ACHIEVING THE EUROPEAN AND NORTH AMERICAN '2020–2030 TARGETS' OF NET-ZERO-ENERGY-BUILDINGS WITH PARAMETRIC 3D/4D-BIM DESIGN TOOLS

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INTRODUCTION

Worldwide, the level of man-made Greenhouse Gas emissions climbed to a new negative record of 30 billion tons in 2010. Many of the thousands of scientists of the United Nations Intergovernmental Panel on Climate Change (IPCC) claim that this was almost the largest absolute jump in any year since the Industrial Revolution since 2003.

For the building sector numerous energy efficiency market changes and resolutions like the mandatory European Union 'nearly Net-Zero-Energy-Building 2018-2020 regulations' for all new public and private owned buildings, or the voluntary U.S. 'American Institute of Architects (AIA) '2030 carbon neutral building challenge' are now set up with various educational resource tools to help minimizing carbon emissions. All these initiatives try to reverse the negative impact. But is this possible? How can Net-Zero-Energy-Buildings become curricular standard and practical routine in education and the profession, worldwide? To date, the basic curricular design process components with integrated project delivery metrics for a robust 3D/4D-net-zero-design regulatory framework are either incomplete or missing even in most accredited architectural schools! However, in some accredited schools, formally based curriculums have begun to change and weave numerous energy efficiency techniques and carbon-neutral design tool resources into their pedagogy. This research paper critically compares how these new criterions of accredited resources for digital 3D/4D-building information modeling (BIM) with 'Integrated Project Delivery' are mandating a better integration of collaborative carbon-neutral designs into the curriculum and practice of the profession.

DESIGNING CARBON NEUTRAL BUILDINGS WITH PARAMETRIC COMPUTATION TOOLS

It is inevitable that 3-D/4-D software tools continue to change the way buildings are designed, built, and benchmarked 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. To meet global emission reduction goals, new cross-disciplinary initiatives to create and disseminate resources with compatible 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 design courses and training is necessary in order to optimize the way we benchmark resource usage, funding and distribution models, standards, and, statutory regulations and laws in accordance with these new objectives.

PERFORMANCE-BASED 3-D/4-D 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 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."[1] (Fig.1)

Country	Target
Denmark	75% by 2020 (c.f. base year 2006)
Finland	Passive house standards by 2015
France	By 2020 new buildings are energy-positive
Germany	By 2020 buildings should be operating without fossil fuel
Hungary	Zero emissions by 2020
Ireland	Net zero energy buildings by 2013
Netherlands	Energy-neutral by 2020 (proposed)
Norway	Passive house standards by 2017
UK (England &Wales)	Zero carbon as of 2016 (see box overleaf)

Figure 1. "European National Strategies to move towards very low energy buildings", selected National Targets for New Buildings Adapted from SBi (Danish Building Research Institute), 2008.

The U.S. 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". 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. (Fig. 1)

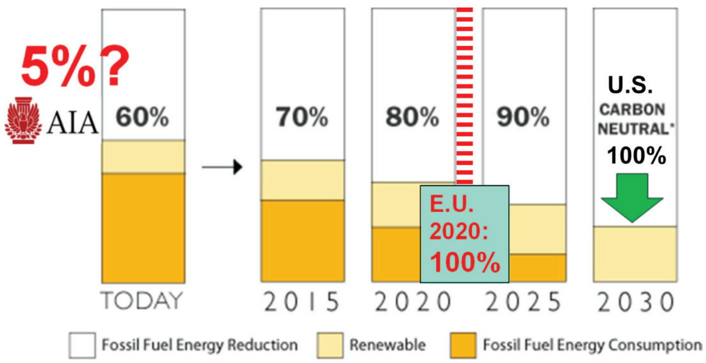

Figure 2. Diagram based on the AIA 2030 Agenda. Comparison between the set goals between E.U for 2020 (mandatory) and U.S. (voluntary). Diagram: Author.

