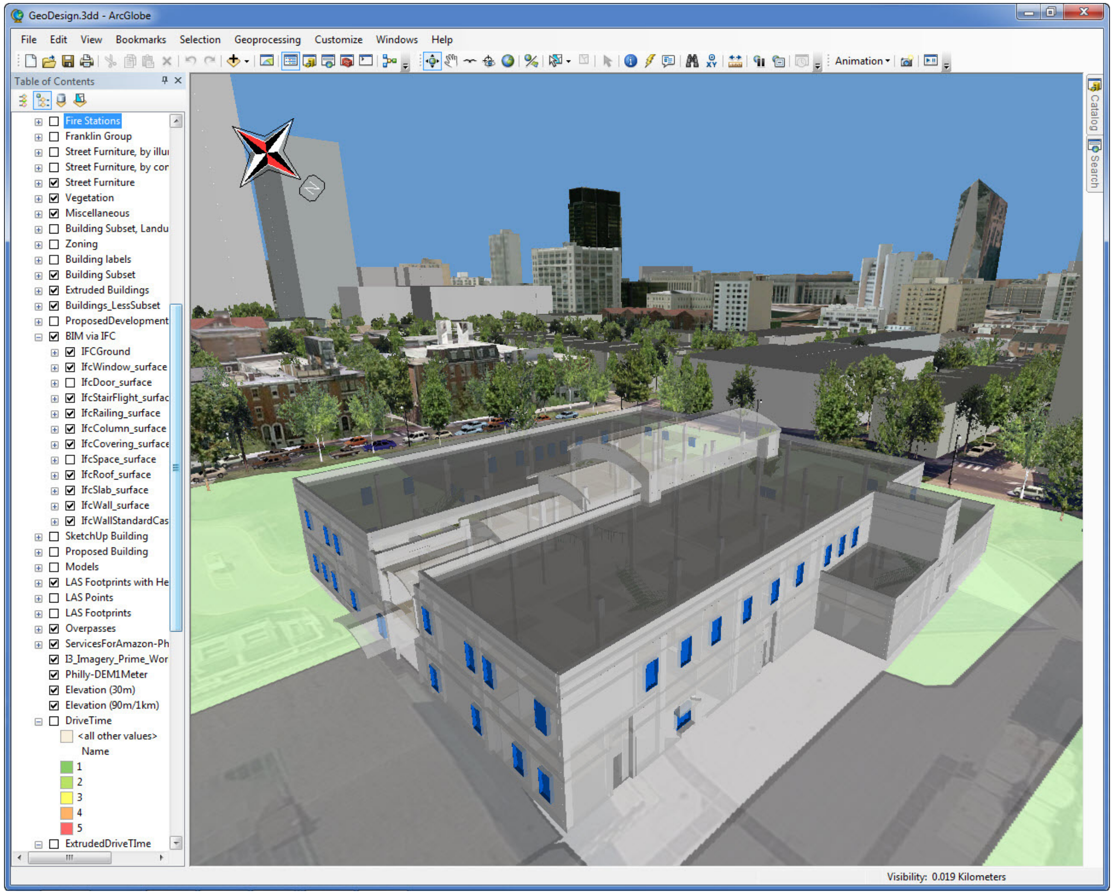


Figure 13: BIM-Derived GIS Data in a Common Data Model, Connected to the Larger World

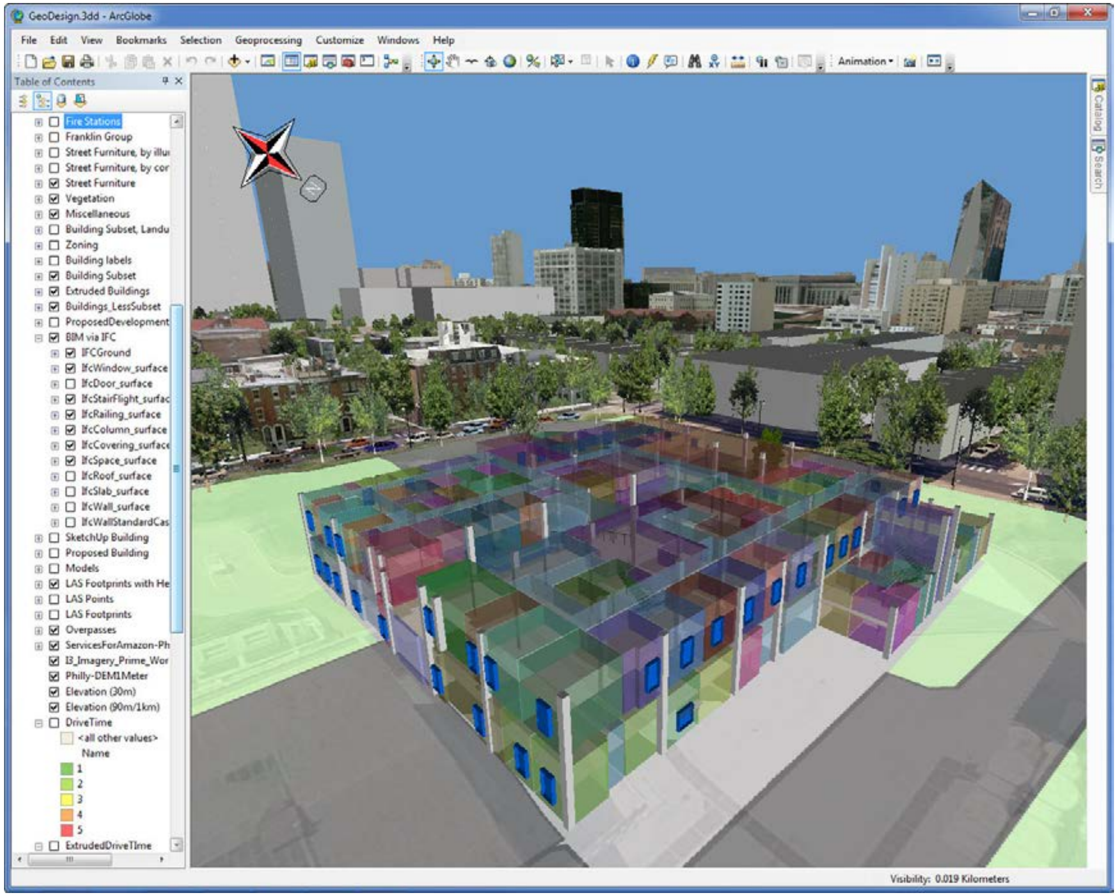


Figure 14: BIM-Derived GIS Data, Depicting the Ability to Visualize Space Utilization

facility managers are now exploring, and in many cases using, GIS to overcome these challenges. Typical solutions include

- Design and configuration of workflows and models to transform existing CAD and computer-aided facilities management (CAFM) data into an integrated GIS model
- Transformation of existing CAD and BIM objects to GIS and, via common keys, relating them to relevant facility information systems (FIS) data
- Design and configuration of executive dashboards and facility viewers to provide stakeholders with a common, coordinated view of the built environment, as well as the status and performance of the facilities managed within it

Facility managers are now exploring, and in many cases using, GIS to overcome these challenges.

