

ACHIEVING THE NET-ZERO-ENERGY-BUILDINGS “2020 AND 2030 TARGETS” WITH THE SUPPORT OF PARAMETRIC 3-D/4-D BIM DESIGN TOOLS

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INTRODUCTION

The level of man-made CO₂ emissions worldwide climbed to a new record of 30 billion tons in 2010. In 2011, at the COP17 U.N. Climate Change Conference in Durban, South Africa, high-ranking representatives from around the world met again to discuss solutions. For the building sector, numerous energy-efficiency market changes and benchmarking resolutions, like the mandatory E.U. “nearly Net-Zero-Energy-Building (NET-ZEB’s) 2018 and 2020 regulations” for all new public and privately owned buildings are now set up to help minimizing carbon emissions and reverse the negative impact.¹ In the United States, the American Institute of Architects (AIA) adopted the 2030 Challenge as a voluntary program, where participating buildings aim to achieve a 90% fossil fuel reduction by 2025, and carbon-neutrality by 2030.² To accomplish these energy goals, designers must strive to best design and utilize the resources available on a site. However, are these goals of achieving carbon-neutral buildings possible? How can NET-ZEB’s become the curricular standard and practical routine in education and the profession? To date, the basic curricular design process components with integrated project delivery metrics for a robust 3-D/4-D-net-zero regulatory design framework are either incomplete or missing. However, formally-based curriculums have begun to weave carbon-neutral design tools into their pedagogy. This research paper critically compares how these new criteria for digital 3-D-building information modeling (BIM), and “Integrated Project Delivery” are mandating a better integration of collaborative carbon-neutral designs into the curriculum and practice of the profession.

The majority of those in architectural academia have been using generative computation primarily for pure, aesthetic form-finding, without applying zero-carbon-energy-driven global performance metrics and CO₂e reduction strategies to reiterate derived carbon-neutral designs. The advantage of 3-D-parametric design is that it links variables, dimensions, and materials to geometry in a way that when an input or simulation value changes, the 3-D/4-D model automatically updates all life-cycle scenarios and components simultaneously.

KEYWORDS

net zero energy, building information modeling, 3-D and 4-D parametric modeling, architectural education, life cycle analysis, integrated project delivery

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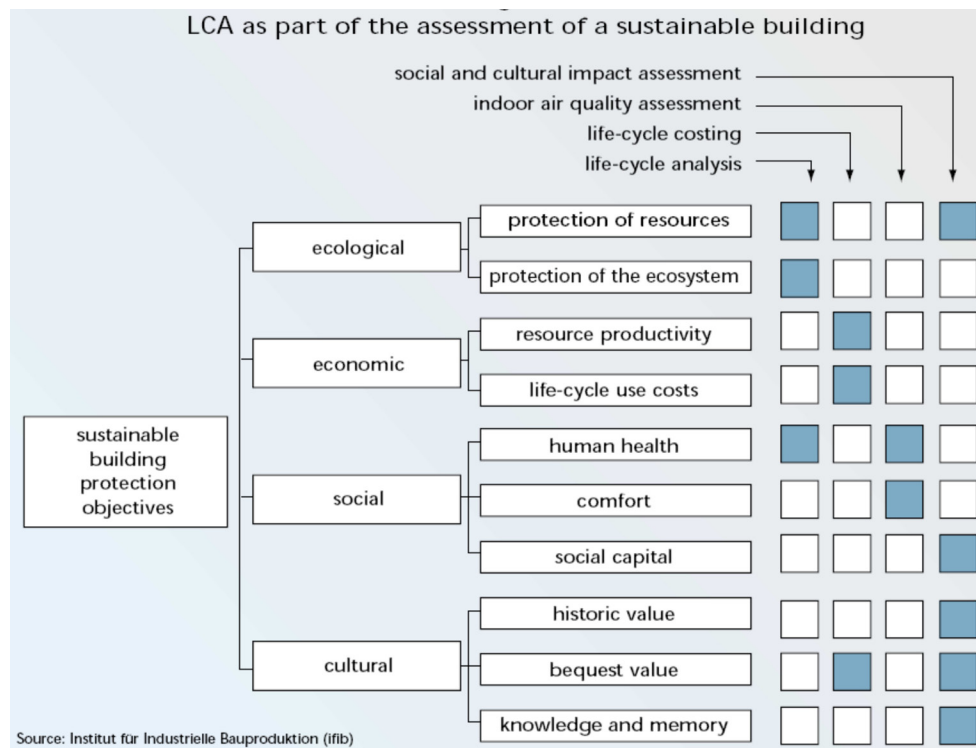
DESIGNING NET-ZEB'S WITH PARAMETRIC 3-D/4-D COMPUTATION TOOLS

3-D/4-D software tools continue to change the way buildings are designed, built, and benchmarked. Today, architects are confronted with new challenges in an increasingly competitive world market. “Integrated Project Delivery” and associated parametric 3-D-digital technology tools are rapidly changing the way architects work toward reducing GHG emissions from buildings. The question is: If committed advocates in the area of sustainable design education, practice, and parametric BIM mega-data-modeling cannot reach GHG emission reduction goals, how will the profession adjust its relationship to the built environment in order to positively affect climate change worldwide?