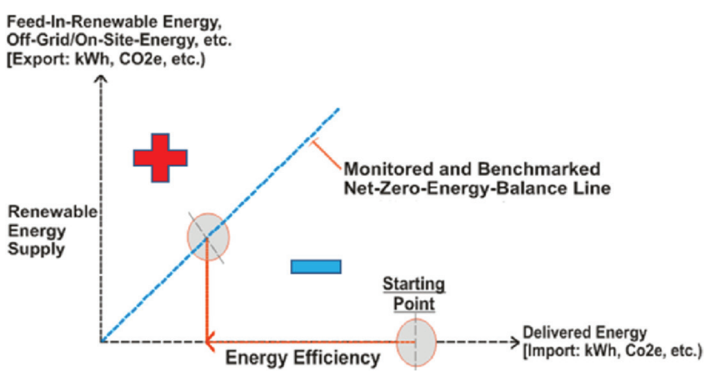

Figure 3. Net-Zero Balance Graph of a NET-ZEB. Source: Author, based on IEA TASK 42Source: IEA TASK 42, accessed on 10/05/2011.

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. The schematic below 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.[2] (Fig.3, 4)

Nonetheless, the major question remains for architects: how can 3-D-parametric modeling assist in reaching these goals of designing, manufacturing and prefabrication, operating, and monitoring NET-ZEB's? 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. Individual assessment systems have been specially developed to meet the individual country's/state's needs, in terms of cultural, social, economical, political, and climatic conditions.

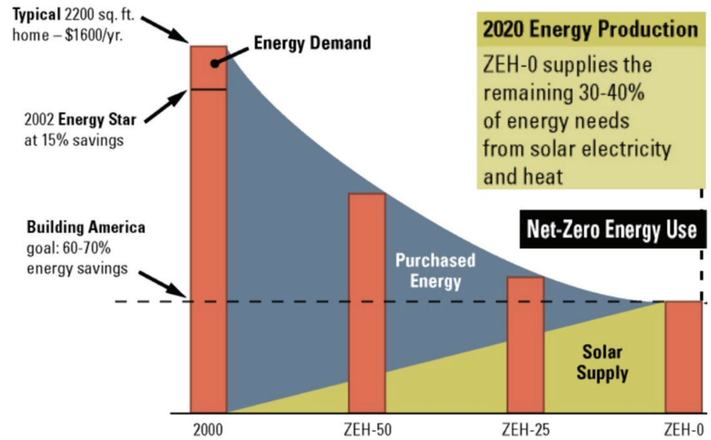

Figure 4. Progression to Full ZEH: Requirements in Building Codes and Policies for New Buildings. Source: Laustsen, IEA-2008. http://www.iea.org/g8/2008/Building_Codes.pdf , accessed on 3/28/2012

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. 3)

Integrating successfully 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 in each country based on there very specific climate, economic and social-cultural indicators. The general pathway to achieve a Net-ZEB consists of two steps: first, reduce energy demand 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. Additionally to the energy efficiency and CO2 reduction modelling, other building rating systems, indicators and performance-monitoring infrastructures, such as LEED, BREAAM, CASBEE or the German DNGB can be incorporated to add qualified information on the overall "Sustainability Performance" of a NET-ZEB.

THE URGENCY FOR DEVELOPING COMMON METRICS AND SUSTAINABILITY RATING TOOLS

Numerous initiatives to develop a uniform international method for assessing and rating the sustainability of buildings have already

