A Scientific Formalism for Product Realization in a Global Manufacturing Enterprise

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Organization and Overarching Goals in this Report

My overarching goals in composing this report are to develop a clear and concise vision of the future of engineering, postulate the needs of design / manufacturing enterprises in the world of 2020, and present solutions to these needs. Towards this end, steps towards formalizing product realization in a global marketplace are presented.

In the first section of this report I present the direction of this report in the form of an interview with the CEO of FutureTechDME[1]. Next, I present the position of FutureTechDME in the next 20 years. In this, I present the partnerships that must be forged, the research challenges the FutureTechDME will face, and the core research directions to address the scientific formalism of product realization in 2020. I present my vision of the world of 2020 around major drives such as technology, economy and communication considerations. Finally, I develop a vision of support technology and academic research to meet the needs of manufacturing enterprises in 2020.

Setting the Context - An Interview with the CEO

My vision of the world of 2020 and the technology needed to support manufacturing enterprises in the world of 2020 is presented in the context of competing for a job opening as a consultant to a high tech manufacturing firm, FutureTechDME. In the job briefing at FutureTechDME, the CEO states:

> *Welcome to the briefing. I am interested in positioning our company, FutureTechDME, to be one of the high tech, global manufacturing enterprises in the year 2020. I want to hire a consultant who is able to define the characteristics of this company in the year 2020, the research challenges it will face, its mode of operation, the partnerships it will need to forge and more importantly the technology that will be necessary to support it employees in being globally competitive.*
>
> *I am particularly interested in the research issues that we in partnership with our colleagues in academia will need to address over the next 20 years, namely, a*

[1] FutureTechDME is the hypothetical enterprise conducting the job interview. FutureTechDME is used throughout the paper to represent a multitude of design and manufacturing enterprises.

scientific formalism for product realization suitable for a global manufacturing enterprise

I am looking for a consultant who understands my needs and is cost-effective. I am looking for a consultant who is able to conceive, research, and articulate a bold plan for the future of our company. I am looking for a consultant who is able to anchor his/her dream in well-documented scholarship. Most importantly, I am looking for a consultant who will join my team for the long haul; a person who is able to keep learning and helping my company negotiate its ways through the first twenty years of this century.

In the following sections, I address several of the main issues readied by the CEO of FutureTechDME, namely:

- The strategic position of FutureTechDME
- The academic partnerships to be forged
- Goals and research issues to be addressed
- Challenges that FutureTechDME will face over the next 20 years, and
- My vision of the world of 2020.

Strategic Position of FutureTechDME

In this section I present my vision of where FutureTechDME will need to be positioned and what partnerships will need to be forged to be successful over the next 20 years. These visions are focused on the following statement by the CEO of FutureTechDME:

I am particularly interested in the research issues that we in partnership with our colleagues in academia will need to address over the next 20 years, namely, a scientific formalism for product realization suitable for a global manufacturing enterprise

FutureTechDME must position itself and invest in two distinct areas, namely, (1) core scientific research areas and (2) the scientific formalization of product realization. In Figure 1, the strategic position of FutureTechDME and the relationships with university research labs is shown. As a leading design and manufacturing enterprise in 2020, FutureTechDME must be strategically positioned in relationships and direction to drive the formalization of product realization.