To meet global emission reduction goals, new cross-disciplinary initiatives to create and disseminate resources and parametric tools are needed. These initiatives should include accessible, cyber-enabled integrative computing infrastructures for carbon-neutral design and post-occupancy measuring with smart-sensor infrastructures. Modification of existing educational courses and training is necessary in order to optimize the way we benchmark energy and resource usage, funding and distribution models, standards, and statutory regulations and laws, in accordance with these new objectives. A new holistic approach to architectural education of quantifying and measuring sustainability with Life-Cycle-Analysis (LCA) is needed, instead of simply describing best sustainability practices with conventional, pure aesthetic-driven formular. Changes to core education and legislative efforts must be based on actual, annually-measured energy performance, carbon intensity, and LCA in buildings (Fig.1).

FIGURE 1. Life-cycle analysis of the built environment.

(Source: Institut für Industrielle Bauproduktion (ifib), Karlsruhe, Nikolaus Koehler, Germany, 2003. <http://www.bvsde.paho.org/bvsaiia/fulltext/lifecycle.pdf>, accessed on Dec. 26, 2011)



WHAT IS A PERFORMANCE-BASED 3-D/4-D PARAMETRIC MODELING CRITERIA FOR DESIGNING NET-ZEB'S?

“The topic of Zero-Energy-Buildings (ZEBs) has received increasing attention in recent years, until becoming part of both E.U. and U.S. policies on energy efficiency in buildings.” For example, the E.U. Directive on Energy Performance of Buildings (EPBD) mandated the implementation of the Building Energy Efficiency Certification in 2002 (Fig. 2), and has progressed to set goals to have all new buildings be “nearly zero energy buildings” by the end of 2020. The qualitative definition was given by the European Council for an Energy Efficient Economy, Article 2(1a): A “. . . nearly zero energy building is a building that has a very high energy performance.” “The nearly zero, or very low amount of energy required, should be covered to a very significant extent by energy from renewable sources, including energy from renewable sources produced on-site or nearby.”³

In the U.S., the Department Of Energy's (DOE) Building Technologies Program is mandating the voluntary strategic goal to achieve “marketable zero energy homes in 2020 and commercial zero energy buildings in 2025.”⁴ In addition, the United States' American Institute of Architects (AIA) has proposed the voluntary “2030 Challenge,” which aims to achieve fossil fuel reduction for all new buildings by 90% in 2025, and aims for these buildings to become carbon-neutral by 2030. Also, in 2007, the U.S. Energy Independence and Security Act became law, requiring all new federal buildings and major renovations (except the private building sector) to meet the required energy performance standards of the 2030 Challenge beginning in 2010.

Another milestone is the U.S. government's Building America 12 Program, which is focused on research and promotion of the drive toward zero-energy buildings. Figure 3 sets out the pathway envisioned by Building America toward a Zero-Energy Home. Some states have begun to set out their ambitions toward NZEB; California has committed to achieving zero net energy for all residential construction by 2020, and for all commercial construction by 2013, while Massachusetts plans to achieve NZEB for all buildings by 2030.⁵

However, the major question remains for architects: how can 3-D-parametric modeling assist in reaching these goals of designing, manufacturing, operating, and monitoring zero-fossil-energy buildings? At present, when it comes to NET-ZEB design and benchmarking, there is no broad international consensus regarding the composition and structure of assessment tools. Each sustainability rating systems is based on the individual systems of various countries and/or states. There is no recognized “best” system, since direct comparisons of the currently available assessment methods are often impossible and individual systems have been

FIGURE 2. Diagram based on the AIA (American Institute of Architects) 2030 Agenda. Comparison between the set goals between E.U for 2020 (mandatory) and U.S. (voluntary). (Source: Author)

