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White Paper—Smart Cities Series

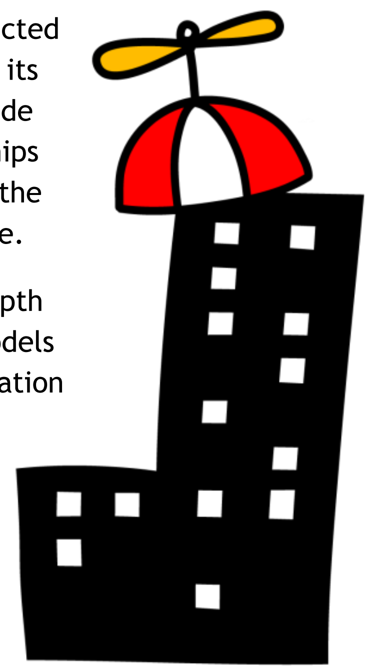
Smart N-dimensional Information Modeling

because smart cities need smart information modeling

Workflow Efficiency <> Entity Efficiency <> Quality

In every industry, people are striving to deliver more with higher quality at lower cost. To do so, many industries have turned traditional ways of doing things upside down—they have engaged in huge paradigm shifts to reinvent their business processes. The driver for successful reinventions can always be traced to better alignment with **workflow**.

We define workflow as the total flow of functional operations, conducted by people or computers or machines, that allow an entity to execute its mission. Workflow encompasses the systems and processes that provide the optimal path to success as well as the interactions and relationships among them. The more efficiently any entity executes its workflow, the greater the quality of its operations and the more successful it will be.



New technologies allow workflows to be modeled in much greater depth and detail than has been done to date. Traditionally, information models were built to describe single entities—for example, a building information model (BIM) describes the building fabric. To support workflow optimization at an enterprise or higher level, the information models must be layered to encompass multiple entities, their respective workflows, and the interaction among workflows. Advances in computing and communications technologies now allow any enterprise to build smart n-dimensional information models (SmartNIM).

The Smart City of the future will be the city operated through a SmartNIM that models all of the workflows that contribute to an enhanced civic experience. These will not only include human-system interaction models but also, for example, utility use and operational models such as the Smart (sic) Grid—which really is not. You cannot build a Smart City as we are attempting to do it today, with dumb support models. The static uni-directional reporting systems currently in place (which are labeled “Smart Grid” but are essentially just one half of the bi-directional system Samuel Insull put in place in the 1890s) and traditional Planning and Zoning systems are a good example of how not to do it in this century.

An Example from the Last Century: Building Information Modeling

In the 20th century building industry, the workflow of building users was the last parameter taken into consideration during the design-build process—if, indeed, it was considered at all. Buildings were designed and built with little or no reference to the workflow that the building would house, nor was the interplay between building and workflow ever reviewed after the building was completed. A building designed in such a way will almost inevitably be unsuccessful, where a successful building is defined as one that facilitates the workflow of its inhabitants. (We are making an important distinction here between the success of the building and the success of the process of building, maintaining, and demolishing it.) Until recently, buyers have accepted successfully completed unsuccessful buildings, or accepted defining the success of a building by its resale value and not how well it serves its inhabitants, because that is the way it has always been—but it doesn't have to be that way!

Building New Paradigms

A few pioneers are breaking the old paradigms, and the results of their work serve to emphasize its importance. Take the work of Gensler[1], a global architecture, design, planning and consulting firm working with clients to support their strategies and improve business performance through design excellence. Gensler's whitepaper, These Four Walls: The Real British Office,[2] explores the effect of workplace design on productivity, job satisfaction, recruitment, and retention.

In one cited case study, a client states that since moving into new offices designed by Gensler, staff retention has improved 150%. Since the cost of turnover is variously estimated as 30% to 150% of yearly salary, such a reduction adds significantly to that company's bottom line. Gensler, in fact, practices what we call workflow-driven design for office spaces. Their whitepaper, which examines such designs in the UK, cites a British Council for Offices[3] (BCO) estimate that building construction, building operation and staff salaries are in the ratio of 1:1.5:15. Building on that, another BCO paper[4] estimates that a 2% to 5% increase in staff performance can cover the total cost of providing their accommodation. In fact, the Gensler whitepaper estimates that, accumulating the impact of workflow-aligned design on job satisfaction, recruitment and retention, the potential productivity increase traceable to workflow-aligned building design is on the order of 19%.

The principle of designing to workflow extends to all manner and nature of building, as well as to the surroundings of the building and ultimately to the city within which it is located.