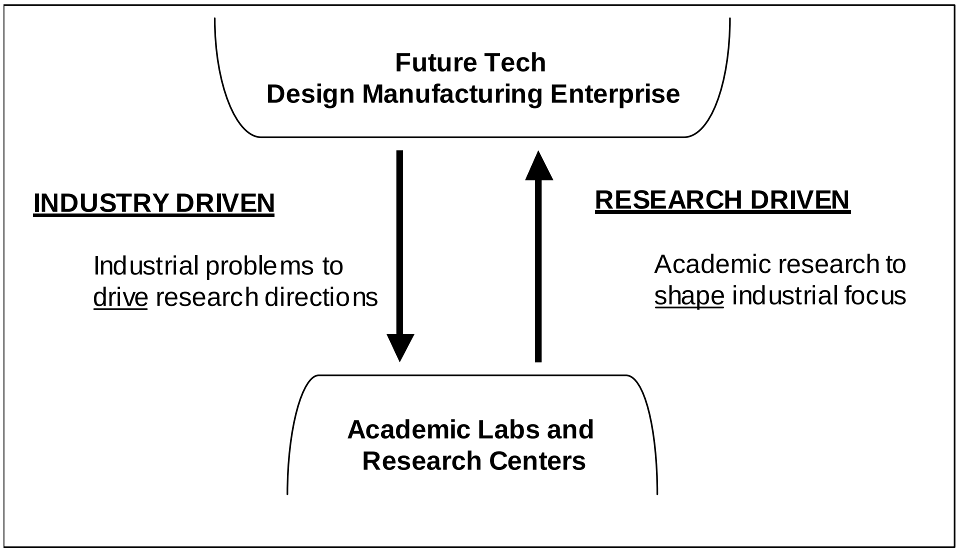

Figure 1. The Strategic Position of FutureTechDME

First, FutureTechDME must continue to design, develop, and manufacture cutting edge products and technical systems. To support the development of cutting edge products and technologies, FutureTechDME must continue to invest time and money in core sciences, such as thermodynamics, machine design, materials design, mechanics of materials, and manufacturing to name a few. Additionally, they must invest in expertise domain knowledge for the realization of technical products. Theoretical research and expertise in these areas cannot be overlooked while developing and pushing the next generation of products from FutureTechDME.

More importantly, FutureTechDME must position itself and invest in the development and formalization of product realization theory and methodology. In addition to continued research in basic sciences and domain expertise, a concerted effort must be put forth to shift product design and realization from an artistic-centered creative activity to a scientific-based, mathematically rigorous endeavor.

FutureTechDME must support the formalization of product realization through research conducted in internal research labs and design centers, but also through cooperative research efforts with university partners. Partnerships with university labs are very important because of the degree of separation from simply "developing product" to creating new knowledge. University labs are able to concentrate on the development of theoretical underpinnings while using case studies and first hand experiences from FutureTechDME as motivation and direction for developing support tools and methods.

In this section, I present an overview of the partnerships FutureTechDME must forge as well as the position in which it must be placed. I highlight the strong need to forge research partnerships with university labs over the long term. In the following sections, I present the position and direction these partnerships should be focused as well as immediate goals for FutureTechDME and associated academic partners.

1.1.1 Research Position of FutureTechDME

FutureTechDME must invest both time and money to support academic research towards the development of product realization tools, methods, and theoretical contributions. The formalization of product realization is a large task that cannot be expected to be solved in a short period of time by a single manufacturing enterprise. However, a concerted effort must be made towards theoretical research and advancements in design theory and methodology. The research focus of FutureTechDME should be directed toward managing information and knowledge in the product realization process.

As we accelerate rapidly into the information age, there has become a seemingly limitless supply of information generated and used in the product realization process. Much of this information about product and process is stored, managed, created, and accessed digitally. The information age, and the advent of digital product realization has not only changed the way in information is exchanged, but also in how product realization is completed. Theoretical underpinnings and methodologies have not been adequately developed so as to maximize the benefit from information technology.

There are two important needs in improving the efficiency and effectiveness of product realization, while achieving a scientific formalization of product realization. First, the underlying methods and core theoretical advancements must be established that links the information revolution and product realization. Secondly, the development of tools to support, manage, and leverage the massive amount of digital information in product realization must also be developed.

While FutureTechDME must not lose the focus of developing high-quality cutting edge products, critical analyses and review of current realization methods and practices must be completed to gain a deeper understanding of product realization as a scientific based activity and improve the realization process. The core focus of FutureTechDME should be on digital product representations or in better terms the "digital enterprise". As part of the enterprise FutureTechDME will specifically focus on engineering and design and the interaction in the design of complex technical systems. In support of this, FutureTechDME should research, develop, and implement engineering information technologies to support product and process information.

1.1.2 Partnerships to Forge for FutureTechDME

The partnerships that FutureTechDME must forge over the next 20 years to be successful in product realization are very important. FutureTechDME must complete research on the theoretical underpinnings and core technologies to support product realization. FutureTechDME must partner with leading academic labs in the areas of product design, strategic planning, computer science with a strong background in engineering product design, innovation and business. Currently there are many design / manufacturing enterprises that are partners with academic lab – however this is to a limited degree.

To be successful in the future, FutureTechDME must forge stronger partnerships and invest in academic relationships. FutureTechDME and the associated academic labs must have a vested interest in the success of product development, creation of digital enterprises for product realization, and the formalism of product realization. As depicted in Figure 1, FutureTechDME must have a strong presence and involvement with the direction of research in product realization through case studies and first-hand experiences. Similarly, academic research labs must shape the future of product realization by establishing new methodologies and theoretical underpinnings in product realization. This relationship must be kept in check to ensure academic research lab don't act as consultants to FutureTechDME and similarly so academic labs do not develop theories or support tools that will not be used by industrial partners.