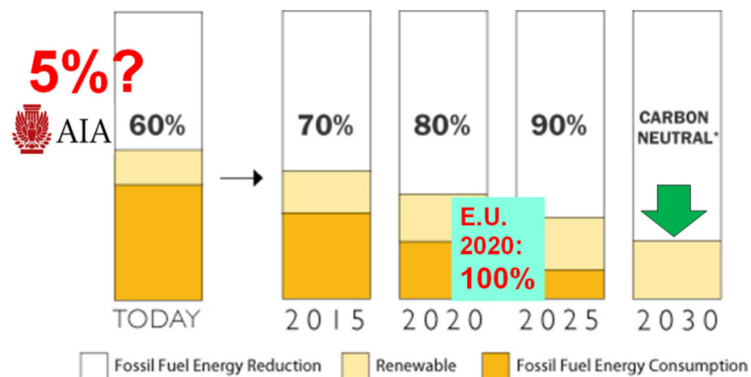
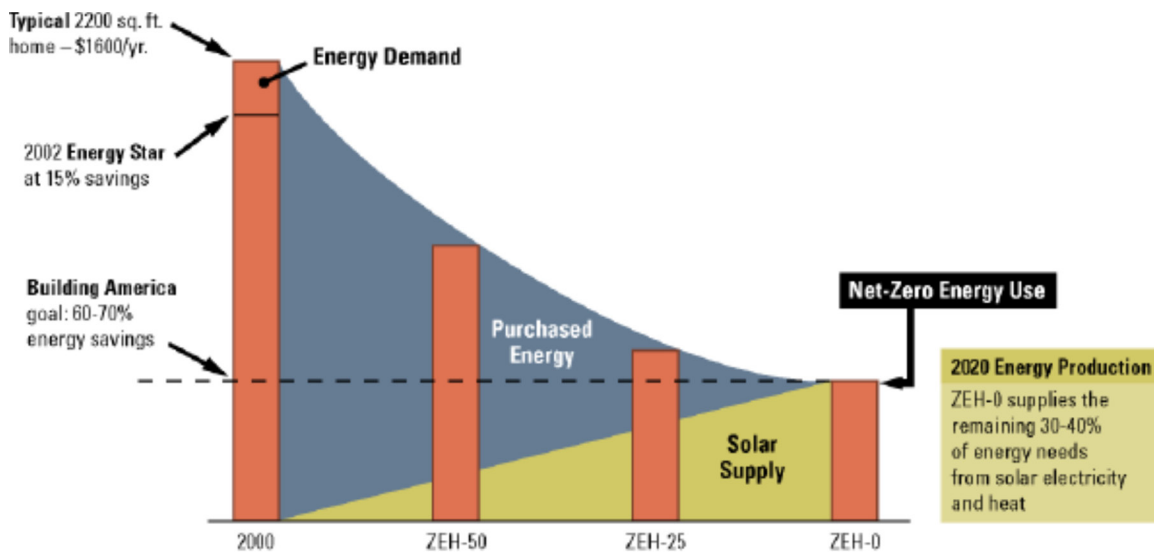


FIGURE 3. Energy Efficiency Requirements in Building Codes, Energy Efficiency Policies for New Buildings. (Source: Laustsen, J. (2008). International Energy Agency (IEA). http://www.iea.org/g8/2008/Building_Codes.pdf, accessed on Oct. 15, 2011)



specially developed to meet the individual country's/state's needs, in terms of cultural, social, economical, political, and climatic conditions.

However, the International Energy Agency (IEA) Task 42 has already set visionary benchmarks for the future versions of NET-ZEB assessment systems. The focus is on finite and scarce resources. Where global warming and public health is at issue, energy is used as the reference quantity with CO₂-equivalent emissions. The IEA-Task 42 suggests that balance in one set of units can be converted to another, but the conversion factors often shift the balance point (Fig. 4).

Integrating parametric models of NET-ZEB parameters into the process of design requires a formalization of generative logic and a systematic way of evolving said logic in concert with an integrated-design-project-delivery process. A successful parametric 3-D/4-D master model must, therefore, keep track of the various parameters and life-cycle scenarios being explored. "The general pathway to achieve a Net ZEB consists of two steps: first, reduce energy demand