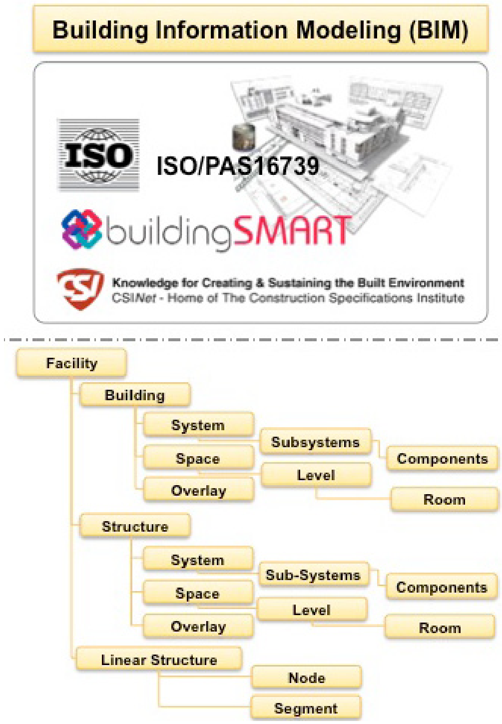


Figure 15: IFC Hierarchy

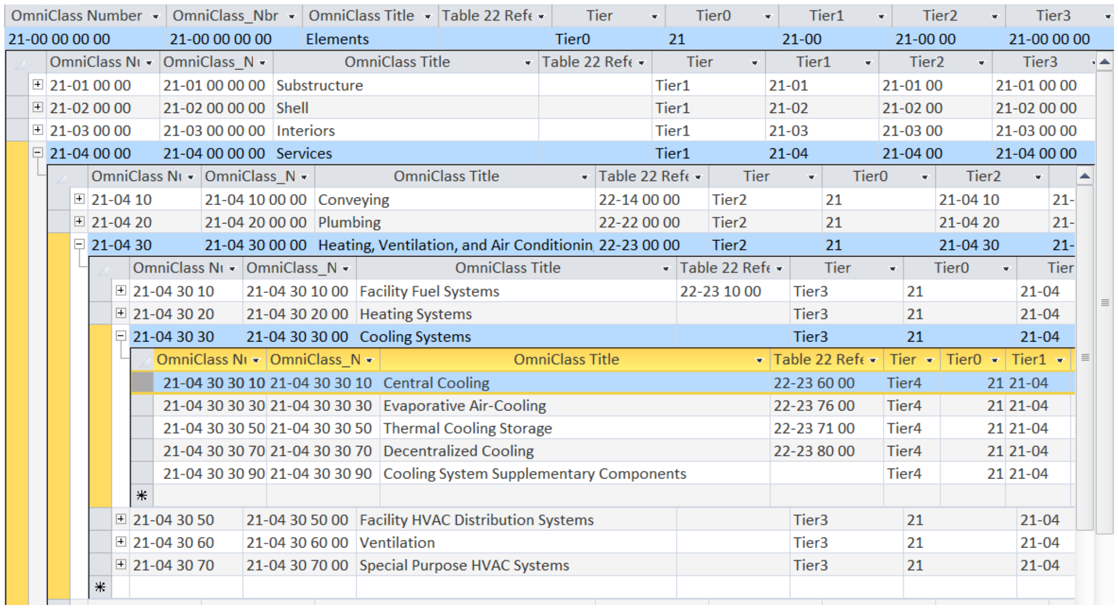
The Relational Database

The fundamental component supporting the power of GIS to extend and leverage existing systems for facilities and building information is a relational GIS database. It is a GIS-based RDBMS that supports all facilities composing the built environment—both inside and outside buildings. Data management and the workflow processes required to collect, manage, edit, analyze, and model infrastructure data can be enhanced through an enterprise GIS approach, and those workflows can be documented and enforced within GIS. Again, GIS is not a replacement for existing facilities and building information systems but rather a complementary technology to extend and leverage their capabilities in an enterprise context.

Data Models and Standards

Industry Foundation Class

One of the truly fascinating aspects of how GIS uses BIM technology and data to design and manage the built environment is that the interoperability standard, Industry Foundation Class (IFC), promulgated by NBIMS US, has proved to be a format that readily works with the data models and relational database technology powering GIS. [61] It provides a practical and coherent hierarchical structure for the elements (doors, windows, walls, floors, etc.) and spatial containers (site, buildings, stories, spaces, conveyances, etc.) that compose a building.



OmniClass Number	OmniClass_Nbr	OmniClass Title	Table 22 Refe	Tier	Tier0	Tier1	Tier2	Tier3
21-00 00 00 00	21-00 00 00 00	Elements		Tier0	21	21-00	21-00 00	21-00 00 00

OmniClass Nı	OmniClass_N	OmniClass Title	Table 22 Refe	Tier	Tier1	Tier2	Tier3
21-01 00 00	21-01 00 00 00	Substructure		Tier1	21-01	21-01 00	21-01 00 00
21-02 00 00	21-02 00 00 00	Shell		Tier1	21-02	21-02 00	21-02 00 00
21-03 00 00	21-03 00 00 00	Interiors		Tier1	21-03	21-03 00	21-03 00 00
21-04 00 00	21-04 00 00 00	Services		Tier1	21-04	21-04 00	21-04 00 00

OmniClass Nı	OmniClass_N	OmniClass Title	Table 22 Refe	Tier	Tier0	Tier2	
21-04 10	21-04 10 00 00	Conveying	22-14 00 00	Tier2	21	21-04 10	21-
21-04 20	21-04 20 00 00	Plumbing	22-22 00 00	Tier2	21	21-04 20	21-
21-04 30	21-04 30 00 00	Heating, Ventilation, and Air Conditionin	22-23 00 00	Tier2	21	21-04 30	21-

OmniClass Nı	OmniClass_N	OmniClass Title	Table 22 Refe	Tier	Tier0	Tier
21-04 30 10	21-04 30 10 00	Facility Fuel Systems	22-23 10 00	Tier3	21	21-04
21-04 30 20	21-04 30 20 00	Heating Systems		Tier3	21	21-04
21-04 30 30	21-04 30 30 00	Cooling Systems		Tier3	21	21-04

OmniClass Nı	OmniClass_N	OmniClass Title	Table 22 Refe	Tier	Tier0	Tier1
21-04 30 30 10	21-04 30 30 10	Central Cooling	22-23 60 00	Tier4	21	21-04
21-04 30 30 30	21-04 30 30 30	Evaporative Air-Cooling	22-23 76 00	Tier4	21	21-04
21-04 30 30 50	21-04 30 30 50	Thermal Cooling Storage	22-23 71 00	Tier4	21	21-04
21-04 30 30 70	21-04 30 30 70	Decentralized Cooling	22-23 80 00	Tier4	21	21-04
21-04 30 30 90	21-04 30 30 90	Cooling System Supplementary Components		Tier4	21	21-04

OmniClass Nı	OmniClass_N	OmniClass Title	Table 22 Refe	Tier	Tier0	Tier
21-04 30 50	21-04 30 50 00	Facility HVAC Distribution Systems		Tier3	21	21-04
21-04 30 60	21-04 30 60 00	Ventilation		Tier3	21	21-04
21-04 30 70	21-04 30 70 00	Special Purpose HVAC Systems		Tier3	21	21-04