As part of the key partnerships, personnel include academic faculty, research scientists, graduate students, and technical contacts / visiting researchers from various industrial partners. A brief description of expected responsibilities include the following:

Academic Faculty – disseminate knowledge and present the research area of information management to student and other colleagues in the domain of information technology. The academic faculty will have the job of conducting research, but also emphasis on the importance of computer technologies, information management, and related topics to the mechanical engineering curriculum. The academic faculty will also have the responsibility of conducting research in the area of information management and technology

Research Scientists – develop technologies and tools to support information management in design and manufacturing enterprises. Research scientist will also be responsible for disseminating knowledge, but will be the prime persons in development and implementation and research towards bridging gaps in current information management.

Graduate Students – Will serve as thought leaders toward information management. Student will work and complete research and implementation. The focus of the work will not be on commercially available tool development or production usage. Proof-of-concept implementation of developed methods and techniques are expected.

Industry Liaison / Visiting Researchers – Engineers and scientist, technical managers will join the lab for periods of time –their focus must not be simply on implementation, but driving the future of product realization. These researchers will be responsible for close ties to industry, case studies, and integration of developed technologies to product usage.

The success of FutureTechDME depends not only on the team members, but also on sharing and disseminating information, experiences between all members of the teams. This information may be case studies, technologies advancements in product realization, feedback from engineers at FutureTechDME, and research findings, theoretical advancements, or the development of support tools from the academic side.

Only through close contact will FutureTechDME be successful in the future of design and manufacturing. By forming these long-term partnerships FutureTechDME can expect benefits in distributed product realization – however these benefits are not immediate. Design and manufacturing enterprises must continue to invest and partner with academic laboratories over the long-term to move towards a formalism of product realization.

Relationships with academic lab are important because of the difference in the goals of the research labs and manufacturing enterprises. The main goals of manufacturing enterprises are to make a profit and produce products. While many enterprises have made a commitment towards continued research, it is not the main goal. On the other hand, the goals of academic research labs are to create and disseminate knowledge. By leveraging the goals and focus of both manufacturing enterprises and academic research lab, leaps and bounds can be accomplished towards the formalization of product realization over the next 20 years.

1.1.3 Goals to achieve for Future Lab DME

To support the formalization of distributed product realization, FutureTechDME and associated university research labs must work towards achieving several goals. A key concern in distributed product realization for FutureTechDME in 2020 is the development and usage of a comprehensive information model for both product and process based information, as well as associativity between each model. In developing a comprehensive, semantically rich information model FutureTechDME-University partnerships must address several issues including,

- Capturing product knowledge and information in the realization process, in a computer and human –sensible manner to support collaborative computer-based product realization
- The utilization of formal product and process models to support knowledge-based product development
- Development of computer-based tools and frameworks to support information sharing through a product and process model representation
- Development of a robust and flexible design process model for use in multi-disciplinary system realization teams

Developing distributed product realization (DPR) frameworks to support the close associativity between product and design process models is becoming increasingly important to successful and efficient product realization.

By developing DPR frameworks, the product realization process can be more efficiently and effectively supported. In turn an increased amount of process and product knowledge and information will be captured so as to reduce the overall time and effort in the realization process.

Future Lab DME will achieve the goal of modeling product and process information to increase the efficiency and effectiveness of system realization through the following objectives

1. Design, develop, and implement method and tools to manage information in the product realization process
2. Work with industrial partners to study and improve the efficiency of information management in product design
3. Support the development of an engineering curriculum toward information technologies in the classroom – emphasis on mechanical engineering
4. Work toward the development of standards

1.1.4 Challenges for FutureTechDME

Over the next 20 years, FutureTechDME will face several challenges on the cutting edge of research and the design and manufacturing of technical products. Several of the challenges FutureTechDME are listed below.

- How to develop partnerships with academia and research centers to push the envelope and shape the leading edge of design and manufacturing.

FutureTechDME will need to forge strong relationships with centers of excellence in academia to develop tools, methods, and technologies to remain a leader in product realization.

