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Emerging CAE technologies and their role in Future Ambient Intelligence Environments

Vision Paper

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Abstract: Dramatic improvements are on the horizon in Computer Aided Engineering (CAE) and various simulation technologies. The improvements are due, in part, to the developments in a number of leading-edge technologies and their synergistic combinations/convergence. The technologies include ubiquitous, cloud, and petascale computing; ultra high-bandwidth networks, pervasive wireless communication; knowledge based engineering; networked immersive virtual environments and virtual worlds; novel human-computer interfaces; and powerful game engines and facilities. This paper describes the frontiers and emerging simulation technologies, and their role in the future virtual product creation and learning/training environments. The environments will be ambient intelligence environments, incorporating a synergistic combination of novel agent-supported visual simulations (with cognitive learning and understanding abilities); immersive 3D virtual world facilities; development chain management systems and facilities (incorporating a synergistic combination of intelligent engineering and management tools); nontraditional methods; intelligent, multimodal and human-like interfaces; and mobile wireless devices. The Virtual product creation environment will significantly enhance the productivity and will stimulate creativity and innovation in future global virtual collaborative enterprises. The facilities in the learning/training environment will provide timely, engaging, personalized/collaborative and tailored visual learning.

Keywords: Computer Aided Engineering • Future Learning Environment • Learnscapes • Ambient Intelligence Environment • Visual simulation • Virtual product creation • Immersive Virtual worlds

1. Introduction

Virtual Product development systems evolved from the integration of modeling, simulation, and visualization facilities with other product lifecycle management and software tools. These tools have enabled innovation and accelerated time-to-market. The pressures of creating increasingly complex systems, reducing the costs of their acquisition and ownership, and improving their performance have led to the development of new capabilities to aid in the analysis, design and manufacture of new products, see for example [1]. The capabilities can be grouped into three categories, namely:

1. Computer Aided Engineering (CAE), Digital Simulation and prototyping facilities, incorporating virtual 3D models, complex high-fidelity simulations and visualizations, as well as design exploration and optimization tools;

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2. Knowledge-based engineering packages (including, geometry modeling and agent-supported simulation);

3. Simulation Lifecycle Management (SLM) suites, which encompass four essential functional areas: simulation data management, integration and process automation, decision support, and distributed collaboration. They leverage Product Data Management (PDM), Product Lifecycle Management (PLM), and other management technologies.

Figure 1. Product Lifecycle Activities.

The term computer-aided technologies (CAx) is currently used to include the various engineering (Computer Aided Design - CAD, Computer Aided Manufacturing - CAM, Computer Aided Engineering - CAE); management (e.g., Simulation Lifecycle Management - SLM, Human Capital Management - HCM, Customer Relationship Management - CRM, Supply Chain Management - SCM); and other tools (e.g., Enterprise Resource Planning - ERP, Maintenance, Repair and Operation - MRO) used in the product life time (see Figure 1). CAx encompasses a broad range of tools, including commercial and available proprietary tools.

As the trends of distributed collaboration, large-scale integration of computing resources, enterprise tools, facilities, and processes continue, a fundamental paradigm shifts will occur in the virtual product creation. Future high-tech systems will be complex systems-of-systems, developed through just-in-time collaborations of globally distributed teams linked seamlessly by an infrastructure of networked devices, tools, facilities, and processes (extended adaptive enterprise). The effective use of immersive 3D virtual worlds can facilitate both the product and process innovations (through enabling product planners and developers to visualize, assemble, test and optimize the product and production processes).

The present paper describes the frontiers and emerging CAE, simulation and virtual world technologies, and their role in the future virtual product creation and learning/training environments.

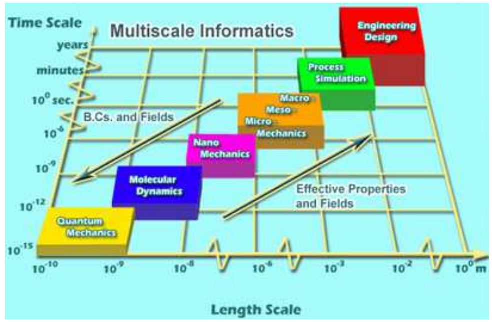


Figure 2. Length and time scales in Hierarchical Modeling.