Figure 16: An Example of the Semantic Structure for OmniClass Table 21—Elements

OmniClass

There is a well-defined and robust taxonomy describing the objects within each leaf of this hierarchy called OmniClass,[62] which is compatible with ISO standard 12006-2. Conveniently enough, it is a self-described "strategy for classifying the built environment." It was designed to "provide a standardized basis for classifying information created and used by the North American architectural, engineering and construction (AEC) industry, throughout the full facility life cycle . . . encompassing all of the different types of construction that make up the built environment. [It] is intended to be the means for organizing, sorting, and retrieving information [about the built environment] and deriving relational computer applications [for it]."[63]

Building Interior Spatial Data Model

The challenge then is preventing the loss of key facility data from BIM as it is mapped and migrated to GIS. Tackling this challenge has been one of the Building Interior Spatial Data Model (BISDM) committee's primary concerns since its inception in 2007. The BISDM committee is a volunteer organization comprising more than 30 public, private, educational, commercial, and governmental member institutions, whose mission focus is to create a GIS schema for buildings. The benefit to the industry is a reliable and functional schema for representing BIM-derived GIS—one that honors the hierarchies and classification schemes for component building elements and spatial containers. The BISDM schema, now in its third iteration, is used by organizations in projects and GIS models throughout the world to manage the built environment.

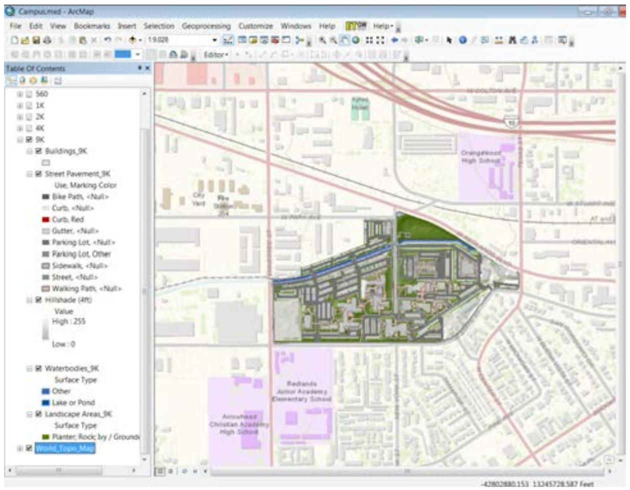


Figure 18: Example of the Detailed Campus and Building Cartography Available via BISDM

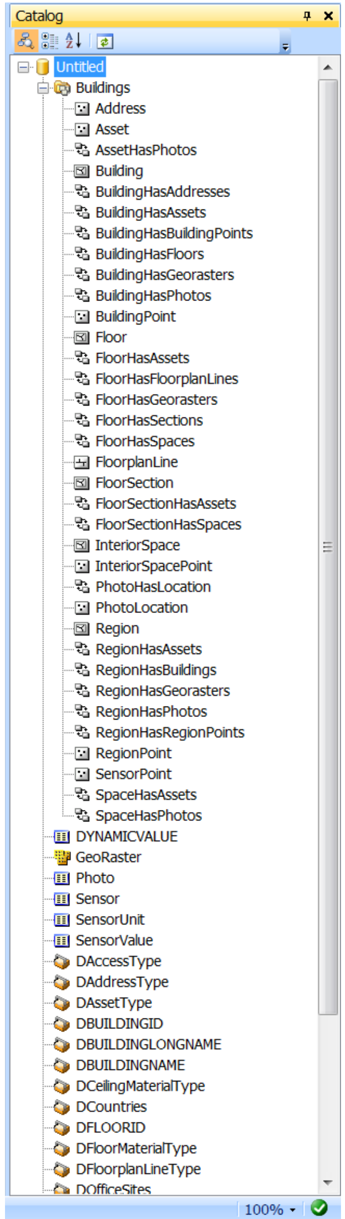


Figure 17: Example of the Relationships between BISDM Building Interior Objects

Figure 19: A More Detailed Example of the Cartography Available via BISDM

This type of detail becomes critical in an enterprise GIS context at other stages of the FM life cycle. For example, as part of an organization's programming and budgeting process, a portfolio manager may need to determine the estimated capital and operating costs of facilities that have been geospatially selected. To do this, it becomes necessary to link the selected features to industry standard sources for cost estimating via the OmniClass common keys previously imported into GIS from a BIM.

By combining multiple BIM and/or CAD data in GIS and structuring it on a common schema such as BISDM, the relational database technology underlying GIS can be exploited to summarize and decompose key facility information for decision makers. Industry stakeholders are able to interrogate their GIS to retrieve the right information, at the right time, about the right place and building element to answer questions regarding the best manner to develop and manage the built environment.

Spatial Relationships and Hidden Patterns

Augmenting this powerful capability is the capacity for GIS to identify spatially related objects, especially those that reside within wholly different domains. The ability of GIS to merge these different worlds of knowledge based solely on location is significant and powerful because it unearths and exposes related patterns that would otherwise go undiscovered. From the scale of a single oversized space in a development proposal for a new community to efforts for the design of more stable global systems, the fundamental key to more sustainable development patterns and processes is finding and changing these patterns between the built and natural environments.

Geographic Fabric

GIS provides the ability to scale from individual assets within a building to a virtually global context. For this reason, GIS technologies have long been used by many in the industry to model and manage infrastructure. These technologies answer questions, such as those about size, value, utilization, operations and maintenance, location, and security, that facility and property managers are increasingly challenged to answer.

This comprehensive view in geographic space of the data managed, at all scales, is commonly referred to as the geographic "fabric." It is a continuous view of all data together in space. A geographic fabric is a collection of many different data elements, all combined in geographic space. When facility and broader data regarding the built environment is combined in this manner, one can ask questions and generate information about an individual site or assets that span an entire site, city, region, or much larger geographic region.

The first step in achieving awareness is to import and aggregate relevant facility data into a GIS, migrating it to a common data model.

Keys to Better Management and Optimal Performance

A GIS-based system for managing the built environment can provide industry stakeholders with

- The *awareness*[64] required to manage it
- The technology, tools, and processes required to *actualize*[65] its potential for optimal performance

Awareness of as-is managed inventories within the built environment and actualization of required to-be inventories will allow industry stakeholders to continuously analyze the effectiveness of their standards, budget, and facility configurations. Management and staff can then make effective plans to improve their standards, budget, facility configuration, and urban form, as required. By executing these plans, the potential for optimal performance of the built environment is physically actualized.

Awareness

The first step in achieving awareness is to import and aggregate relevant facility data into a GIS, migrating it to a common data model. The second step requires that tabular attribute data found in key enterprise data stores (e.g., inventory management, financial management, environmental management) is joined to the geometry of the virtual model via common keys stored in the related datasets. This geospatial information model serves as the primary data source for all managed facilities throughout the entire FM life cycle (figures 20 and 21). The final step in providing awareness of the built environment requires delivery of a common, coordinated view of the geospatial information model in geographic space, linked to relevant process documentation. Awareness in this context is simply a shared geospatial representation of an as-is inventory.