- FutureTechDME will need to make significant investments in time and financial resources with academic partners towards a scientific formalism for engineering product realization. In this time when enterprises are cutting down back on research and development and strategic partnerships with universities, FutureTechDME must envision the long term and make investments for long-term success.
- Information technology must be infused into business and product development practices. As product development becomes more distributed information technologies will increasingly support FutureTechDME internal to the company and with outside vendors and suppliers. While there may be an initial investment for hardware, software, and training of IT, the return on investment will be greater over the long term. There may Infusing ideas of information technology to engineering student, especially mechanical engineering
- A good balance between domain experts and systems engineers must be achieved to remain competitive and foster good communication amongst stakeholders in the realization process. The complexity of modern, and future, products is pushing the limits of integration between engineers, managers, designers, and various stakeholders involved in the realization process. Engineers will be the thought leaders and managers in the realization process and must be knowable in a multitude of fields as well as integrating various areas. The organization and mode of operation of FutureTechDME must be structured to maximize the efficiency and effectiveness of systems engineers in the product realization process
- Developing support technologies and frameworks for product realization. FutureTechDME must be visionary in product realization and not just “fight fires” throughout the realization process. As changes are infused to the realization process a reflection process must be completed to ensure improvement in the realization process and the development of support technologies to remain leaders in the world of 2020.
- FutureTechDME must develop processes and products that are open and flexible to change as future demands and needs change. By developing open and flexible engineering systems [1] FutureTechDME will remain competitive in design and manufacturing over the long haul. The open systems paradigm should be followed for the products FutureTechDME develops as well as the processes they follow in product realization.

The vision of the world of 2020 and the needed support technologies are predicated on the intimate involvement of FutureTechDME as a both a thought leader in product realization as well as a leader of design and manufacturing over the next 20 years. The challenges that FutureTechDME provide motivation for envisioning the world of 2020, postulating the needs of a design and manufacturing enterprise in 2020, proposing the necessary support technologies to meet these needs, and finally developing a scientific formalism for product realization. These challenges are only a few that enterprises will face over the next 20 years. However, they are keys in shaping how product realization will be completed and how enterprises will operate.

Establishing the World of 2020 – Postulating the Future of Engineering Product Development

In this section I provide a historical view of engineering, design, and manufacturing. Based on this view, I propose what the future of engineering will be like and postulate how engineering product development will be completed.

Motivation for developing my Context of the world of 2020

The motivation for developing the world of 2020 is to develop design methods and support tools to meet the needs of the future. In this effort, I attempt to paint a vivid picture of the future of engineering. I present an overview of design-manufacture characteristics of the past and present and postulate what the future will be. From these characteristics, I identify the drivers of the world of 2020 and develop characteristics for the future of engineering product realization.

Questions Posed to Develop a More Concise View of the World of 2020

To aid in the development of my view of the world of 2020, I have formulated several questions

- *Why should be pursue a scientific formalism for product realization for a global manufacturing enterprise*

Design is a complex activity often driven by the personal expertise and experience of those involved. As companies become increasingly global the experience, background, education, and views of the designers and engineers involved in the product realization process may vary dramatically. The methods, tools, and techniques for the design of technical products must be formalized into a scientific based, mathematically rigorous activities to ensure that geographically and culturally distributed design teams are "speaking the same language" to ensure successful product development.

- *What is the purpose and benefit of using a design methodology?*

A design methodology can increase the probability of producing a successful product or process. More over, in the event that obstacles are faced, a systematic design approach will lessen the risk of a design. For example, if obstacles are encountered well into the detail design phase, the systematic approach will minimize the number of steps that must be repeated to remedy the problem. From a legal standpoint, the systematic approach should emphasize detailed documentation. Because the design is completed in a standard manner, with specific augmentations for the specific design, there is a higher chance of keeping records of the process and the decisions made throughout the design.

By following a design methodology, the process can be referred to in the future for changes made to the specific product or can be used to decrease the time for related products.

- *What are the implications of enterprises in manufacturing?*

When I envision enterprises, I think of large multi-locational companies – how are such companies going to operate in the future. What is going to be the structure of the companies and how are design processes going to be managed. Current trends in business today have shown that large companies have many different subsidiaries that are not always a walk away. What sorts of issues are these companies going to face.

- *How will information and knowledge be shared with members of a design group?*

Information, documentation, and calculations must be shared amongst group member to complete assignments. How will this information be shared when passing papers is not adequate and mail is not quick enough? Granted now we have fax machines and email, but this is often not adequate to pass large amount of information. An network-based design repository will serve as a central database for information relevant to group work and allow groups to meet and interact as though they are face to face in a traditional classroom environment. In addition to being able to access information in the repository it must be able to be process and/or used by all stakeholders in the design process. Standards must be developed to enable seamless sharing of information in the design process. These standards will become more important as products become more complex and information continues to be stored and created digitally.

- *What will the standards of "business" be amongst members of the group?*

Prior to tackling a design problem, the "right" group must be formed. This is not accomplished by picking names out of a hat, but rather should be completed with logic and thought. Groups should be formed based on the interests, goals, and value that each member can bring to a group. In forming a team, the idea of developing a code of conduct and work ethic should be addressed. In this contract of sorts, such issues as design goals can be clarified, ethical issues can be resolved and task allocation can be determined. The code of conduct should be developed and formed to maximize the efficiency of the team.