2. Frontiers of CAE and Simulation Technologies

The frontiers of CAE and simulation technologies, which are knowledge domains in transition, can be grouped into the following four categories:

1. *Making Simulations Easier, Faster and Robust.* Among the various activities of this category are:

    - Higher fidelity representation of product's geometry, physics, environment and function. This includes the use of multivariate B-splines and NURBS for accurate representation of geometry, and then constructing a coarse mesh of spline elements (which has the potential of efficiently integrating CAD with Finite Element Analysis) [2],
    - Verification and Validation of Digital Simulations [3, 4],
    - Multiphysics, multilevel and multiscale visual simulations (see for example [5] and Figure 2),
    - Material characterization/material informatics (adding an "informatics" dimension to the analysis of materials science phenomena, by processes which can permit one to gather and survey complex, multiscale information, see [6, 7] and Figure 3,
    - Hybrid/Heterogeneous simulations,

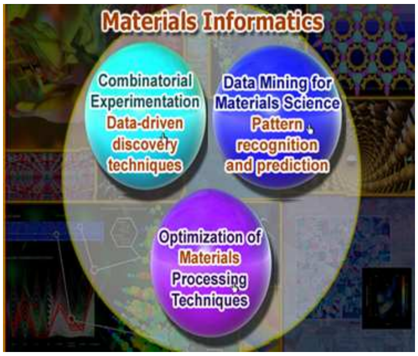


Figure 3. Basic Components of Material Informatics.

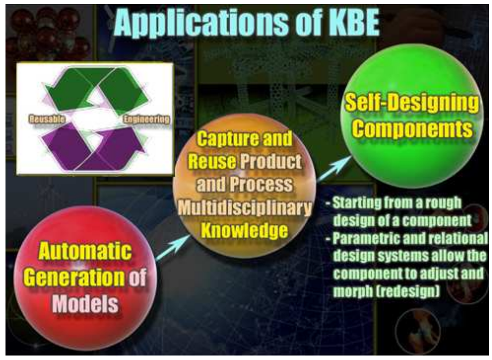


Figure 4. Past and current applications of KBE.

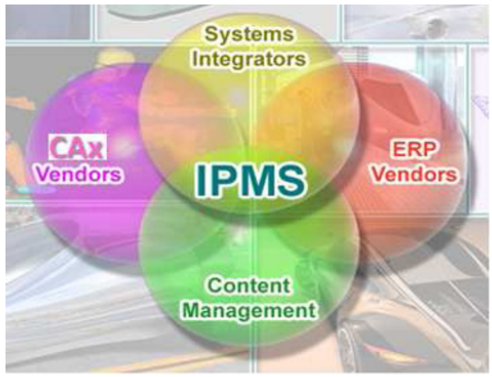


Figure 5. Integrated Product Management Systems (IPMS).

- Automating non-creative tasks (e.g., model and mesh generation) [8].
- Application of knowledge-based engineering (which evolved from automatic generation of models to the capture and reuse of product and process multidisciplinary knowledge to the building into the parametric and relational design systems the capability, to enable the components to adjust and morph automatically, see Figure 4).

2. *Product Lifecycle Simulation activities*, including
   - Collaborative, integrated virtual product creation
   - Technology, geometry and process modeling
3. *Large Scale integration for the extended Enterprise*, this includes collaborative management of product information from inception to retirement through development of Integrated Product Management Systems (IPMS), incorporating Simulation Lifecycle Management, see [9] and Figure 5.
4. *Broadening Applications of CAE and Predictive Simulations*. Among the new applications are:
   - Integrated multimodal vehicles (including NASA's Personal Air-Land Vehicle concept; DARPA's submersible aircraft; the PLASVEE challenge problem that Boeing created for NAFEMS; and the Russian Personal Air-Land Vehicle, see Figures 6 and 7).
   - Biologically-inspired systems (structures with nervous systems, self-healing and self-repairing structures, see Figure 8).
   - Biological systems. The simulation of biological function has advanced enormously since the early attempts to use computers to understand how biological systems work. The emergence of effective approaches, the increase in computational power, and a rapid expansion of the field have enabled the simulation of ever more challenging biological problems.
   - Cyber-physical systems – which are tight integrations of computation, networking and physical objects, in which embedded devices are networked to sense, monitor and control the physical world (e.g., civil infrastructure, healthcare, and transportation systems).
   - Homeland and border security applications (e.g., simulations of multi-events, multi-threats of the interconnected critical infrastructure systems).
   - Sustainable and renewable energy systems (e.g., simulation of grid operation and integration of wind, solar, geothermal heat and other renewable energy resources). As an example,

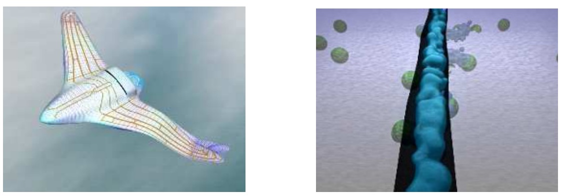
the *Virtual Nuclear Reactor* project funded by the US department of Energy aims at using advanced simulations to improve reactor safety, increase reactor power, and extend reactor life.

a) b)

Figure 6. a) NASA's Personal Air-Land Vehicle b) DARPA's submersible aircraft.

a) b)

Figure 7. a) Russian Air-Land Vehicle b) NAFEMS PLASVEE.



a) b)

Figure 8. a) Structures with nervous systems b) Self-repairing structures.