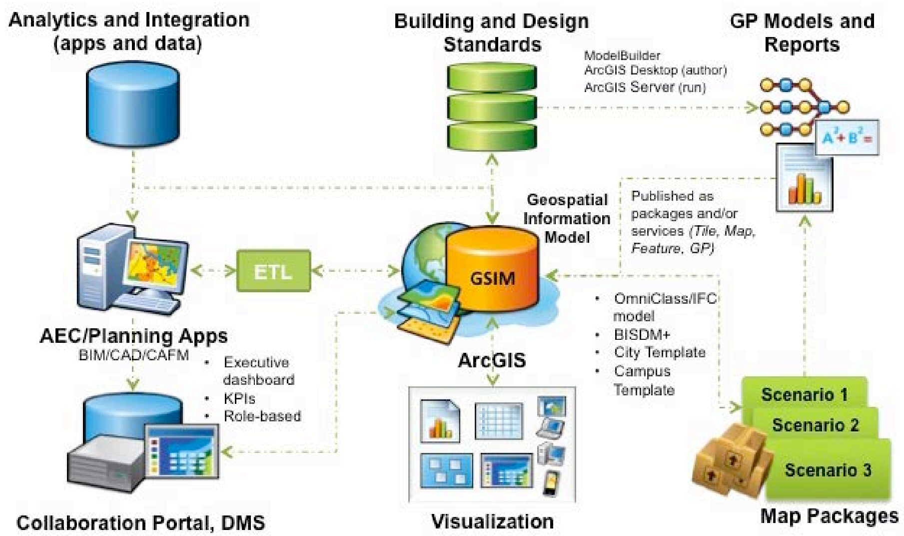


Figure 20: Geospatial Information Model Framework: GIS for the Built Environment

Actualization
Capabilities and Functionality

GIS also provides industry stakeholders with the tools required to actualize performance of the built environment they manage. This capability meets their requirements to

- Achieve predictive capability for performance of the built environment and the facilities within it
- Minimize suboptimization
- Extend facility service life
- Prevent and understand failures

More specifically, it provides the functionality required to manage performance of the built environment in geographic space, including

- Delivering basemap data per required extent
- Converting BIM and CAD to GIS
- Geospatial clash detection
- Mobile condition assessments
- Performance monitoring
- 2D, 3D, and 4D geospatial visualization and analysis
- Trends in location and geography
- Geospatial visualization of inventory, activities, plans, performance, costs, and budgeting
- Dashboard visualization of facility performance

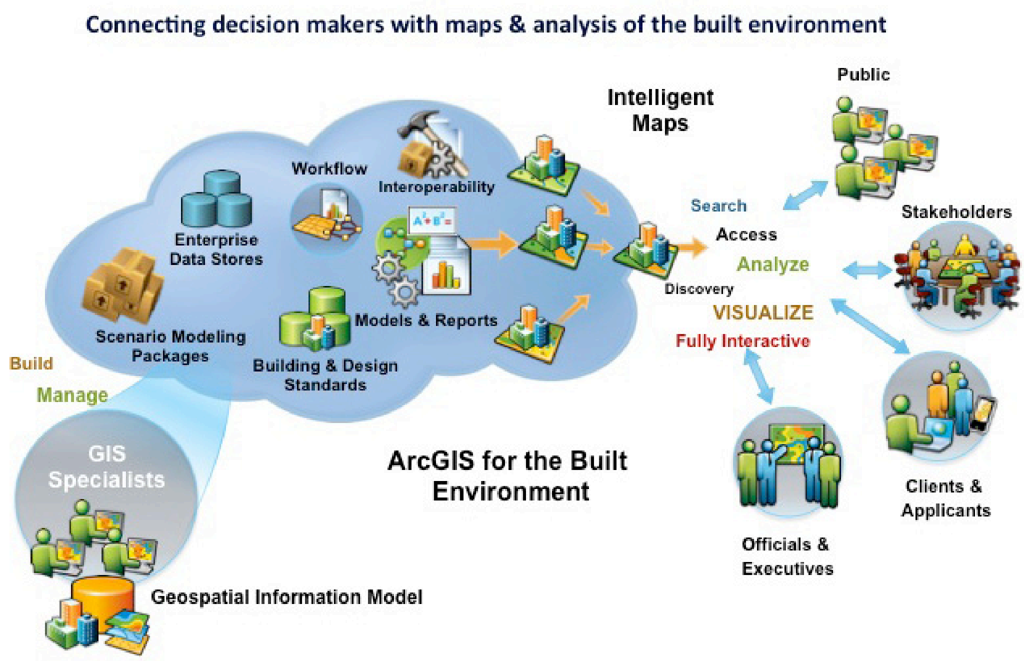


Figure 21: Connecting decision makers with maps and analysis of the built environment.Okay,

The Steps to Optimize Performance

Step 1—Systems Integration

Integrate with key stakeholder identified systems and connect other authoritative data to the geospatial information model. These are the data warehouses required for FM utilization operations. Most often, these include

- CAFM
- Integrated workplace management system (IWMS)
- Inventory management system (IMS)
- Financial management system (FMS)
- Document management system (DMS)
- Construction management system (CMS)
- Building automation system (BAS)
- Computer maintenance management system (CMMS)
- Personnel management system (PMS)

Step 2—Standards

Actualize optimal performance by creating a database of relevant standards tied to associated GIS spatial objects; in other words, join the space and functional adjacency standards for an agency or an organization to building-level spaces represented in GIS. In this manner, delta reporting[66] can be enabled for objects that industry stakeholders require to be represented in GIS.

Step 3—Delta Reporting

Provide the results (visual and tabular) of the delta report in GIS and represent the key performance indicators (KPIs)[67] for performance in geographic space. Once the built environment has been virtually modeled in the geospatial information model, facility design and project management teams can perform almost real-time assessments of design scenarios throughout the FM life cycle based on the impact of KPIs. This capability allows facility managers to model their to-be inventory.

Step 4—Scenario and Adaptive Management

Enable scenario and adaptive management capability from within GIS. Using GIS scenario management tools, stakeholders can lay out and manage multiple views of the model(s), including 2D, 3D, and 4D visualization. Geospatially enabled adaptive management is simply the continuous and rapid analytic evaluation of multiple design scenarios in geographic space. The ability to determine, on the fly, the differences between various alternatives provides GIS users with a powerful tool to conduct spatially based strengths, weaknesses, opportunities, and threats (SWOT) analyses for the purpose of achieving better outcomes. SWOT analysis is a strategic planning tool to identify those aspects of different project alternatives.

The Benefits of GIS Technology as the Underlying Platform

Presently, GIS technology companies such as Esri provide this functionality out of the box. By utilizing a common data model to describe the built environment in combination with tools that essentially take a snapshot of a project alternative, Esri® GIS technology is able to package each scenario and then, because they are all based on the same data model, run a delta report across each package to determine quantitatively how each alternative differs from the other(s).

Through the use of GIS, it is possible to measure spatial coefficients, relationships, and so forth, which is key to obtaining the numerical results needed for any empirical study.[68] In the case of managing the built environment and the facilities within it, the most important numerical result is the metrics defining qualitatively and quantitatively how well managed facilities are performing.[69] The superiority of using GIS to provide a SWOT analysis for the built environment is that facilities in a GIS environment are spatially aware. Conversely, in a CAD-, BIM-, or even CAFM-based system, one is only aware of the objects in those files. Generally, one is modeling only one building at a time. Consequently, one is aware of all the components, equipment, floors, and spaces within that building; however, there is no awareness of other objects in the same class external to that building.

The superiority of using GIS to provide a SWOT analysis for the built environment is that facilities in a GIS environment are spatially aware.