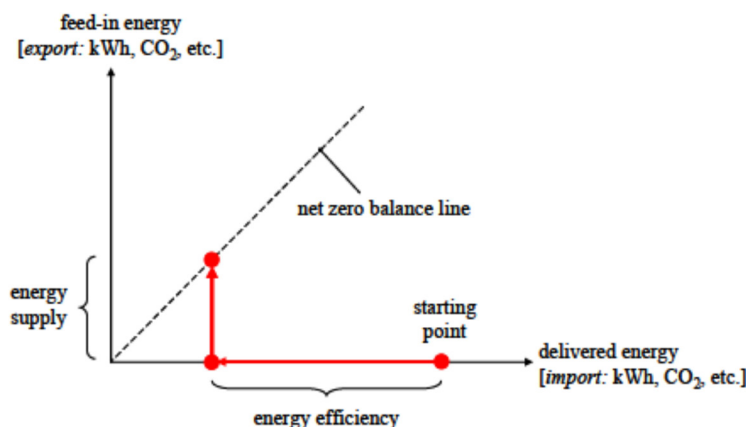


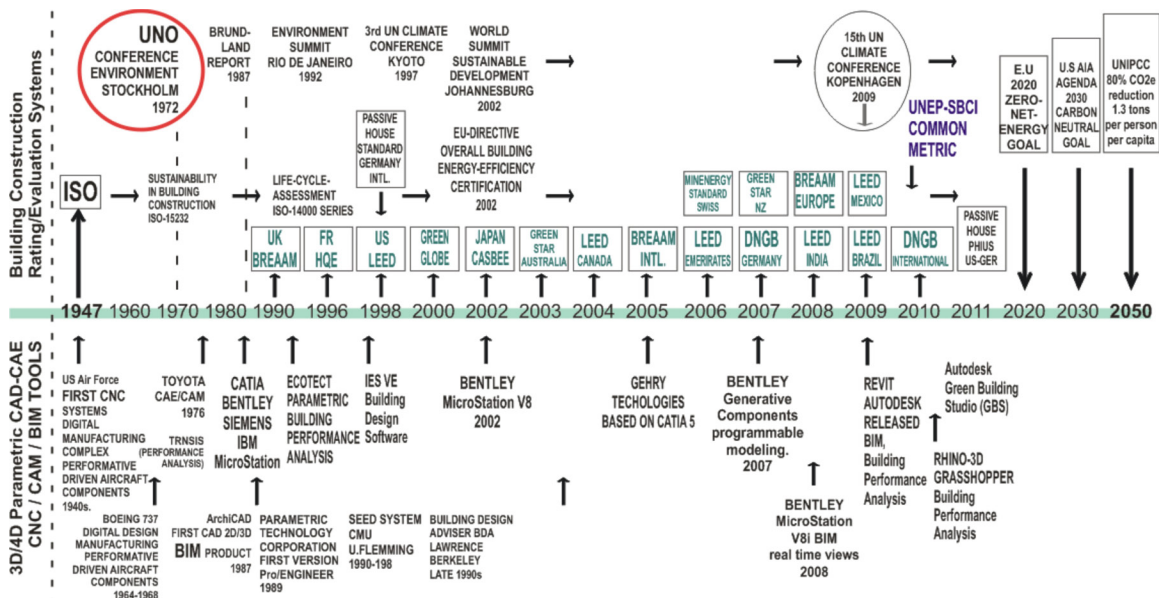
FIGURE 4. Net-Zero Balance Graph of a Net-Zero-Energy Building. (Source: IEA TASK 42, accessed on Oct.5, 2011)

by means of energy efficiency measures. Second, generate electricity, or other energy carriers, by means of energy supply options to get enough credits to achieve the balance.”⁶ Additionally, other building rating systems—indicators and performance-monitoring infrastructures, such as LEED, Green Globe, BREEAM or DGNB—can be incorporated to add qualified information on the overall “Sustainability Performance” of a Net-ZEB.

Building Energy Use Benchmarking and Sustainability Rating Tools

Numerous initiatives to develop a uniform international method for assessing and rating the sustainability of buildings have already been launched worldwide. For decades, resource assessments and calculation of GHG emissions for international benchmarking of countries, cities, and buildings have been coordinated under the umbrella of the United Nations Framework Convention on Climate Change (UNFCCC). The organization is also an international clearinghouse for data collaboration and coordination for building energy efficiency and carbon-metric measuring, including sustainability rating systems such as the Sustainability in Building Construction, Life Cycle Assessment, and Building Energy Performance of ISO (International Standard Organization, ISO 14040/44, ISO TC 59/Sc, or ISO 17/W64), with 158 country members; BREEAM Intl.; DGNB Intl. in Germany; HQE or CSTB in France; CASBEE in Japan; Green Star in Australia; China's Green Building Label; UEA in Dubai; and Energy Star or LEED Intl. in the United States. Some of these are also united under the umbrella of the World-Green Building Council (WGBC) (Fig. 5).⁷ However, as mentioned above, no uniform seal or common metric of quality for Net-Zero-Energy buildings has yet been established.

FIGURE 5. Comparative timeline of sustainability and building construction rating systems, climate change conferences, and GHG's reduction goals (above axis). Timeline of the 3-D/4-D parametric CAD/CAE/CNS/CAM and BIM software tool releases (below axis). (Diagram: Thomas Spiegelhalter)



At the national level, many countries have different assessment methods that simultaneously exist (in the U.S., LEED, Green Globe, Energy Star, etc.). Launched in 2006 by the United Nations Environment Program (UNEP), the Sustainable Buildings and Climate Initiative (SBCI) is developing the Sustainable Building Index (SB Index),⁸ and the Common Metric integrative tools for promoting and developing carbon-neutral or zero-fossil energy buildings at the international level have been available since 2009. UNEP-SBCI is a partnership between the private sector, government, non-government, and research organizations, formed to promote sustainable building and construction globally.

The most commonly used metrics for building-energy-performance measuring are: (1) Energy Intensity = kWh/m²/year (primary, secondary, and tertiary energy); or, (2) Carbon Intensity = kgCO₂e/m²/year. In general, the Energy Performance and Carbon Metric tools are applied to the specific inventory of building typologies, based on specific climate zones under post-occupancy study. They incorporate real energy usage data. Inventories are developed from a top-down or bottom-up approach: Carbon mitigation monitoring measures are based on regional and national scales, whereby a top-down approach is considered; individual building projects are assessed utilizing a bottom-up approach.⁹