3. Drivers for a Profound Change in the Role of CAE and Simulations

There are a number of compelling motivations for a fundamental paradigm shift in virtual product creation, as well as for a change in the role of CAE and simulations in future environments. Among these are:

1. Digital life and the Ambient Intelligence Environments (described in a subsequent section).

2. Imperatives of Global Economy and Global Virtual Enterprises (Examples include the Airbus coordinated Value Improvement through a *Virtual Aeronautical Collaborative Enterprise* – VIVACE, see [10]); the changing business models (e.g., *Design Anywhere, Manufacture Anywhere* – DAMA); the extended supply chain; and the need for creating 24/7, on demand, global workforce.

3. Competitive product and marketing innovations, and the associated demands for mass customization and for taking virtual product creation into new realms (e.g., US Department of Defense *Computational Research and Engineering Acquisition Tools and Environment* – CREATE).

4. Grand Engineering challenges, including Energy Production and Distribution; Environmental Remediation and Sustainability (e.g., Climate Change and Global Warming); National and homeland security; Reverse Engineering of the Brain; and the accelerating pace of generating new knowledge (faster than the workforce can learn it).

5. Emerging and Frontier technologies that will serve as the power tools of the future in addressing grand engineering challenges. These include Nanotechnology, Biotechnology, Information/ Knowledge technology, Cognitive Science and technology, and Synthetic Biology (NBICS).

4. Future Ambient Intelligence Environment

Ambient Intelligence is a vision introduced by the European Information Society Technology Advisory Group (ISTAG) in 2001, based on the convergence of ubiquitous computing, ubiquitous communication and intelligent user-friendly interfaces [11]. An extension/update of that vision, is to have people living and working in a digital environment, surrounded by intelligent tools, intercommunicating devices, and robotic networks, which are seamlessly integrated and embedded into, the environment and beam information to each other. All the devices and facilities will be sensitive and responsive to the people, and anticipatory to their behavior. They can react intelligently to the users' gestures, actions and contexts.

5. Future Virtual Product Creation

Major Components

The major key elements of future Virtual Product Creation (VPC) are:

1. Biological inspiration to provide insight into future smart products (i.e., what is designed).

2. Participatory virtual product creation using *crowd sourcing*, and mobilizing collective intelligence to provide mass customized personalized products [12].

3. Virtual representation of the entire value chain, from raw materials, to product and production planning, to life time maintenance and remote service. This also include advanced tools and facilities for predictive product realization, end-to-end simulation and virtual testing tools, supply chain management facilities, as well as tools for managing complexities and uncertainties.

4. Ambient Intelligence Environment incorporating virtual world facilities, powerful collaborative technologies and platforms to significantly enhance creativity and innovation (i.e., how future products are designed).

5. Natural, intuitive, multimodal and other novel interfaces to: a) increase the bandwidth of human-technology interaction, and b) enable faster, better and more complete access to all types of information related to the product [13–15].

6. Tools for managing complexities and uncertainties, including handling complex multiphysics data and varying degrees of model fidelity; emergent synthesis tools for handling hierarchical complexity; risk analysis and optimization tools.

7. Effective VPC frameworks/ infrastructures to enable capturing the knowledge used in the product creation in an explicit, reusable and traceable format.

Experience gained from *Massively Multiplayer Online Role Playing Games* (MMORPG); mashing the virtual worlds with web 2.0/3.0; and the Metaverse concept can be used to develop a *Massively Multiorganization Online Virtual Product Creation* (MMOVPC) Environment. Such an environment can provide a high degree of interactivity in the various lifecycle phases of the product, with the various product development/support teams, as well as with the customers (see Figure 9).

Figure 9. Massively Multiorganization Online Virtual Product Creation (MMOVPC) Environment, with separate islands for each of the Product Creation Phases.

6. Future Learning and Training

The fusion of learning, entertainment and other technologies is leading to the integration of learning spaces, platforms, environments and tools into new concepts to address the needs of future learners. Among these concepts are the *3D Massively Multilearner Online Learning Environments (MMOLE)*, and the *Learnscapes*. Both concepts are described subsequently.