- *What is the role of information technology in the product realization process of open systems?*

As we enter the information age what support tools are needed to drive the changing face of engineering design. While I do not think that the development of tools will drive paradigm shifts in manufacturing they will help to change the shape of how engineering is done.

Understanding our past and our present

In order to postulate the future of engineering product realization, we must study the past and present. The characteristics and paradigm shifts we identify from the past will aid in developing a more concise vision of what the future has in store. Tummala [2] characterizes several differences between the 20th century to the 21st century (see Table 1).

Table 1. Shifts from the 20^{th} Century to the 21^{st} Century in Design and Manufacturing.

20^{th} Century Industrial Age	**21^{st} Century Information Age**
1. Mass production	Mass customization
2. Labor serves tools	Tools serve labor
3. Labor perform repetitive tasks	Labor applies knowledge
4. Command and control structure	Common control structure
5. Capital intensive	Knowledge intensive
6. Capitalist own production means	Labor owns production
7. Capital is primary driver	Knowledge is primary driver

The characteristics presented in Table 1 provide a good basis on which to further postulate the world of 2020. There has been a shift from mass production to mass customization in many consumer products. Additionally, there has been a shift from human labors serving the tools to tools supporting human labor. Finally and most importantly, there has been an increase in the importance of knowledge in manufacturing that has driven not only how goods are produced, but also how they are designed. There has been a shift from the Industrial Age in the 20^{th} Century to the Information Age in the 21^{st} Century.

1.1.5 Historical Trends in Product Realization

Roman [3] makes the following assertion about the world of the past and the present as drivers for the future

> *Historically, the main conditions that sparked paradigm shifts in design and manufacturing were changes in technology of energy, resources, transportation, communication, markets, management, and economic, political and production ideologies*

I paraphrase several key points that have drastically changed engineering design from [3]:

- Shift from working with natural forces to working against them
- Shifts from static, season-constrained energy sources to more mobile, reliable and cheaper sources
- Shifts from old closed mercantile trade practices to free market ideology where government is involved
- Shifts to faster, far-reaching, all-weather, affordable transportation
- Shifts from small scale, limited markets to larger markets with more specialized and exclusive goods and services with the distribution and marketing systems to support them
- Increased political power to companies due to changes in legislation and lobbying strategies that help these companies get favor from legislation

In addition to looking over the historical trends and paradigm shifts in product realization of the past, it is beneficial to examine the current trends in product realization. In the following section I take a closer look at the current trends in design and manufacturing.

1.1.6 Present Trends in Product Realization

In a survey of current product realization practices, the following trends in product realization are identified:

- Large corporations must manage a tremendous amount of data, information and knowledge between multiple locations are multiple times
- There is often a drive to "fight fires" in product realization to solve problem temporarily, but not get to the root of the problem
- Outsourcing – non-core activities are being pushed down the supply line (design line). Enterprises are concentrating on only the essential activities. Companies must have a longer term plan
- Market pressure has pushed manufacturers to develop improved quality products in a shorter time – there is a need to develop and use information technology

In addition to the general bullet points above, I highlight several key factors of the Information Age and the effect on distributed product realization. In the Information Age, we expect that amount and availability of information throughout the entire design process will continue to increase. However, a major obstacle in the Information Age is not the volume of information in the design process, but how the information is managed and how usable the information is in the realization process. Several key points in the managing information in the product realization process are the following:

Engineering is becoming digital – Companies are using technologies such as computer aided drafting (CAD), finite element analysis (FEA), system engineering tools, email, and product data management systems (PDM) to manage engineering systems realization. However, these tools are still in their infancy and are not used efficiently or effectively.

Computer Aided Design (CAD) – most CAD applications are used for detailed design and usually only captures shape information (some material information). Current tools do not support conceptual design or exploration of functional principles independent of form. Additionally, CAD files are most often in proprietary format and can not easily be shared between design firms and various groups

Finite Element Analysis (FEA) – Integration between formal tools – there is a huge gap between engineering synthesis tools (e.g. CAD) and engineering analysis tools (FEA). There is not a close association between design models and analysis models – thereby making it difficult for analysis driven design. This large gap decrease the efficiency of design in the detail phase

Product Data Management (PDM) – Product Data Management systems offer a great file management system. In our view, this capability is tremendous. However, PDM are the most immature of engineering tools and their use is not well known or studied. At the present time, PDM offer a fantastic method to store and share part/assembly files but are not well integrated into the design process. When and where PDMs are used in the realization process are not well known or well studied.