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[1] http://www.gensler.com
[2] http://www.gensler.com/uploads/documents/7fcf25b05a2c0839c44655d1645c40ec.pdf
[3] http://www.bco.org.uk/
[4] The Impact of Office Design on Business Performance, British Council For Offices, June 2006

The trend toward requiring developers to design Master Plan Communities (albeit fairly primitive and with little feedback from the users when finished) rather than racks of housing acknowledges that a community has a workflow, a sequence of interrelated activities that take place within it, and that designing to that workflow improves quality of life in that community, which in turn gives greater value to the community and consequently to the developers' profit line. It's important to note also that workflows are dynamic and evolve in real time; they are not static historical reports, and designing to workflow means designing for flexibility and outcomes.

In the 21st century, leaders in educational reform are arguing that school design can impact educational outcome as much as curriculum design. Innovative healthcare leaders are pointing to the impact that facility design can have on outcomes in their industry. Just as new advances in multi-dimensional CT imaging are revolutionizing medical treatment for human beings by allowing doctors to view the workings of the human body in different ways, so will n-dimensional imaging revolutionize the design of the facilities where that treatment is delivered by imaging the workings of the human workflow systems in the interior of the facilities. This realization that the ability to execute soars when form follows function is repeated again and again in multiple sectors of our society. The eventual waste caused by ignoring this principle is incalculable, as is the impact on the non-profit sector, which is frequently called on to mitigate the social results of dysfunctional design.

The 2-Dimensional Legacy

So why are buildings not designed from the workflow out—a design/build process driven by n-dimensional modeling? Real n-dimensional models are readily achievable today at modest cost using existing technologies and building on legacy applications where it makes sense to do so. Real 3- and 4-dimensional models have been used for decades in a few industries, such as the design and manufacture of airplanes and petrochemical plants. In the 21st century, these industries have moved firmly into n-dimensional technologies. These same n-dimensional models also have templates built from successful entity operational knowledge (see Southwest Airlines for examples), templates that can be replicated to drive the operational quality of the entity even higher.

In the construction industry, however, 2-dimensional representation remains the norm. Most architectural firms have been pushed into the 3-dimensional modeling arena, although even the existing 3-dimensional modeling tools are frequently just seen as rendering tools and not fully utilized for design. In the trades, mechanical contractors led the move to 3-dimensional modeling as a working tool, and a few construction contractors have embraced 4-dimensional modeling as a working tool. Some outlier firms, led by mechanical engineering firms, are beginning to understand and apply 5-dimensional modeling. But true n-dimensional modeling requires a paradigm shift[5] in the approach to construction, and there, we suspect, is the sticking point. As other industries are achieving success by partnering with their clients, the building industry must learn to build for their clients' workflows, for the total cost of ownership over the lifespan of the entity.

N-Dimensional Modeling

Table 1 clarifies what we mean by n-dimensional modeling by comparing 1-, 2-, 3-, 4-, 5- and n-dimensional models. Some companies are touting their 4-dimensional modeling capabilities today under diverse labels (including BIM and VDC), but if you examine what they are really offering, the offerings fall under the definition of pseudo-4-dimensional modeling that we give in the table section "The 20th Century Way."

How do we distinguish between "real" and "pseudo" 3- and 4-dimensional modeling? Let's begin by reviewing some definitions:

- Model: schematic or mathematical representation of a real system that accounts for its known properties and is used to simulate a process, predict an outcome, or analyze a problem
- Dimension: measurable size; Cartesian coordinate; aspect, feature, characteristic
- Parametric design: design process driven by the application of parameters and constraints that represents objects through vector geometry

We begin with the assertion that true n-dimensional modeling must be parametric—it encompasses all three definitions of "dimension," but is driven by the third. It represents the object of the model by generating a virtual representation based on defined parameters (the dimensions defined as the aspects, features and characteristics of the object). Such a model can be manipulated directly by acting on the model itself as it is displayed on screen or it can be manipulated by changing one or more parameters. Moreover, the model is dynamic, since it is possible to define parameters such as the laws of gravity or hydrology or the characteristic movement patterns of crowds as dimensions of the model. It also incorporates feedback loops that report back the calculated (pre-construction) or real (post-construction) impact of specific design decisions. This allows the viewer to see the downstream consequences of design decisions as dynamic simulations during the pre-construction phase and opens the door to real-time "what if" analysis before, during and after construction.

Expanded bi-directional communication is also integral to n-dimensional models. In Table 1, 5-dimensional modeling is defined as 4-dimensional modeling with a feedback loop from the real world to the model. For example, a thermostat sends an ambient temperature reading to the controlling model and the model adjusts the thermostat accordingly.