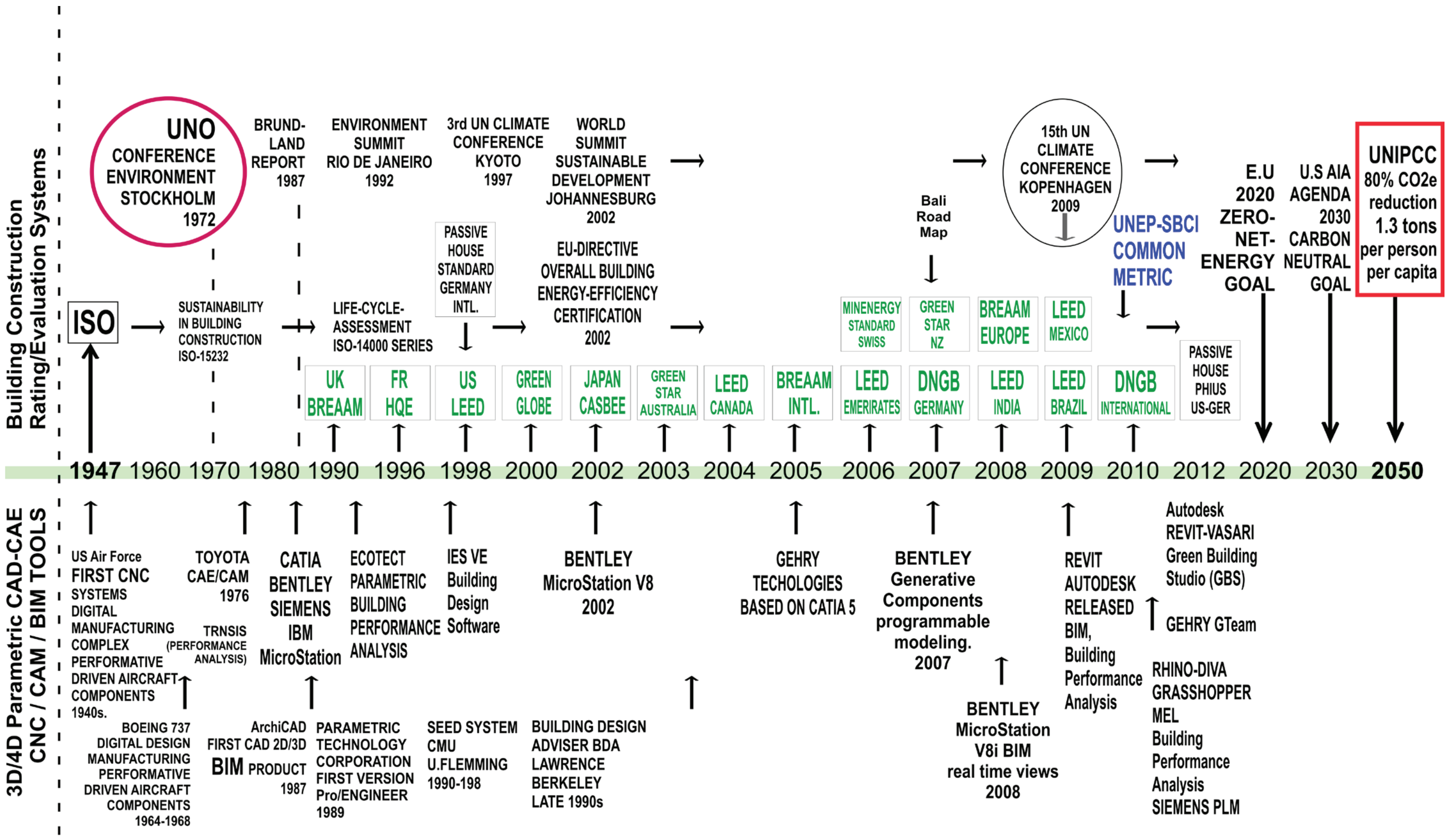

Figure 5. Comparative timeline of sustainability and building rating systems, climate change conferences, and GHG’s reduction goals (above axis). Timeline of the 3-D/4-D parametric CAD/CAE/CNS/CAM and BIM software tool releases (below axis). Diagram: Thomas Spiegelhalter

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 and carbon-metric measuring, including sustainability rating systems, e.g. 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., DNGB Intl. in Germany, HQE or CSTB in France, CASBEE in Japan, Green Star in Australia, Chinas Green Building Label, UEA in Dubai, and Energy Star or LEED Intl. in the US, some of which are also united under the umbrella of the World-Green Building Council (WGBC). (Fig. 4)[3] However, as mentioned above, no uniform seal or common metric language for achieving Net-Zero-Energy buildings has yet been established so far.

At national levels, many countries also have different assessment methods that simultaneously exist and compete with each other such as LEED, Green Globe, Energy Star in the United States.