Communication – The prime method of communication amongst distributed engineering teams is still (1) telephone (including teleconferencing), (2) email, and (3) design meetings. This is often a difficult and expensive way to share design information. Email is a quasi one-way line of communication with little or delayed immediate feedback. The telephone offers two-way lines of communication but is often hard to explain complex concepts across the phone line. Design meeting, the traditional way for design reviews in product realization are more expensive and require more time. The benefits of phone and email are the availability and cost, but lack the bandwidth of sharing information.

Design Meetings – Design review and meetings are becoming distributed – they are often limited by bandwidth and communication mediums. The method in which information is shared is a limiting factor on distributed design teams

Expert Systems – they are making a comeback after a long decline of usage. The value of an expert system is becoming more important as there is a need to capture deep knowledge in many locations

Manufacturing – manufacturing is still by basically traditional means (machine tools) there is a growing trend toward non-traditional manufacturing. Part and components can no longer be manufactured with traditional tools. Additionally the technology for non-traditional manufacturing is spilling over to prototyping and digital communication

Design Enterprises – the view of design-manufacture enterprise is changing. Due to the changes in the market there is an increase in only completing core activities and outsourcing the fabrication. I believe this has caused the decline in design as intellectual property rights are being diluted. Not only is fabrication leaving enterprises, but the design cycle is also being outsourced.

In the section that follows, I establish my view of the World of 2020. This is a vital part to answering my Q4S because it drives my assumptions and requirements list for a design method.

Developing the World of 2020

I highlight several characteristics of the world of 2020 in engineering design and product realization. These issues range from political and economic concerns to technical concerns that will shape the way in which product realization will be completed over the next 20 years.

Political/Economic

- Global standards
- Smaller politically, larger economically
- Super economies (e.g; India, China)
- Trade will keep on being used as political and economic tool
- Standardization at a global scale

Social/Cultural

- Mass communication: greater homogenization of cultures globally

– Degradation of moral values learned form religions will increase
– Better defined code of ethics
– English will be the dominate language

Technological
– Increased computer capabilities
– Internet based communication
– Virtual prototyping/simulation will cut design time
– Integration of manufacturing and design

Business
– Most companies will move to developing comprehensive systems rather than discrete components
– Other companies will provide renting and maintenance rather then selling
– Process environmental data for sustainable development efforts
– Mass customization

Environment
– World concern, e.g., global warming, ozone, reduction in bio-diversity
– Government involvement in market via green taxes
– Renewable resources in response to increase cost of total energy production

Design environment
– Distributed, working simultaneously from various location
– Increased communication with supply chain companies
– Internet backbone
– More accurate determination of customer demands (via information technology)
– OES methodologies

1.1.7 A Discussion of the Drivers for the World of 2020

Despite the advances in computing and computer supported engineering tools, significant gaps still exist in product and process modeling. Engineers have at their disposal numerous tools to aid, and even sometimes complete complicated analysis of many different types. In as much the ability of the computer to "crunch" numbers has been harnessed wonderfully to support engineering analysis. However, there are very few applications, that successfully provide a framework for integrating and capturing both product and process knowledge and information generated throughout the design process.

As the product realization process becomes increasingly distributed, the need to fill these gaps and develop methodologies, tools, and techniques will ultimately lead to higher quality systems produced in shorter times while incurring lesser costs. The current generation of computer support frameworks and tools cannot adequately support distributed product realization. If product realization continues to become increasingly distributed, as it is expected, and computer support frameworks are not developed these gaps will only grow larger.

In the past, the realization of technical products was completed by designers or teams of designers at a single company. This enabled the sharing of information and collaboration on the synthesis of ideas and the analysis results relatively easily when compared to the current product development practices.

However, the design of complex technical systems is increasingly becoming a set of collaborative tasks among designers or teams of designers that are physically, geographically, and temporally distributed. The complexity of modern products means that a single designer or design team cannot manage the complete product development effort.

While the advantages of a distributed, collaborative product development process lie in the fact that companies can leverage from a variety of different resources, can capture a wider market share during product development, and reduce cost and time to market by leveraging the expertise of other design firms or companies. For example, companies, therefore, do not need to employ experts in all domains of the product; they can simply outsource specific tasks or activities.

The disadvantages of a distributed, collaborative product development process caused the burden of sharing and exchanging product information, knowledge, and expertise. Engineers and designers must exchange this information across distributed networks because of the presence of geographically and temporally distributed design teams.