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[5] Our "future history" article, "Risonanza™: AATG's Quantum Monitoring Ushers in the Future of Cyber Information Modeling Systems," projects one possible future arising out of such a paradigm shift.

Table 1. N-Dimensional Modeling Types and Characteristics

Direction of Control	Tools to …	Types of Models	Characteristics
Controlled by construction = lowest initial, highest lifetime cost	Design Bid Build	The 20th Century Way: • 1-dimensional model = planar representation or verbal description • 2-dimensional model = CAD plan • 3-dimensional model = Extruded CAD or isometric view tied to Cartesian coordinates along X-Y-Z axes, created and displayed by raster technology • 4-dimensional model = 3-dimensional model with a non-integrated Bill of Materials (BOM) or project management plan	• Fixed dimensions (size and coordinates) • Closed system • Static
	Design and Build Design, Build, and Maintain Building	The Turn of the Century Way: • 3-dimensional model = Parametric model with unlimited Points-of-View (POVs) created and displayed by vector technology; the whole or any of its parts may be moved or resized on the fly and affected components will be altered according to the parameters and constraints defined by the user • 4-dimensional model = 3-dimensional model with integrated project management, containing parametric quality, scope, time and cost information (including bill-of-materials) • 5-dimensional model = 4-dimensional model capable of receiving readings and information from sensors and intelligent components of the structure and sending control instructions back	• Flexible dimensions (size, coordinates and parameters) • Open system • Dynamic • Relational ("complex")
Controlled by workflow = highest value, lowest lifetime cost	Design, Build, and Operate Building	The 21st Century Way: • n-dimensional model = multi-dimensional model with integrated parametric workflow that communicates with all related 1-, 2-, 3-, 4-, and 5-dimensional models	• Flexible dimensions • Open system • Dynamic • Relational • Bi-directional real-time
	Operate Entity	"Cyber Resonance Model Imaging linked to Real Time Structures," as described in our "future history" article, "Risonanza™: AATG's Quantum Monitoring Ushers in the Future of Cyber Information Modeling Systems."	

Today, we have the ability to build truly “smart” buildings with Heating-Ventilation-Air Conditioning-Data (HVACD) systems with integrated SCADA[6] using ubiquitous sensors and power over Ethernet to intelligently operate both the building and the business equipment in it to support the workflow. In an n-dimensional model, the HVACD module also takes into consideration waste heat from office equipment and temperature load from scheduled room occupancy based on employee calendars, for example, and proactively adjusts settings in anticipation of use.

The system also knows where the human inhabitants are and how they move through the building. It realizes that the air they breathe consists of nitrogen, oxygen, argon, neon, helium, methane, krypton, hydrogen, water vapor, and carbon monoxide as well as the carbon dioxide that they inhale, so that carbon dioxide is not the only air component that is measured by air quality sensors. In Los Alamos, in a room with huge glass windows overlooking the great views of the mesa, scientists (being who and what they are) played around with the air controls of the room and built in some Rube Goldberg devices, one of which supplied controlled oxygen (yes, they knew it was a fire hazard). It should come as no surprise that everyone who met in that room, knowing or unknowing of the adjustments that had been made, commented on what a fantastic place it was for really productive meetings. Next up for them was natural light control, which made the results even better.

It’s not coincidental that the oxygen-enriched meeting room was built in a laboratory. Often, when a builder or architect is queried as to why this or that was not considered for inclusion in the building design or operation, as it obviously improves the human experience of the environment, the answer is a curt “IBC.” A building can be constructed in complete compliance with International Building Code (IBC), but in such a way that the humans inside it will be miserable. The IBC is a static paper code enforced at arbitrary inspection points during construction; the resulting structure is dynamically used by human beings who follow an active workflow that responds to changes in the real world. Chaos and catastrophe are predictable outcomes of the disconnect between paper code and evolving workflow.

This disjunction is just one example of inefficiencies introduced by the use of paperwork and forms as surrogates for the real world. Before the IBC, before LEED, before Green Building, there was bioclimatic design and architecture—design focused on the relationships between climate and living beings. Bioclimatic architecture (which of course was not called that at the time) was what, thousands of years ago, led to buildings in deserts designed to self-cool and capture water; building compounds in tropical climates designed to self-cool and dissipate humidity; and habitable environments that are warm, dry, and comfortable in arctic weather.