To overcome these competitions and streamline better the process of building energy benchmarking the United Nations Environment Program [UNEP], and the Sustainable Buildings and Climate Initiative [SBCI] is developing the Sustainable Building Index [SB Index] since 2006. The agenda is to provide ‘Common Metric’ integrative tools for promoting and developing carbon-neutral or zero-fossil energy buildings at the international level for (1) Energy Intensity = kWh/m2/year (primary, secondary, and tertiary energy), or, (2) Carbon Intensity = kgCO2e/m2/year. UNEP-SBCI is a partnership between the private sector, government, and non-government, and research organizations formed to promote sustainable building and construction, globally.[4]

PARAMETRIC 3-D/4-D CAE/CAD/CAM SOFTWARE 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, ship-building, 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

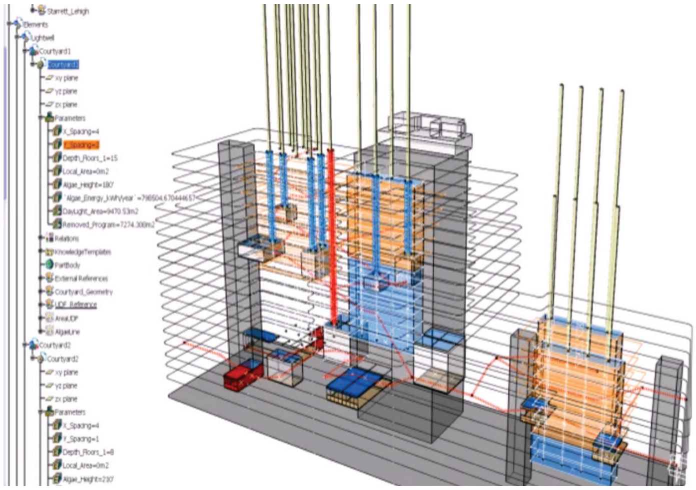

Figure 6. Parametric Starrett-Lehigh Building Adap-tation Modeling: CATIA V5R20, Columbia University 2010. Source: http://www.catiacommunity.com, accessed on 5/12/2012.

own 3-D and 4-D-parametric software for designing, manufacturing and prefabrication, assembly, life-cycle-testing and optimization. (Fig. 4) This allowed associative geometry for the manipulation of 3-D/4-D-parametric design 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). For example the 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 Systèmes 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 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 any more 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, students and architects are 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 students and architects to become a computer programming experts.

One example of said advanced technology is the Green Building XML scheme, referred to as the 'gbXML' standard, to analyze benchmark and achieve 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, Grasshopper, Autodesk Revit and Vasari with Building Information Modeling (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 and project integrated delivery process towards the Net-ZEB goals in 2018 (E.U.) and 2030 (U.S.)

OVERCOMING THE DIFFERENCES IN USING PARAMETRIC PERFORMANCE BASED 3-D-MODELING TOOLS

Despite these promising tool resources, there is still a significant difference between how industrial designers and aerospace, aviation, shipping, and automobile engineering students use performance based parametric computing technology with integrated life-cycle-cost soft-ware engines to design zero-fossil-energy operated flying, swimming, diving, and driving infrastructures to architecture students. Since the 1980s, industrial designers and engineers have employed a different methodological use of 3D/4D-performative software in the aerospace, ship building, and automobile manufacturing than in traditional generative CAD and BIM architectural design. In architectural academia, generative compu-tation has been primarily used for pure, aesthetic form-finding without applying zero-carbon-energy driven global performance metrics and CO2e reduction design strategies to reiterate derived designs.

Depending on the software types used, so-called 'genetic,' 'generative,' or 'morpho-genetic' 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, social-cultural indicators, costs, etc.).

The advantages of parametric life-cycle design is widely ignored in academia even it is obvious, that it links variables, dimensions, materials, and sensors to geometry in a way that when an input or simulation value changes, the 3D/4D-model automatically updates all systems and components simultaneously. These parametric 3D/4D models become manageable for designers to conduct various 'what if' life-cycle scenarios to design, optimize and change specific parameters, and benchmark indicators as needed.

Other missed opportunities in 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) Without participatory and integrative practice planning, the chances of the successful holistic design development of each sustainability option cannot be assessed, and this is representative 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.