The current trend in product development is pushing the envelope of available technology for information management. Neither a design process model nor a product model currently exist that captures all aspects of the product development process so as to support the seamless sharing of information. The lack of an integrated product and process information model for product realization is a major limiting technology in distributive product realization.

The current state of support technologies such as email systems, fax machines, teleconferencing, web-based product data management (PDM) systems, central file servers and repositories, and concurrent engineering frameworks to name a few have allowed engineers and designers to collaborate in distributive product realization processes to a limited degree. However, these current technologies capture only a small percentage of the information associated with realization of technical products. In order to decrease many of the gaps and inefficiencies in the product realization process additional support tools and methodologies must be developed.

Based on the above discussions and shifts towards a digital information rich product realization environment, the key drivers for technical product realization in the world of 2020 are identified as the following:

1. Companies will develop products in a distributed and multi-disciplinary team to meet the rising demands of consumers: for high quality, reduced turnaround time, and decreased cost.

2. Companies will reduce overall cost through the use of “digital design environments” to more efficiently and effectively share product information and knowledge throughout the entire product realization.

3. The Human-Computer Cyborg will change in focus and utilization – computers will be utilized more efficiently and effectively in the design process. The expert systems and artificial intelligence will become more mature and ubiquitous in the context of engineering product realization. The value of the Human-Computer Cyborg will be increased.

4. Product Realization Computer Support Frameworks will be more transparent – computer frameworks will support the design process more seamlessly. Technologies such as distributive product realization framework and product data management systems will support the engineer/designer not hinder. The current support tools and engineering tools are not integrated enough to be transparent. For example, PDM systems require substantial effort and time to use. The future state of tools will not require this additional effort and will support the product realization process.

Key Characteristics of the World of 2020 - Summarized

The following list a summary of characteristics that will impact product realization in the world of 2020.

<u>Computers and Computer Support Framework</u>

- Human Computer-Cyborg will be stronger and used more frequently in the realization process not just for crunching numbers, but for knowledge based engineering design
- Advancements in the use of knowledge systems to support human designer
- Design will be more computer-based
- Seamless integration of software tools
- Additional tools to help designers to synthesize ideas
- We will see a tremendous shift in computer usage from where it all ready is today
- Expert systems

<u>Information</u>

- Digital age – information cannot just be passed by word of mouth
- Information age – endless amounts of information
- Information driven design
- Digital information will be available
- Use of standard information models
- Documentation of decisions throughout the design process will be more important from less of a legal issue and more of an efficiency issue
- World Wide Web will change from information rich to knowledge rich source

Realization Teams

- Distributed – from intra and inter company
- Distributed product teams
- Distributed – tele-commuters will be a big part of the work force
- More integration of multi-disciplinary design teams
- There will be fewer experts in the workforce in a deep area and more integrators of teams – knowledge will be lost

Design & Manufacturing

- Manufacturing will change to be even more flexible as there will be more of a need to have customer input
- There will be a trend toward alternative manufacturing methods
- Companies will begin to realize that outsourcing all aspects of the realization team may actually be causing the demise

Customer Related

- Products will be more flexible for customer demands
- Customer will drive the product process (changing from just specifying the assembly to much more high level specification)
- Consumers will be more aware of environmental concerns – may drive industry to change more

Governmental Issues

- Governments will increase the penalties for not "Life-cycle" engineering
- Governments will have more involvement with manufacturing and product realization
- The separation of countries will still be evident – while most say it would be great to have a completely unified world, I do not know if this can be achieved because of competitiveness between nations

In the following section a discussion of support technologies needed for product realization in world of 2020 is presented. As previously mentioned the goals put forth in this report are towards the scientific formalization of product realization through the development of theoretical underpinnings and core methodologies. I do not assert that the development of support technologies alone result in the formalization of product realization. However, there is currently a significant gap between theoretical underpinnings in distributed product realization and the associated support tools. To address these gaps and work toward a formalism, my first steps are in the development and implementation of technologies to support the current state of distributed product realization.

Technology Needed to Support FutureTechDME in 2020

In this section, a discussion of the needed technologies to support distributed product realization is put forth. The drives in this technology, as previously highlighted, are the following:

1. Companies will develop products in a distributed and multi-disciplinary team to meet the rising demands of consumers: for high quality, reduced turnaround time, and decreased cost.

2. Companies will reduce overall cost through the use of "digital design environments" to more efficiently and effectively share product information and knowledge throughout the entire product realization.