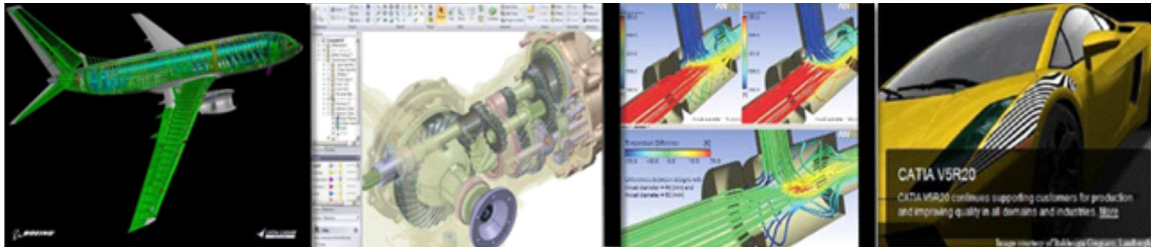
SHORT HISTORY OF 3-D/4-D PARAMETRIC CAE/CAD/CAM SOFTWARE MARKET DEVELOPMENT

Since the 1980s, 3-D-parametric and performance-based planning engineers and industrial designers have employed a completely different methodological use of software in aerospace, shipbuilding, automobile manufacturing, and electronic industries than in traditional generative Computer-Aided Design (CAD) and Building Information Modeling (BIM). During that early period, most large companies, i.e., Siemens, IBM, and Boeing, and even smaller organizations like Bentley and Italodesign Giurgiaro Lamborghini, developed their own 3-D and 4-D-parametric software. This allows associative geometry for the manipulation of 3-D/4-D-parametric models by changing variables and linking them to efficient manufacturing and life-cycle-product management. Since 1984, CATIA Systems Engineering has developed solutions for modeling complex and intelligent products with parametric solid/surface-based packages, utilizing NURBS for core surface representation that includes life-cycle-product management engines.

These system-engineering approaches cover load requirement descriptions, envisioned systems architecture, expected behavior modeling, and the virtual life-cycle product scenario (or embedded software generation). The new IBM and French CATIA Dassault Systemes Global Alliance life-cycle product management software suites compete with German Siemens NX and SolidEdge, Pro/ENGINEER, Bentley, Autodesk, and others in the CAD/CAM/CAE market.

Since 2010, CATIA, DELMIA, ENOVIA, SIMULIA, SolidWorks, and 3DVIA have been registered trademarks of Dassault Systemes and its subsidiaries in the U.S. and/or other countries. The CATIA Dassault platform was first tailored to architectural design and used internally in Gehry Technologies with the Digital Project (DP) application. Now, DP is an architectural design BIM tool that is commercially distributed by Gehry Technologies for architects with full interoperable parametric geometrical data definition and surfaces. Users can define and parameterize variables at the detailed geometry-level, and, among objects, geometry sets, and libraries. Existing system and product files can also be referenced from other files to increase

FIGURE 6. Parametric Dassault Systemes CATIA V5R20 Parametric Modeling. (Source: Image Courtesy of CATIA, <http://www.catiacommunity.com>, accessed on Feb.15, 2012)



the reusability of designed parts and products utilized in complex assemblies, workbenches, STL-rapid prototyping, systems routing, fitting simulation, knowledge-engineering optimization, material library, and catalog editor—to name a few. Today, interoperable parametric software packages, such as CATIA, Dassault Systems, and DP-BIM, enable multiple input routines, including climate, materials, energy use, CO₂e, fluid dynamics, codes, zonings, cost, liability, etc. These assist and trigger automatic performance-based form-finding with multiple design constraints and parametrically coded “what-if” life-cycle-scenarios for the whole product life cycle—from resource extraction, fabrication, assembly, and operation to future recycling or re-use. Currently available parametric BIM software meta-data packages allow companies to integrate 3-D and 4-D best-practice models and large knowledge repositories. There is no need anymore for extensive and repetitive coding and scripting for this Intelligent Information Flow Management of reusable parametric models and creative design processes.

For the first time, architects will be able to explore an algorithmic approach to architectural design that applies computational methods. New ways of simplifying and customizing software with varying degrees of complexity and compatibility between different programs is now possible without requiring architects to become a computer programming experts.

One example of said technology, the Green Building XML scheme (referred to as the “gbXML” standard), achieves gains in interoperability that can result in significant cost and environmental savings. This was developed to facilitate a common interoperability model integrating a multitude of 2-D/3-D and 4-D-design and development tools used in the building industry, such as Bentley, Graphisoft, Archicad, AutoCAD, Rhino, Autodesk Revit with Building Information Modelling (BIM) capabilities, Ecotect and Green Building Studio, and many more. GbXML is now being integrated into a range of different software CAD and complex engineering tools. It is now fully compatible for use in 3-D/4-D parametric design, with Generative Components to create more sustainable buildings and optimize building performance. A major advantage to parametric design is that it links variables, dimensions, and materials to geometry in a way that when an input or simulation value changes, the 3-D/4-D model automatically updates all systems and components, simultaneously. As a consequence, developed parametric architectural 3-D/4-D models become manageable for designers to conduct various “what-if” scenarios to optimize and change specific parameters and benchmark indicators as needed. Such an interoperable software framework enables multi-domain collaboration at the outset, while reducing the need for acquiring deep trans-domain knowledge; the result is the participation of multiple contributors to the entire design process.