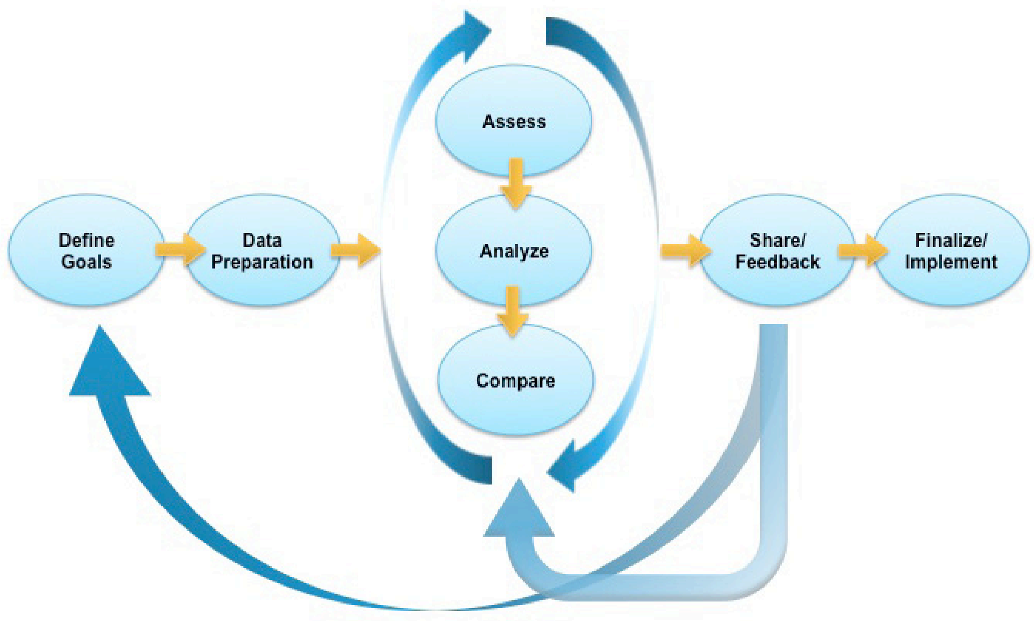


Figure 22: Adaptive Management—A Model for Iterative Decision Making

Tightly coupled to the concepts of scenario management and delta reporting is that of geospatially enabled "adaptive management." It is a geodesign[70] process providing project managers with the ability to rapidly assess and test multiple alternatives, or scenarios, helping them make the most educated and informed decisions based on those alternatives and achieve cost savings and better facility performance. The continuous feedback (see figure 22), combined with the high level of transparency for GIS data among industry stakeholders, provides almost real-time assessment of performance throughout the FM life cycle, enabling course correction as needed. "Transparency of information breeds self-correcting behavior. If everyone understands the goals of the organization and [project managers] make information available . . . it becomes empowering. It breeds a common sense of purpose."[71]

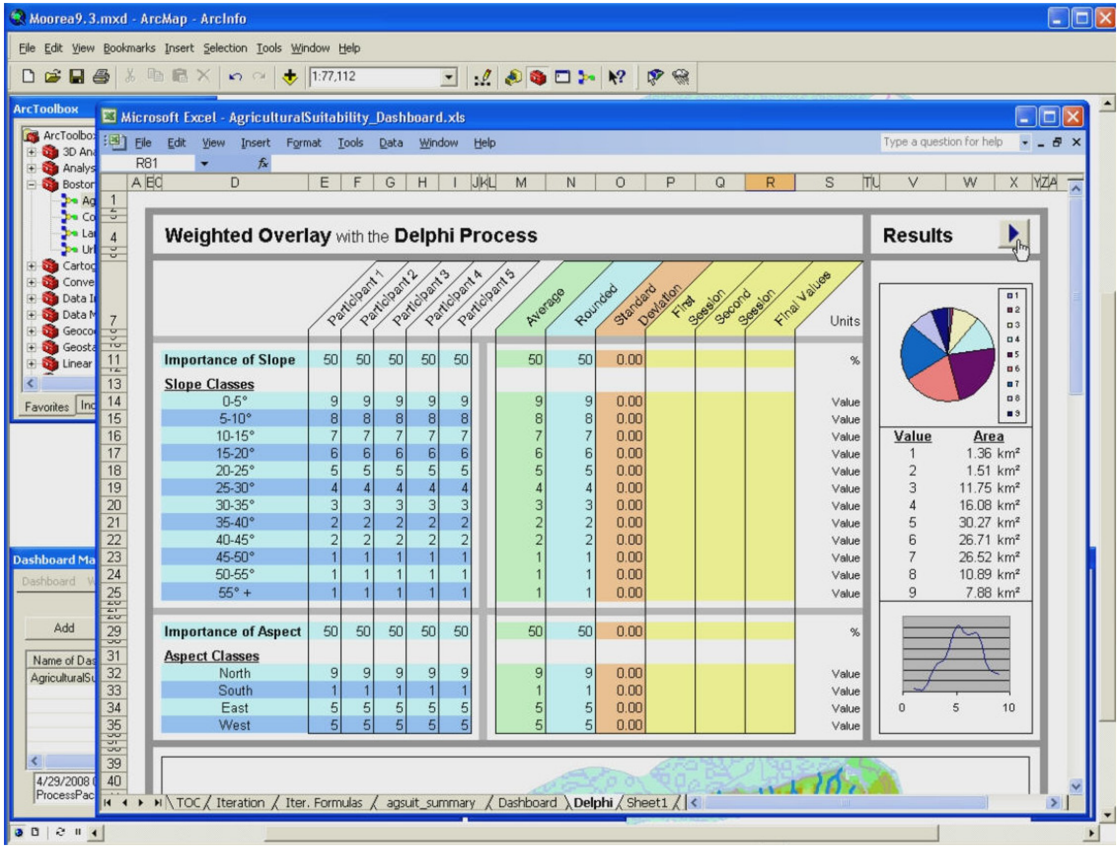


Figure 23: Example of Tabular Reports and Input Forms for a Decision Model Linked to the Underlying GIS Data