[6] SCADA stands for **S**upervisory **C**ontrol **A**nd **D**ata **A**cquisition, a computer system for collecting and analyzing real time data. Power plants, refineries, water systems and telecommunications are among the industries that have been routinely using SCADA systems to monitor and control their operations since the 1990s.

Somewhere along the way, while incorporating GIS/GPS/BIM/VDC and massive computing power into the design process, the emphasis in architectural design has shifted to focus on the shell in isolation, and its self-referential efficiency only. The building profession has lost sight of the fact that the fundamental intent of a building is to moderate the relationship between human beings and their climatic environment as it has narrowed its focus to accumulating points in abstract scoring systems. This is not unique to the building profession: "Smart" grid technologies focus on the grid's own state, not on whether users are able to execute tasks that depend on the energy delivered by the grid to their satisfaction. This closed-loop self-inspection is exactly what Edison and Insull railed against in the 1890s. In fact, Edison and Insull knew more about the needs and satisfaction of their customers than any of today's power companies.

Smart N-dimensional Information Modeling

Consider, for instance, a smart n-dimensional model for an industrial campus that incorporates the BIM for each building, becoming an operational control program and making continuous adjustments to the buildings' operating infrastructure, perhaps even to the internal layout, to ensure that building operation is optimized for business success. If this SmartNIM were also connected to a truly smart electrical grid, it would be exchanging information with the power producer to optimize the consumption-production interaction. If this SmartNIM were also to incorporate the business information systems, it could track productivity and profitability against projections and make adjustments accordingly—including bioclimatic adjustments to the building. This, then, is a true 21st century SmartNIM system, and it is an essential component of the executive's control panel, perhaps even the primary interface for today's executive to control the operation of the entity.

What happens if we extend this concept to a more sophisticated environment, like healthcare? What if the whole system were to "understand" the relationship between patient wellbeing and how the workflows in the hospital or health environment operate? Ask any architectural company today how they tailored the design of the healthcare infrastructure to match the workflow of the caregivers with patient wellbeing and do not be stunned when you are asked "What workflow?" In short, if we are really concerned about patient wellbeing, we need to push for a dynamic change in how we view any of these facilities.

Some Definitions

We've described a SmartNIM as a dynamic, n-dimensional virtual surrogate of a business and the environment within which it operates. Information about the workflow of the business is incorporated into the model and the model continues to collect and deliver information about how the business is operating throughout the life of the business. It is, in fact, a real-time on-line simulation of the business that operates in the virtual world in every respect as its counterpart operates in the real world.

In this context, "business" describes any activity involving actions and transactions, commercial or non-commercial. One of our family members is an engineer for the National Park Service: she is involved in the "business" of designing and implementing ecostructure for preserving our national parks. So SmartNIM can drive any organization or entity, whether for profit or not for profit, private sector or public. In his monograph *Good to Great and the Social Sectors,* Jim Collins points out "The critical distinction is not between business and social, but between great and good."[7] Collins continues to challenge the perception that the social sector faces different realities than the business sector by driving home the point that the success of an organization depends on its ability to deliver superior performance over a long period of time. This is true whether the organization is an airline, a builder, a supermarket, a city, a school district, or a YMCA.

Responding to Change

A key concept in Collins' book *Good to Great* is the acknowledgement of the fundamental dichotomy that drives a great business: "enduring great companies preserve their core values and purpose while their business strategies and operating practices endlessly adapt to a changing world."[8] He refers again to this concept in the monograph for the social sectors, and shows how it remains valid for any type of organization. We quote Collins, but any number of experts and analysts have pointed out the same principles: the successful organization will respond nimbly and quickly to changing conditions but never veer from its vision (or mission or purpose or core competency or …).

What Collins calls the core values and purpose of the organization, in our lexicon, are the prime parameters, the guiding principles that inform the model. These are constant, they do not change over time and they should always drive the workflow, the operation of the organization. Business strategies and operating practices (in our lexicon, the goals and the workflow) are subject to—in fact required to—change in response to changing conditions. How fast and how effectively an organization adapts its goals and workflow to changing conditions, as well as how precisely those changes cleave to the original (and constant) guiding principles, determines how successful it will be.