EARLY EXAMPLES OF PARAMETRIC CAE/BIM DESIGN TOOLS FOR MANUFACTURING BUILDINGS

Since 1976, Toyota has been applying its lean computer-aided engineering (CAE) and manufacturing principles to its energy-efficient housing division. Japanese companies such as Sekisui Heim work with finite component sets from which they offer their clients a controlled degree of customization, while building high-quality designed buildings in a fraction of the time of conventional site-stick-and-built-methods. Most of these companies did not evolve from traditional craft-based construction firms, but instead were set up by building material companies to create a showcase for their products with parametrically engineered and integrated building systems.

In the mid 1990s, 3-D-parametric Building Information's Modeling (BIM) with mass customization emerged to transform industrial design practices, design, and planning with integrated project delivery. These new technologies dovetailed with Computer Aided Engineering (CAE) and Computer Numerical Control (CNC) systems in the Japanese, U.S., and European prefabricated building manufacturing industries. The late 2000's robotics systems emerged as fully automated construction and deconstruction processes of high-rise buildings in Japan, and have since become more influential in manufacturing, deconstruction, re-use, and recycling businesses in Europe as well. This kind of increasing fabrication knowledge has reduced the gap between parametric design modeling, multiple-scenario testing, prototype development and realization, building management and operation, and more predictable life cycle. Today, intelligent parametric 3-D-feedback information enables rapid digital prototyping of scale models and is moving the construction industry toward full-scale automated fabrication of future Net-Zero-Energy Buildings.

Overcoming the Differences in Using Parametric Performance Based 3-D-Modeling Tools

There is still a significant difference between how product and industrial designers, and aerospace, aviation, shipping, and automobile engineers, use performance-based parametric computing technology with integrated life-cycle-cost software engines to design and manufacture flying, swimming, diving, driving or flexible infrastructures. In architectural academia, generative computation has been primarily used for pure, aesthetic form-finding, and for generating complex environments, without applying global performance metrics and GHG's emission-reduction strategies to evaluate and reiterate derived designs. Depending on the software types used, so-called "genetic," "generative," or "morphogenetic" architecture produces design processes focusing solely on more aesthetic-driven geometries. These are mostly dictated by a limited, non-interactive programming language and specific spatial conditions, but not by directly and interactively modeling shapes based on performance and life-cycle parameters (i.e., climate, material, systems, costs, etc.).

Other missed opportunities for testing complex spatial thinking with integrated performance metrics and life-cycle-analysis tools include the use of programming/coding of multiple-shared-constraints through other disciplines in the early design stage. "This uncertainty, particularly in early stages of design, can be so large that the performance metrics of different options are indistinct from a decision making point of view" (Sanguinetti et al. 2009).¹⁰ Without participatory and integrative practice planning, the chances of the successful holistic design development of each sustainability option cannot be assessed, and this is representa-

tive of missed opportunities at arriving on carbon-neutral design. Research in building design has demonstrated that the most efficient, best-performing, and most environmentally sustainable buildings are designed utilizing integrated practice. In these integrated practice projects, various disciplines are involved in building design: conceptual design, project conception, planning and detailing, as well as the commissioning, operation and maintenance stage are included to improve the overall building performance and life-cycle of systems.

PARAMETRIC DESIGN CASE STUDIES

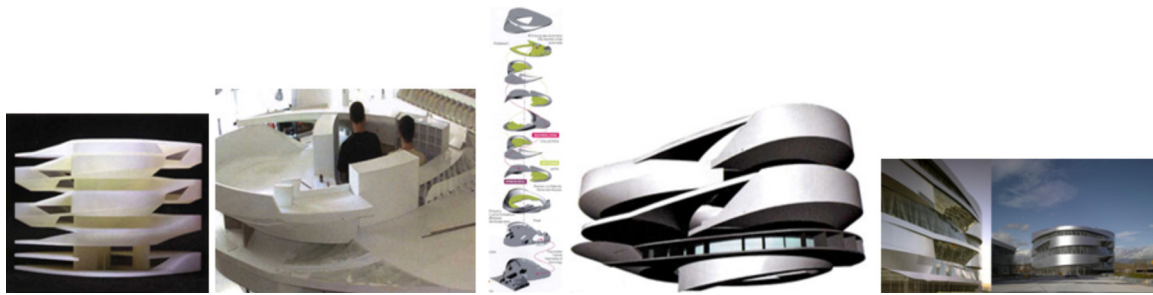
One successful “Integrated Project Delivery” example is the new “Q1, ThyssenKrupp Headquarter” in Essen, Germany, which was parametrically designed by Chaix & Morel Et Associés (Paris, France) and JSWD Architekten + Planer (Cologne, Germany), and was completed in 2010. The building is certified with the German Sustainable Building Council’s (DNGB) Gold Certificate for its successful “Integrated Practice” of ecological and economical building systems and sustainable operation management. In 2011, the ThyssenKrupp Headquarter won an award for its architectural design and technological solutions, employing energy-efficient heating and cooling systems: The building’s primary energy requirements are 50% lower than the legal limit for new buildings in Germany and its ecological footprint is characterized by 27% less CO₂ emissions than other similar buildings.