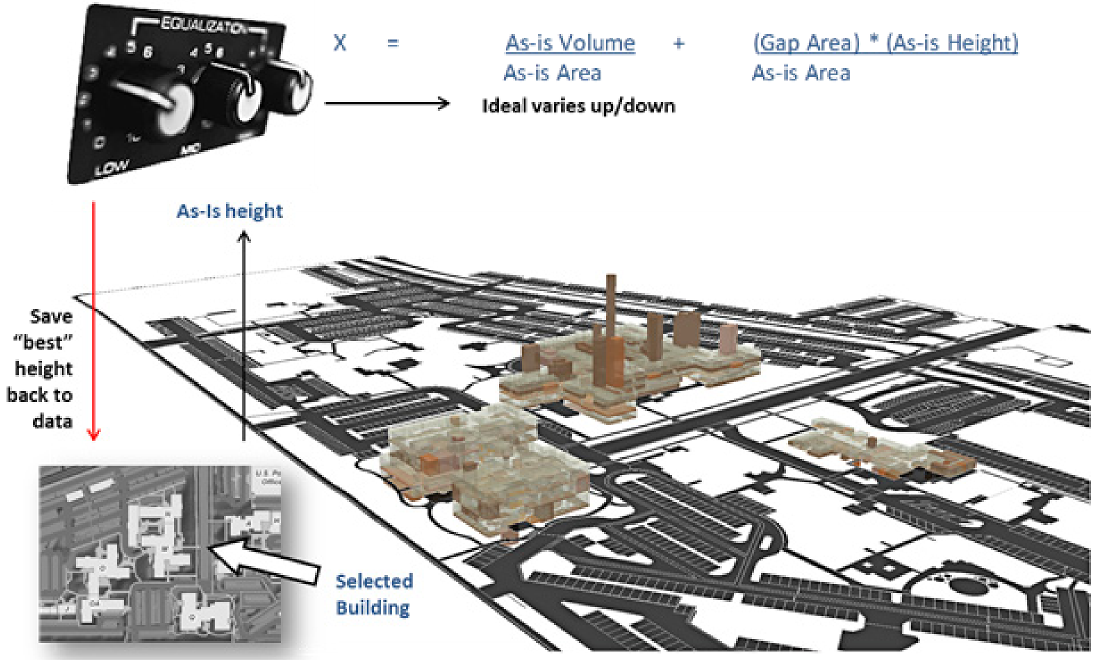


Figure 24: An Example of Using the Geospatial Information Model and Linked Performance Standards to Drive Design of the Built Environment

GIS makes more evident the interplay and interaction between the facilities under consideration and all the other inventoried objects in the natural and built environment.

With GIS, one gains awareness of all other inventoried objects in that feature class, as well as other related feature classes, such as the number and status of all the spaces within a half-mile of a subject building. Moreover, because a building in GIS is spatially aware, it is cognizant of the proximity and impact of features in wholly unrelated domains. For example, one may be able to determine whether there are external environmental factors that may affect the construction process, or if an event such as a protest is planned to occur on a route that would delay the arrival of a critical construction component. In other words, via the overlay of thematic layers, a GIS makes more evident the interplay and interaction between the facilities under consideration and all the other inventoried objects in the natural and built environment. With GIS, it becomes immediately clear what the strengths, weaknesses, threats, and opportunities are for management of the built environment.

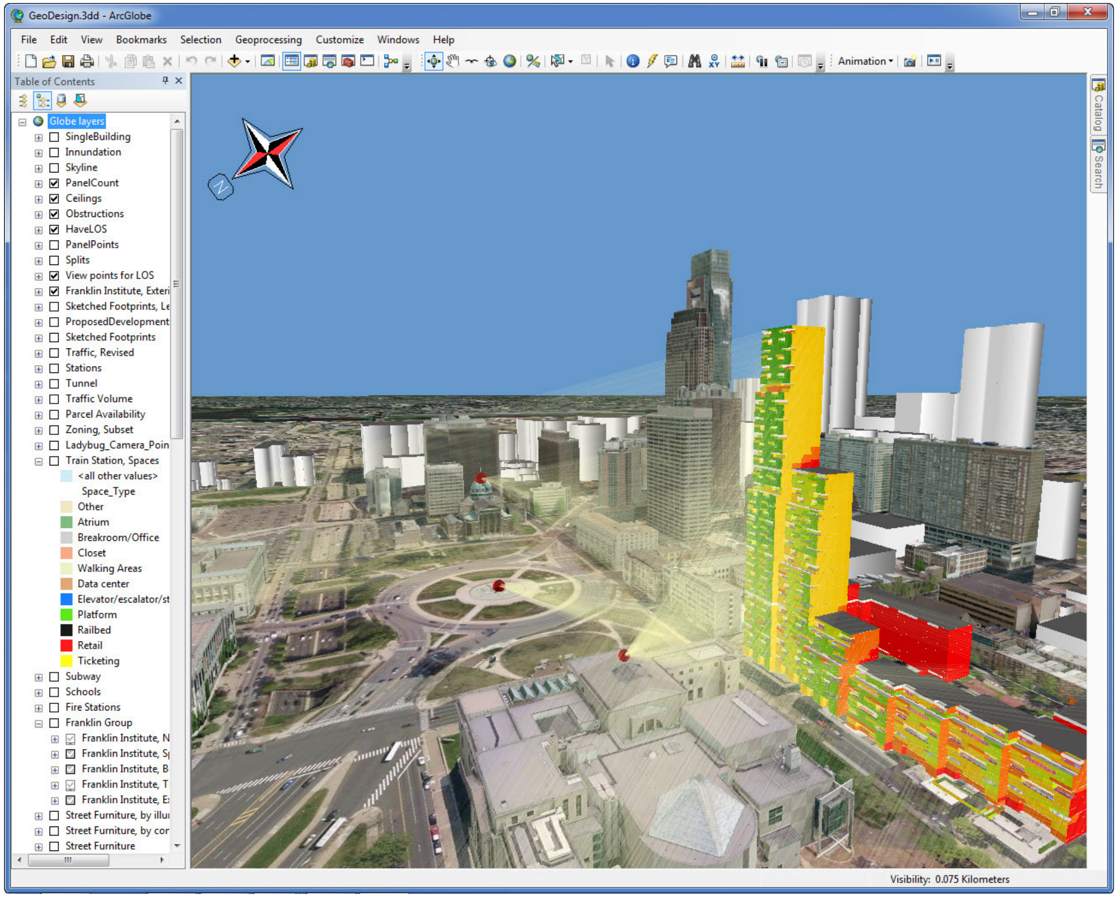


Figure 25: An Example of Using GIS-Based Line of Sight (LOS) Analysis to Determine Desirability of a Proposed Design

Conclusion

To conclude, industry stakeholders can use GIS as an enabling technology to better manage the built environment. It is a powerful system that can provide the support the industry requires to realize more sustainable development practices and patterns.

GIS for Stewardship

GIS provides industry managers and executives with the tools required to be better stewards of the built environment. It provides a common and coordinated awareness enabling stakeholders to visualize and analyze the links between the built environment and the standards, policies, and values that guide its development and ultimate form. This is the awareness required for responsible planning and management of resources to optimize performance and ensure compliance with applicable standards, policies, and values.

GIS for Sustainability

Tools to achieve awareness and optimize performance are vital in mitigating the waste of limited fiscal, material, and personnel resources on marginal and even ill-advised projects. GIS can be used as an enabling technology to help ensure the future viability of the built environment by providing industry decision makers with a means to visualize performance and virtualize scenarios to improve it. This predictive capability enables managers to abandon run-to-failure maintenance strategies and instead adopt strategies for preventive and reliability-centered maintenance, which can dramatically lengthen facility service life, as well as reduce operating costs. The visualization, virtualization, and simulation tools provided by GIS technology better enable industry stakeholders to meet sustainability goals.

GIS for Savings

With the adoption of a more advanced technological approach to shaping and managing the built environment, the growth trend in the cost to construct and maintain facilities can be reversed while simultaneously making them more sustainable. Changes brought by the computing and information revolutions made it possible for the information flow through industry business processes to be more efficient, "while at the same time improving the ability to share information between [them]."[72] Using GIS for a common coordinated view and shared awareness enables better collaboration among the various disciplines required to manage the built environment. The benefits are less scope creep and reduced conflict between phases. Shared awareness reduces the unknowns, leading to fewer project contingencies and risks and lower costs. Furthermore, use of GIS allows managers to avoid unnecessary costs or improve the timing and scope of required future acquisitions.