SmartNIM Guides Pro-Active Change for Superior Results

A SmartNIM is a model that accurately represents the physical and strategic reality of an organization. The representation is driven by parameters, variables, or constants that define

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[7] Collins, Jim. *Good to Great and the Social Sectors*. New York: HarperCollins, 2001, p. 195
[8] Collins, Jim. *Good to Great*. Boulder: Jim Collins, 2005, page 2

the dimensions of the organization. For example, if we build a SmartNIM for a flood control authority, it begins with the topography and the hydrology of the region (constants) and it allows immediate visualization of the impact on a watershed of paving or building over specific areas (variables). It allows the authority to specify the rate of flow permitted through each channel or river (parameters). Flood control structures—dams, detention ponds, drainage channels, etc.—are shown as built and are also available in a library to rapidly demonstrate what if scenarios. Those that are already built collect information, as do remote weather monitoring stations that are tied into the BIM, about the real fall and flow of water and compare that information to the hydrology assumptions that drove the original model. The feedback informs the model: if the assumptions are validated over time, the design of the next structure is based on the same calculations; if they are invalidated, the model suggests revised hydrology calculations for that terrain based on the collected experience.

A SmartNIM is a single, interconnected system that correlates intangible values, tangible real constants, operational reality, and real and projected costs. It allows different stakeholders to access different viewpoints into the business or enterprise, from a mile-high bird's eye view to the drill-down view that provides actionable details, and to access these viewpoints through a simple web-based interface that does not require individual desktop licenses. All of the supporting documentation, all of the cost data, all of the detailed design documents are accessible through the same web-based interface. If necessary, security protocols limit access to sensitive information through password login or other security methods.

In the example cited above, for instance, the Executive Director of the flood control authority should be able to — in a single session and without leaving his keyboard — bring up an overview satellite or aerial photographic image of his entire area of authority, drill down to a close-up of a specific culvert (perhaps even a web-cam view) access the details of how and when that culvert was constructed (including the specifications and drawings, materials characteristics, manufacturer or construction company that provided it and what it cost) and read both the current and the historical flow of water through that culvert in cubic feet per second. Moreover, the flood control authority's SmartNIM should be able to speak to the county's SmartNIM to determine who owns the land on either side of that culvert and whether maintenance of that particular culvert is the responsibility of the state or the authority, and in fact what maintenance was last performed and by whom.

Let's take a more complex model: a utility director at a university campus who has to look way beyond the seasonal weather cycles that affect demand on an energy system. S/he has to contend with the ups and downs in demand when students and faculty have their seasonal breaks, peaks and valleys in demand that are very different from "normal" utility usage, and still keep the campus functioning. With today's information feedback, a lot of planning ends up being seat-of-the-pants, reacting after-the-fact to not only weather changes, but to load-impacting campus activities and behavioral factors. A SmartNIM template that communicates with the Academic Calendar, enrollment counts, game schedules, event calendars, etc. can proactively anticipate demand and eventually discern operational patterns—invisible with today's systems—to continually improve planning accuracy.

This is done in real time with real world monitoring feeding information to the viewing model, not reactively based on reports requested from a static historical model in a proprietary relational database attached to a GIS system. The operational staff in a smart city, as well as its citizens, should be able to see data that affects them in real time and how that data impacts progression towards achieving the city's quality of life targets. The same can be done with any utility system—energy or water or transportation—and any system function.

If this seems unrealistic, it may be because our expectations have been largely shaped by the sales propaganda of companies that are selling 20th century mass-produced technology, whether it fits or not. As each organization is different, each SmartNIM will be different. There is no one-size-fits-all shrink-wrapped box that delivers a SmartNIM for everyone, but the 21st century is about mass customization, not mass production. A SmartNIM that is based on commercial products integrated with flexible open-source software bridges can include and leverage legacy data sources and processes to provide all the features we have named at reasonable cost and speed.

Assuming that it can be done, why would one want to do it? The answer, again, will vary depending on the organization. If we return to the example from the building industry, a potential productivity increase of from 2% to 19% would seem to make a compelling case for a private company to invest in a SmartNIM for its production campus. For the flood control authority, the ability to leverage the always limited resources of a public agency to provide better protection to its ratepayers is a compelling motive. For a school district, the potential that better learning environments will lead to better student outcomes is a powerful incentive.

The bottom line is that a well-built and well-used SmartNIM can help any organization increase its real value by improving its ability to deliver superior performance over a long period of time. To understand the potential of a SmartNIM, the biggest paradigm shift in thinking that must take place is the realization that, with the SmartNIM, it's the business model that constantly drives the technology model—unlike today, when it is not unusual to see organizations bend their workflow to accommodate a proprietary black-box technology that they have committed to. The kicker for SmartNIM is that it costs half of what today's MIS/IT systems cost, can be deployed in 25% of the time, is far less complex, requires far less training and ramp up time, and is three times more efficient—and can all be done today. Smart Cities need smart systems, yes, indeed!