CASE STUDIES: NET-ZERO-ENERGY BUILDINGS

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), prefabricated and completely assembled 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. (Fig.6)

Another example of 3-D-parametric design demonstrates the use of Product-Lifecycle-Management (PLM) software. PLM is developed by SIEMENS and 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 energy efficient building designs such as the new Siemens Real Estate headquarters at Masdar City in Abu Dhabi by Architect Sheppard Robson, 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. (Fig.7)

Figure 7. Parametric Design for the Siemens' headquarters at Masdar City. Architect Sheppard Robson. Image Courtesy: Siemens, http://www.e-architect.co.uk/dubai/dubai_building_news.htm, accessed on 3/29/2012.

For example the parametrically designed Siemens Real Estate headquarters at Masdar City in Abu Dhabi sets clear standards to achieve an innovative office concept with highest quality architectural design, the most efficient use of space and energy and to be one of the first buildings of its kind in the region to have LEED Platinum status. An iterative process of traditional design and parametric analysis resulted in an efficient and compact form that has reduced material and embodied carbon. The project is now on site and is due to complete in late 2012. The building envelope was conceived as a box within a box: an inner highly-insulated, airtight facade designed to reduce thermal conductivity, and a lightweight aluminum external shading system which minimizes solar gain while maximizing daylighting and views from the building. The variation in the form of the shading systems was designed to offer legibility to the architectural expression with each facade tailored to suit its solar orientation. (Fig. 7)

It is not new that the simulation of any building typology or infrastructure on computers can be done long before anything is built. These parametric 3-D/4-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 or any other manufacturing facility, component circulation routes, reducing the risks associated with transferring production to another location, and even the strain on a worker's back.

"The main industries that took up parametric modeling 10 to 15 years ago were aerospace and automotive manufacturing," says Neil Dunsmuir, vice president of marketing, EMEA, for Siemens PLM Software. "They had the money available to invest in technology."[5] The families of software products developed to meet and respond to these and other sectors' demands are well known, and include Catia, SolidWorks, Autodesk Inventor, PTC — one of the early pioneers — and NX and SolidEdge, from Siemens PLM Software.

Another example is the design and manufacturing of the new dragon-shaped terminal Airport in Beijing by Norman Foster which demonstrates trouble-free construction and commissioning of the 50-km-long baggage handling system. Siemens architects and engineers first built and tested the complex facility in the virtual world. (Fig.8)

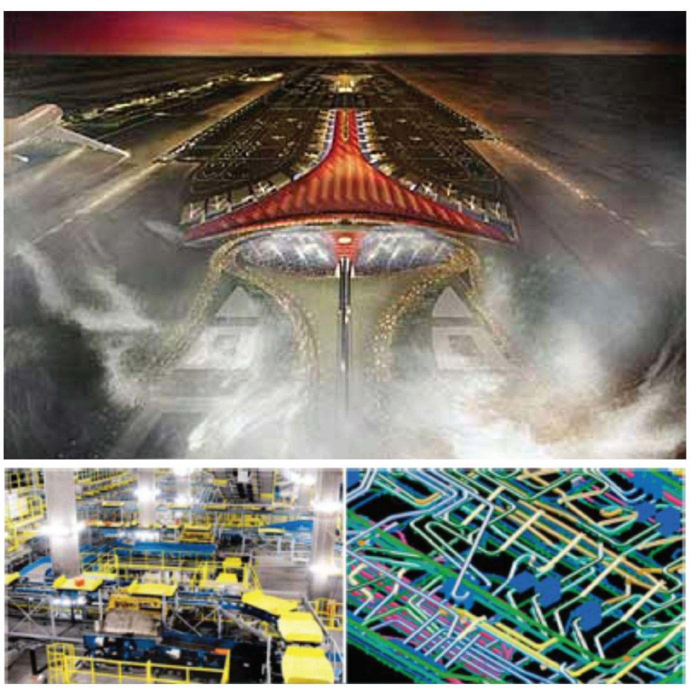

Figure 8. 50-km-long baggage handling system, Beijing, China. Source: Siemens, pictures of the future, fall 2007.