A much more experimental and parametrically designed building is the Mercedes-Benz Museum in Stuttgart, Germany, which was completed in May 2006. The complex was designed by the UN-Studio Architects team of Ben van Berkel and Caroline Bros (Amsterdam, Netherlands), the structural engineer team of Werner Sobek (Stuttgart, Germany), the climate engineering by Transsolar Energietechnik (Stuttgart), and the infrastructure design by David Johnston of Ove Arup (London).

FIGURE 7. Integrated Project Delivery. Example: Thyssen-Krupp Headquarter, Essen, Germany. Planning and design: Chaix & Morel Et Associés, Paris, and JSWD Architekten + Planer, Cologne. (Source: Thyssen-Krupp, Essen, Germany, 2011.)



FIGURE 8. Mercedes-Benz-Museum 3-D Parametric Design Model. (Source: <http://www.unstudio.com/news>, retrieved on 2-25-2012)



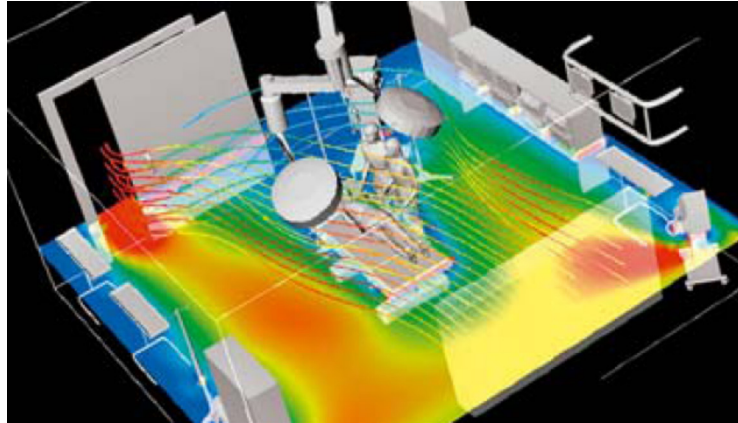
The Museum celebrates legendary automobile, bus, and truck design developments of Daimler Benz, with multiple displays from 1886 until today. The 35.000-m² complex includes a museum, shop, restaurant, offices, and an auditorium. The building's program ascends incrementally from ground level, spiraling around a central atrium.

The parametric 3-D-Building Information Design Model, which incorporated sophisticated geometry, was developed in collaboration with Arnold Walz from Stuttgart. Walz optimized the model for the overall building design. He also helped to synthesize and integrate all the structural, mechanical and programmatic elements for the new landmark building. The integration and coordination of specialists in the early stages of the planning avoided many planning obstacles and simplified the parametric data exchange and the reiteration process. One of the major design challenges included the innovative design language of the sculptural appearance of the museum complex. The architects linked their geometrical 3-D-model on the organization principle of the trefoil and on the clover leaf loop concept (Fig. 8). Therefore, a special parametric design process was developed to simplify the overall project delivery method of executing the double-curved concrete surfaces throughout the museum.

This manufacturing process involved cutting elastic elements to a planar in order to shape any required curvature. The design and construction technique was used for the majority of the façade shuttering elements, as well as for those sections of the cladding that are all double curved. The folding building surface is expressed in the concrete construction, in the environmental control systems, and in the daylight-redirecting devices. The parametric 3-D/4-D planning stages and the construction took place from 2001 to 2006.

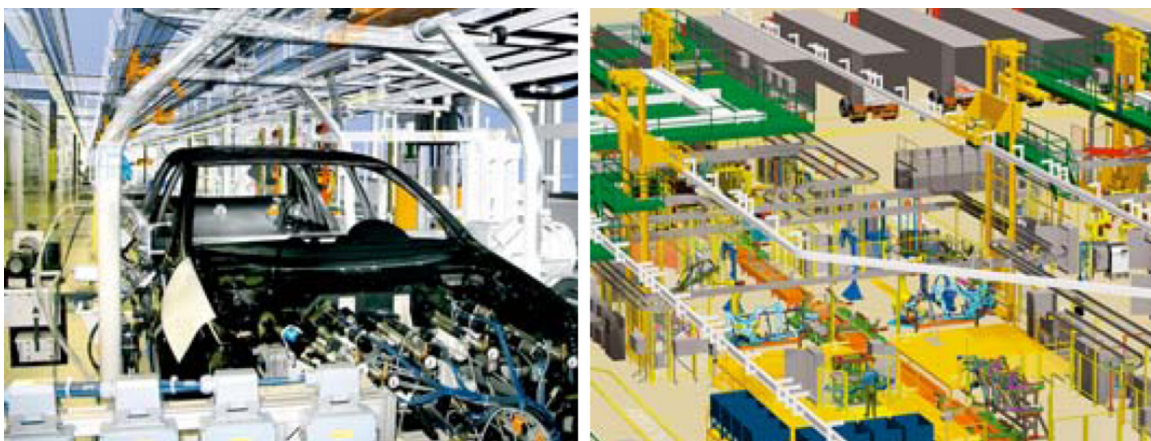
Another example of integrated 3-D-parametric design demonstrates the use of Computational Fluid Dynamic (CFD) simulation tools in the area of health care facilities. SIEMENS parametric 3-D-simulation tools enable the design, manufacturing, and the visualization of operating room airflows in hospitals to help multiple interdisciplinary planning teams in the early design stage to share data and optimize the placement of HVAC systems and vents within the thermal-electrical context of body heat and lighting. This kind of integrated project modeling delivery methodology helps the designer to simulate and control how surgical wounds in this operation room can ideally be ventilated so that thermal comfort standards such as the ISO 7733 can be matched and constantly monitored. In Figure 9, the airflows of the general causes of hospital-based infections by the presence of airborne germs during operations are shown.