Summary

GIS technology can be exploited by the industry to provide key facility information for decision makers when they need it. This ability derives from the relational database technology underlying it, as well as its capacity to identify spatially related objects. Spatial relationships allow GIS to merge different worlds of knowledge—it is significant and powerful because it unearths and exposes related patterns that would otherwise go undiscovered. In closing, GIS for the built environment can:

- Provide a common and coordinated view, thereby increasing collaboration and understanding while reducing risk and its associated costs
- Enable visualization, analysis, and comparison of possible alternatives to optimize performance
- Provide the analytic tools for stakeholders to determine which strategy is the best to pursue in the short and long term
- Answer questions regarding the best manner to develop and manage the built environment

Works Cited

Allen, T. (2006, June 12). Commandant, US Coast Guard. (N. T. Patricia Kime, Interviewer)

Ameri, F. K. (2009). *Using SWOT Analysis in Map and Spatial Information Office of SCI*. Tehran, Iran: University of Technology.

buildingSMART alliance (bSa). (2007). National BIM Standard US. *NBIMS Committee.* Washington, DC: National Institue of Building Sciences.

buildingSMART alliance (bSa). (2011, 12 28). *about bSa.* Retrieved 12 28, 2011, from bSa: www.buildingsmartalliance.org/index.php/about/.

buildingSMART alliance (bSa). (2011). National BIM Standard US. *NBIMS Committee*. Washington, DC: National Institue of Building Sciences.

Department of Energy (DOE). (1983). *Non-Residential Buildings Energy and Consumption Survey: 1979 Consumption and Expenditures*. Washington, DC: Energy Information Administration.

Department of Energy (DOE). (1995). *Buildings and Energy in the 1980's (DOE/EIA-0555(95)/1*). Washington DC: Energy Information Administration.

McElvaney, S. (2012, 09 16). Project Manager, Esri GeoDesign Services. (P. Wallis, Interviewer)

National Institute of Science and Technology (NIST). (2002). NIST 04-867: *Cost Analysis ofInadequate Interoperability in the Capital Facilities Industry.* Washington, DC: NIST.

National Institute of Science and Technology (NIST). (2007). *NISTR 7417—General Buildings Information Handover Guide: Principles, Methodologies & Case Studies.* Washington, DC: NIST.

National Research Council (NRC). (2011). *Predicting Outcomes from Investments in Maintenance and Repair for Federal Facilities.* Washington, D.C.: The National Academies Press.

National Science and Technology Council (NSTC). (2008). *Federal Research and Development Agenda for Net-Zero Energy, High Performance Green Buildings.* Washington, D.C.: NSTC.

OCCS Development Committee. (2012, 02 08). *OmniClass: A Strategy for Classifying the Built*

Environment. Retrieved 02 07, 2012, from www.omniclass.org.
Pacific Northwest National Laboratory. (2010). *Buildings Energy Data Book*. Washington, DC: Department of Energy.
Sano, M. (2003). *Integration of the SWOT Analysis as a Coastal Management Tool with a GIS.* Genova: University of Genova.
The Federal Facilities Council Ad Hoc Task Group on Integrating Sustainable Design, L.-C. C. (2001). *Federal Facilities Technical Report No. 142 "Sustainable Federal Facilities"*. Washington DC: National Academy Press.
US Census Bureau. (2011, 12 28). *US Census 2012 Statistical Abstract—Construction & Housing.* Retrieved 12 28, 2011, from US Census: www.census.gov/compendia/statab/cats/construction_housing.html.
US Department of Commerce, Bureau of Economic Analysis. (2011, 12 28). US BEA, *National Economic Accounts: Current Dollar and Real GDP.* Retrieved 12 28, 2011, from US DOC, BEA: http://www.bea.gov/national/xls/gdplev.xls.
US Department of Housing & Urban Development (HUD). (2011, 12 28). *US Housing Market Conditions.* Retrieved 12 28, 2011, from HUD.gov: www.huduser.org/portal/periodicals/ushmc.html.
Virilio, P. (1993). *"The Third Interval: A Critical Transition" In Re-Thinking Technologies.* Minneapolis: University of Minnesota Press.

About the Author

Patrick Wallis is a project manager with Esri, providing technical expertise in support of facilities management, master planning, ports, and maritime projects. He is an architect and designer by training (M.Arch, LEED AP), as well as a certified planner (AICP) and GIS professional (GISP), with nearly 14 years' project experience shaping and managing the built and natural environment. His technical expertise is in facilities acquisition, real estate management, municipal and master planning, economic analysis, and GIS solutions.

Wallis' past work experience includes positions as a senior planner and portfolio manager for the US Coast Guard (USCG), senior planner for the Town of Moraga, and US Army Corps of Engineers officer. Prior to working at Esri, he spent almost seven years with USCG, where he was responsible for the performance of more than $3 billion in facilities and real estate. In that position, he supervised numerous regional strategic planning efforts including the creation and use of improvement plans, master plans, and specific plans. He was also appointed to numerous IPTs to reengineer the Coast Guard's civil engineering program and was a member of the Department of Defense Real Property Classification Panel. Wallis also serves as a member of the NBIMS US Committee (2011–present), and the NBIMS US BIM/GIS Integration Team (2011–present).

Notes

[1] "US Capital Facilities Industry Encompasses the Design, Construction, and Maintenance of Large Commercial, Institutional, and Industrial Buildings, Facilities, and Plants." Cost Analysis (National Institute of Standards and Technology [NIST], 2002), iii–iv.

[2] Virilio, "The Third Interval," 1. Simultaneously "here" and elsewhere. In Paul Virilio's "The Third Interval," published in 1993, tele-present is used to convey the compression of intervals of time (duration) and space (extension), via use of advanced technologies, based on the absolute speed of electronic transmission. He describes this as the third interval of the title. This speed is not used in the traditional sense of quickly traveling great distances, but rather to "see, to hear, to perceive, and thus, to conceive more intensely the present world." Virilio held that "the sudden emergence of an interval of the third type," signaled the world was undergoing a radical transformation affecting traditional human relationships with the environment."

[3] NIST, Cost Analysis, 21.

[4] Pacific Northwest National Laboratory, Buildings Energy Data Book, tables 1.3.1, "Estimated Value of All U.S. Construction Relative to the GDP," and 1.3.2, "Value of New Building Construction Relative to GDP, by Year."

[5] Pacific Northwest National Laboratory, Buildings Energy Data Book, table 1.3.1. Includes renovation; heavy construction; public works; residential, commercial, and industrial new construction; and noncontract work.

[6] 2010 dollars.

[7] National Research Council (NRC), Predicting Outcomes, S-2.

[8] 2010 dollars.

[9] US Department of Commerce, Bureau of Economic Analysis, 2011, National Economic Accounts: "Current Dollar and 'Real' Gross Domestic Product."

[10] Pacific Northwest National Laboratory, Buildings Energy Data Book, table 2.3.3, "Residential Aggregate Energy Expenditures, by Year and Major Fuel Type."

[11] Pacific Northwest National Laboratory, Buildings Energy Data Book, table 2.1.4, "Residential Delivered and Primary Energy Consumption Intensities, by Year."

[12] Pacific Northwest National Laboratory, Buildings Energy Data Book, table 1.3.2, "Value of New Building Construction Relative to GDP, by Year."