Using 3D-parametric simulation tools, rail technology specialists at Siemens can run through all of the optimization possibilities in the digital world at an early stage in the development process, whether they're working on the nose section of a train or the ergonomics of the driver's cab. (Fig 9) These simulations are replacing huge piles of paper plans of assembly instructions. 3D graphics of individual work steps make assembly work simpler, faster, and more precise as the diagram. Fig 9 of the trains in the assembly hall shows. All product life cycles are simulated from design to operation, service and maintenance.

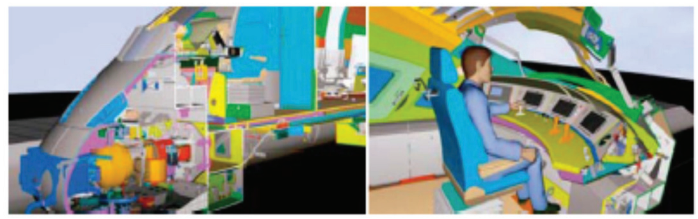

Figure 9. ICE-High Speed train nose section (left), ergonomics study of the driver's cab (right). Source: Siemens, pictures of the future, fall 2008.

RADICAL CHANGE NEEDED IN ACADEMIA AND IN THE PROFESSION

These areas of 3-D/4-D product, infrastructure design and manufacturing in the aerospace, shipbuilding and automobile industry have an advantage over the traditional practice of architecture firms. With 3D-parametric modeling and digital smart-sensor-infrastructures, industrial and product designers as well engineers are able to produce a virtual mock-up of their entire product. These mock-ups allow them to simulate different scenarios to test critical spatial scenarios, materials, systems, performance and life-cycle constraints without having to build a physical model. A complete city infrastructure, factory, production plant, container or cruiseship or aircraft can be modeled with million parts designed and envisioned both individually and in dynamically changing contexts. Parts of the design process, such as the HVAC, or routing of hydraulic and electrical systems, that were once performed through extensive physical mock-ups are developed digitally. (Fig. 10)

With 3D-4D parametric modeling technology, even the most complex production and life-cycle processes can be visualized in detail, resulting in optimized configurations and the ability to rapidly adjust to clients demands. It is obvious, that the architectural education and professionals need to embrace the level of product or industrial design thinking in order to survive and adapt to the challenges of creating NET-ZEB's buildings and infrastructures in the future.

CONCLUSION

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; this incorporates worldwide, interchangeable parametric BIM mega-

Figure 10. Mercedes Benz Factory, Stuttgart, Germany (above), view on factory and museum, (below), production lines. Source: Siemens, Pictures of the Future, fall 2007.

data systems in order to virtually construct any 3-D/4-D building type by designing and modelling all building processes, elements, and assemblies, including all life-cycle constraints.

The major 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. The international market will sort out the most optimally integrated, interoperable, and practical parametric 3-D-BIM design tools needed to resolve the challenges of creating globally connected collaborative carbon neutral design societies from the onset. 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, manufacturing, prefabrication and assembly processes of carbon neutral buildings.

REFERENCES

1. Nearly zero energy buildings: achieving the EU 2020 target. Source: European Council for an Energy Efficient Economy. http://www.eceee.org/buildings/Steering-2-zerobldgs.pdf. Accessed 5/23/2012
2. AIA Agenda 2030 Commitment: http://www.aia.org/about/initiatives/AIAB079458, retrieved on 5/23/2012.
3. Igor Sartori, Assunta Napolitano, Anna J. Marszal, Shanti Pless, Paul Torcellini, Karsten Voss. "Criteria for Definition of Net Zero Energy Buildings." IEA SHC Task40/ECBCS Annex52: Towards Net Zero Energy Solar Buildings.
4. Spiegelhalter, Thomas and A. Lee. „ Climatic Tropism in Buildings: Designing with Natural Response Cycles for Better Performance. " Design *Principles & Practices – An International Journal,* Volume 5, No. 4. (Common Ground Publisher, 2012)
5. SIEMENS PLM and Automation, http://www.plm.automation.siemens.com/en_us/products/velocity/solidedge/st4/, retrieved on 5/23/2012