FIGURE 9. Hospital 3-D/4-D-air-flow-design scenarios. (Source: Image courtesy SIEMENS, Pictures of the Future, fall 2008.)



Product-Lifecycle-Management (PLM) software developed by SIEMENS is assisting the 3-D modeling and managing of the entire lifecycle of a micro-scale or large-scale product—from conception, through design and manufacture, operation to service, re-use, to recycling or disposal. Whether applied to visualizing building or automotive production lines, or planning entire factories, the simulation can optimize virtually every aspect of production, including the total life-cycle, based on sustainable and resource-efficient strategies. The simulation of any building typology or infrastructure on computers can be done long before anything is built. These parametric 3-D virtual models contain thousands of parameters, most of which are from real building models. For example, these 3-D or even 4-D models are used in calculating optimal building or machine arrangements for a factory, component circulation routes, the risks associated with transferring production to another location, and even the strain on a worker's back.

FIGURE 10. Mercedes Benz Factory Stuttgart (right), Production lines (left). (Source: Image courtesy Siemens, Pictures of the Future, fall 2007.)



PARADIGM SHIFT: TOWARD COLLABORATIVE 3-D/4-D-PARAMETRIC MODELING TARGETS FOR NET-ZEB'S

All these aforementioned creative engineering areas of product and infrastructure design and manufacturing in the aerospace, shipbuilding, and automobile industries still have an advantage over the traditional practice of architecture firms. With 3-D parametric modeling and integrated digital smart-sensor-infrastructures, engineers and industrial designers are able to produce a virtual mock-up of their entire product. With 3-D parametric simulation technology, even the most complex production processes can be visualized in detail, resulting in optimized configurations and the ability to rapidly adjust to clients' demands. It is overdue that both the architectural education and the profession need to embrace a greater level of product and industrial-design thinking in order to survive, compete, and adapt to the challenges of creating truly measureable and performance-based-carbon-neutral buildings.

Today, most researchers, practitioners, and industry pioneers in the performance-based architectural design movement endeavour to develop collaborative, real-time 3-D/4-D computation tools that incorporate worldwide, interchangeable parametric BIM mega-data systems in order to virtually construct any 3-D/4-D building type by modelling and designing all building processes, elements, and assemblies, including all life-cycle constraints.

The goal is to allow multi-users from different disciplines and building-science-related research communities around the world to use the collaborative Integrated-Best-Practice-methodologies to simulate “what if” scenarios while evaluating and benchmarking energy and resource usage with GHG reduction targets. It is apparent that worldwide sustainable parametric 3-D/4-D-design—as a major building design trend-driving process—will radically change the industries and planning societies, requiring quick and informed changes within a framework of integrated and intelligent design workflows, linking design, practice, research, education, and analysis.

CONCLUSION

The demand for international indicators and benchmarking BIM data-tools for efficient design, operation, maintenance, and post-occupancy measuring will continuously increase pressure on the markets. The international market will sort out the most optimally integrated, interoperable, and practical real-time parametric 3-D-BIM design tools needed to resolve the challenges of creating globally connected collaborative design societies from the onset, toward having truly Net-Zero-Energy Buildings in the near future.

Traditionally, architects and engineers have relied upon rules of thumb: general principles and simplified calculations in order to design environmentally sound buildings without having to measure real energy and resource usage. However, Net-Zero-Energy-Buildings can be incredibly complex, and it is only through parametrically developed 3-D/4-D designed, measured, and quantitative “what-if” scenarios and analysis that the profession may determine whether or not these strategies will be effective in realistically matching the required environmental performance.

Global connectedness woven into multiple planning communities of networks will be crucial to the success of this endeavor. Global clients increasingly expect to benchmark building energy and resource usage performance to global standards. Project networking has also been enabled through new digital tools. Global teams have instant access to project docu-

ments of all kinds. There is a fundamental change needed that requires nothing less than the complete reworking of the relationships and roles of educators, architects, and manufacturers, with 3-D/4-D-parametric modeling tools, smart-sensor-infrastructures, life-cycle-scenarios, and integrated-project-delivery, in order to collaboratively use the talents and insights of all participants in the design and manufacturing processes of zero-fossil-energy buildings.

Schools, universities, and professional associations of multi-stakeholders in the building sectors worldwide are called upon to collectively develop relevant core curricula with parametric 3-D/4-D-software frameworks in synthesis of aesthetic and technological parameters through generative/digital design tools in practice.

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