[13] The Federal Facilities Council, Sustainable Federal Facilities, 1.

[14] NIST, Cost Analysis, iii–iv.

[15] Ibid.

[16] The Federal Facilities Council, Sustainable Federal Facilities, 4.

[17] "Stove-piping" references the long vertical silos, or flutes, that directed smoke away from the fires contained within a stove—each stove having its own pipe. In this context it uses the image of multiple long vertical silos, each separate from the other, as an analogy to a business process where each stovepipe represents a separate discipline with no real connection to other disciplines, to the detriment of the entire process.

[18] Ibid., 1–3.

[19] Ibid., 1.

[20] NIST, General Buildings Information, 1.

[21] Scope creep refers to the incremental expansion of a project's initial scope, without formal approval by established stakeholders, and without an approved increase in its due date or funding.

[22] OCCS Development Committee, 2012. The diagram has been adapted from OmniClass table 31, "Phases," which lists the primary FM phases as Conception, Project Delivery Selection, Design, Construction Documents, Procurement Stage, Execution, Utilization, and Closure. Stakeholder roles are derived from OmniClass table 34, "Roles." Copyright © 2011 the Secretariat for the OmniClass Development Committee. All Rights Reserved. www.omniclass.org/.

[23] Primary sources are Department of Energy's (DOE) Buildings Energy Data Book, US BEA Current-Dollar and "Real" Gross Domestic Product tables, US BLS Historic CPI Index (1913–2011), and US Census Median Home Values 1940–2000.

[24] The Federal Facilities Council, Sustainable Federal Facilities, 1–3.

[25] The Federal Facilities Council, Sustainable Federal Facilities.

[26] NIST, Cost Analysis, 2–3.

[27] Ibid.

[28] Ibid.

[29] NIST, General Buildings Information Handover Guide, 2007, 22.

[30] NIST, Cost Analysis of Inadequate Interoperabiltiy, 2–3.

[31] Ibid.

[32] NIST, General Buildings Information Handover Guide, 1. The original cash values from this reference were converted to 2010 dollars using the average US Consumer Price Index change from 2007 to 2010, as reported by the US Bureau of Labor Statistics at ftp://ftp.bls.gov/pub/special.requests/cpi/cpiai.txt

[33] Ibid.

[34] Ibid., 1.

[35] 2010 dollars.

[36] NIST, Cost Analysis of Inadequate Interoperability, 2002, ES-6.

[37] NIST, Cost Analysis of Inadequate Interoperability, ES-3.

[38] Pacific Northwest National Laboratory, Buildings Energy Data Book, 3.4.1.

[39] Ibid., 1.1.3.

[40] Based on a compound annual growth rate (CAGR) from the years 1980 to 2003 of .56% for the US commercial floor space to building ratio, with floor space as the numerator and the number of buildings as the denominator, as reported by the US Energy Information Administration's Commercial Buildings Survey, table B1. See Internet site: http://205.254.135.7/emeu/cbecs/cbecs2003/overview1.html.

[41] Pacific Northwest National Laboratory, Buildings Energy Data Book, table 3.2.1, "Total Commercial Floorspace and Number of Buildings, by Year."

[42] US Department of Commerce, National Economic Accounts. 2010 dollars.

[43] Data points from 1979 are found in DOE, Buildings and Energy in the 1980s, Table 2.3, "Number of Commercial Buildings and Total Floorspace, 1979 and 1989." This data excludes residential, industrial, agricultural, laboratory, and federal government facilities. Data points from 2010 are based on Pacific Northwest National Laboratory, Buildings Energy Data Book, Table 3.2.2, "Principal Commercial Building Types, as of 2003 (Percent of Total Floor Space)". Projected growth from the 2003 data is based on a compound annual growth rate (CAGR) of .56% from the years 1980 to 2003 for the US commercial floor space to building ratio, with floor space as the numerator and the number of buildings as the denominator.

[44] Pacific Northwest National Laboratory, Buildings Energy Data Book, table 2.2.1, "Total Number of Households and Buildings, Floorspace, and Household Size, by Year." Sourced to the Statistical Abstract of the US 2008, Oct. 2007, No. 948, p. 626, 1980–2000 households, No. 2–3, pp. 7–8 for population; EIA, Annual Energy Outlook 2011 Early Release, Dec. 2010, table A4, pp. 9–10 for 2005–2030 households, and table A19.

[45] US Census Bureau, Census 2012 table 971, "Characteristics of New Privately Owned One-Family Houses Completed."

[46] 2010 dollars.

[47] BEA, Current and Real Economic Gross Domestic Product (1929–2011), www.bea.gov/national/xls/gdplev.xls.

[48] Pacific Northwest National Laboratory, Buildings Energy Data Book, table 2.1.4, "Residential Delivered and Primary Energy Consumption Intensities, by Year."

[49] 49 percent and 42 percent, respectively.

[50] Pacific Northwest National Laboratory, Buildings Energy Data Book, tables 2.1.4, "Residential Delivered . . ." and 2.2.1, "Total Number of Households and Buildings, Floorspace, and Household Size, by Year."

[51] Ibid.

[52] Periods of flat growth in residential floor space represent a lack of data points for those years.

[53] The Federal Facilities Council, Sustainable Federal Facilities, 12.

[54] NPV is an economic summing technique that accounts for the time value of money (e.g., a dollar today is worth more than a dollar five years from now).

[55] HUD, US Housing Market Condition.

[56] bSa, About bSa, www.buildingsmartalliance.org/index.php/about/.

[57] bSa, National BIM Standard.

[58] Ibid., 21.

[59] Ibid.

[60] Ibid.

[61] Per the official buildingSMART website for the IFC standard, http://buildingsmart.com/standards/ifc/model-industry-foundation-classes-ifc., "IFC format is registered by ISO as ISO/PAS 16739 and is in the process of becoming an official International Standard ISO/IS 16739."

[62] www.omniclass.org/.

[63] Ibid.

[64] Awareness: An "as-is" inventory, noting how many, how much, and where based on standards, values, and science.

[65] Actualization: A "to-be" inventory, noting optimized quantities and locations based on standards, values, and science. These are documented qualitative, quantitative, and functional requirements the client is subject to (e.g., International Building Code, ground transportation "level of congestion" standards, and health department facility space standards). The to-be represents the inventory that is required and not the one actually on hand.

[66] Delta reporting documents the difference between the as-is and to-be inventories.

[67] KPIs are documented qualitative, quantitative, and functional standards to which industry stakeholders, including facility managers, are subject, such as recapitalization requirements, repair requirements, and Facility Condition Index (FCI).

[68] Sano, Integration of SWOT Analysis, Page 3.

[69] F. Ameri, Using SWOT Analysis.

[70] "GeoDesign provides a new way of thinking that integrates science and values into the design process, by providing designers with robust tools that support rapid evaluation of design alternatives and the probable impacts of those designs. It provides the framework for exploring issues from an interdisciplinary point of view and for resolving conflicts between alternative value sets. In this sense, it can be seen as an integral framework for intelligent, holistic design that moves from designing around geography to actively designing with geography." McElvaney (project manager, GeoDesign Services, Esri), in interview with the author, September 2011.

[71] T. Allen (commandant, US Coast Guard), in interview with N. T. Patricia Kime, June 2006.

[72] NIST, General Buildings Information, 2.

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