1. *Massively Multilearner Online Learning Environment (MMOLE)*
   MMOLE is an adaptation of Massively Multiplayer Online Role Playing Games (MMORPG) to learning. It uses the Metaverse concept (a vision of an immersing and lifelike virtual world very similar to the real world), and combines elements of Digital Game-Based Learning (DGBL) with those of Mobile Digital Media, Grassroot video, Open Educational resources, and Virtual worlds (see Figure 10).

2. *Learnscapes*
   This refers to the integration of the continuum of available technology-rich networked platforms, environments and spaces for personal and collaborative, formal and informal learning.
   The major components of Learnscapes are:

   - *Hyperconnectivity* of humans, computing devices, information and robotic networks.
   - *Interactive, Immersive Classrooms* with 3D Visual simulation facilities (see Figure 11).
   - *Blending the immersive Physical and Virtual Worlds* (see Figure 12).

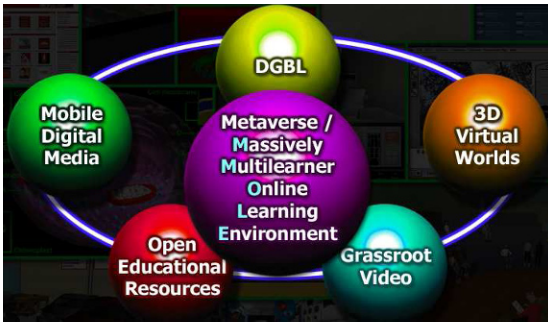


Figure 10. Massively Multilearner Online Learning Environments (MMOLE) concept.

Figure 11. Interactive Immersive Classroom.

3. *Intelligence and Automation.* This includes expanding the role of Intelligent agents, bots and robotars. Two of the obvious roles of bots are: a) Replacing people in jobs where the tasks can be given to autonomous software agents (e.g., animated avatar giving a scripted presentation and answering questions, using more advanced question/answering systems than the ones currently available on the web, without human control), and b) Intelligent Information retrieval and customization.

The MMOLE and Learnscapes can help in providing the learners with the digital and cognitive skills needed for the future technical workforce (see, for example [16]). These skills include:

- Drawing insight from information and extracting learning from experience.
- Reflecting on the learning (i.e., having metacognitive skills, including metamemory, metacomprehension and the ability of self regulation).
- Using analytical, systemic, and creative thinking (expert thinking – having the synthetic ability to recognize relevant patterns in unfamiliar contexts; linking dynamic concept mapping and problem solving in complex domains).
- Having the flexibility to work across disciplinary and cultural boundaries to generate innovative solutions (complex communication – including persuasive speaking, inductive reasoning, and making inferences).
- Becoming competent with a variety of learning resources (i.e., using multiple learning sources and perspectives).
- Evaluating information quality/validating information (having the judgment to distinguish reliable from unreliable information).
- Coming up with multiple interpretations and outcomes, when there is more than a single correct answer.

Figure 12. Blended immersive physical world and virtual world with holographic life-like avatars.

7. Concluding Remarks

The concept of *virtual product creation* – digital simulation of the various phases of product creation from concept selection to design, manufacturing, operation, to upgrade or retirement dates back to the 1990s. However, in recent years significant CAE capabilities and holistic approaches have been developed for the accurate prediction of the product characteristics and functions; simulation of manufacturing processes; and product optimization. Today, large and complex multidisciplinary simulations can be performed by globally distributed teams using grid computing technologies and cloud computing. The frontiers of CAE and simulation technologies are described in the paper.

The significant increase in the CAE and simulation capabilities can be attributed to the developments in a number of leading-edge technologies and their synergistic combinations/convergence. The technologies include ubiquitous, and petascale computing; ultra high-bandwidth networks, pervasive wireless communication; knowledge based engineering; networked immersive virtual environments and virtual worlds; novel human-computer interfaces; and powerful game engines and facilities.

The pace of development of CAE and simulation capabilities is likely to accelerate in the coming years. The associated technologies will serve as the backbone of the future Ambient Intelligence environments for product creation and learning/training.

The fusion of Massively Multiplayer Online Role Playing Games (MMORPG) with virtual worlds and other technologies will lead to new Ambient Intelligence environments for product creation and learning. A *Massively Multiorganization Online Virtual Product Creation* (MMOVPC) Environment can significantly enhance the productivity and stimulate creativity and innovation in future global virtual collaborative enterprises. Future concepts for learning environments will address the needs of future learners, and provide timely, engaging, personalized/collaborative, and tailored visual learning. Among these concepts are the *3D Massively Multilearner Online Learning Environments (MMOLE)*, and the *Learnscapes*, which are described in the paper.

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