3. The Human-Computer Cyborg will change in focus and utilization – computer will be harnessed more efficiently to be used in the design process. The usage of expert systems and artificial intelligence will become more mature and ubiquitous in the product realization process – humans will never be replaced, but the value of the Human-Computer Cyborg will be increased.

In direct response to these drivers, technology needed to support distributed product realization is the development of a distributed product realization framework based on standard product and process models. The framework must support a variety of formal engineering tools and support the flexible and open nature of engineering product realization.

There are several formalized design process models, such as the Pahl and Beitz systematic design method [4], that are adequate for realizing technical product in the world of 2020 – but the supporting technology base to support engineers that adhere to formal product models is not adequately developed. Techniques such as Decision Based Design (DBD) put forth by Mistree and colleagues [5,6] offer additional methods for modeling the product realization process. However, computer based frameworks and implementation are still lacking to support information rich distributed product realization.

In order to support the information-rich nature of distributed product realization computer-based support frameworks must be developed. The framework must support the product and process models in an open and flexible nature. The realization of technical products is a flexible activity that cannot be universally prescribed for all design domains. However, a certain level of prescription is valuable in the design process in that it captures and reuses experience based knowledge. To support knowledge based engineering design a flexible design process model should be implemented on a computer platform. The design process model should be strongly associated with the product information model, as one does not exist without the other.

In a review of several distributed product realization frameworks, the X-DPR framework, developed by Panchal and colleagues [7] provides a step in the right direction for developing a collaborative, integrated product realization framework. The X-DPR Framework is a computer system that allows designers to capture and complete meta-design of distributed product realization processes in accordance with the DSP philosophy. The system is designed such that a designer can easily model his/her design process using visual tools.

However, there are several shortcomings in the framework for distributed product realization. Below, I present several enhancements to the X-DPR framework that must be addressed to more fully support distributed product realization toward developing a the next generation DPR framework.

Extreme flexibility of the X-DPR frameworks - The first area of note is the extreme flexibility in designing design processes in X-DPR framework.. This flexibility can be looked at as positive because the system is flexible and open to a wide domain of application. On the other hand the flexibility can be considered negative as little expert direction is provided when completing tasks.

The X-DPR framework more readily supports a descriptive design process. The overall design of the design process is dependent on the designer that is responsible for that portion of the process. For example, the established tasks and associated information flow are dependent solely on the experience of the design and are subjective. Problems will arise when working in groups to establish the design process. Different engineers will establish different information flow and the overall process will not be easily integrated.

I propose establishing families of design tasks and associated families of services. These families, much like a database can be expanded, as new services are made available. I propose this is possible because there are a finite number of tasks that engineers perform for their given domain. For this same reason, formal tools and services are established based on what tasks are commonly completed.

Standardized Information Flow Interfaces - The second enhancement augmentation to X-DPR is the formalization of task interfaces. Currently, the interfaces associated with all tasks are information flow in and out of the particular task. By establishing standard interfaces, it will be easier to achieve modularity of engineering tasks.

The information flows between activities must be standardized. Tasks can be created with an information flow for which an agent does not exist – therefore an agent must be created or the task must be changed. Incompatibility in task completion and sequence may be addressed through establishing standardized information ports.

To address several of these problems and enhance the meta-design process, standard interfaces must be established through the formalization and identification of information content and information format (file or protocol type).

While standardization of interfaces restricts designers to a particular task they also enhance the level of knowledge in the meta-design process. I propose idea of creating tasks with known and established information interfaces. By developing a standardization of information flow in meta-design I will be a step close to measuring design freedom and design knowledge in a quantitative manner.

In the current X-DPR framework, tasks and the associated information flows are created are based on the designer's experience – a descriptive approach. In our view, the descriptive approach is solution focused and does not adequately capture knowledge in a formal and reusable manner. I propose to explore the following augmentation to the X-DPR framework

Catalog of Available tools - The idea of developing a catalog of available tools both hard and soft tools is an excellent idea. First, just as in any task, tools may be needed to perform or complete the task to the desired quality. In everyday life, we ensure that we have the proper tools before embarking on a task. For instance, I do not attempt to change my oil in my automobile before I know that I have the proper wrenches, oil-collection pan, and replacement oil.

In the product realization process, this idea is complicated because of the need to plan. In the meta-design stage an engineer may decide that a particular task must be completed. However, if the support tool is not available then when that task is encountered in the realization process it can not be performed.

As I previously mentioned this is true for software tools and support frameworks, as well as machine tools. Suppose an engineer develops a process plan to manufacture a product for a tool or technology that is not available. Again when that activity is encountered, there will be a large delay and may be the demise of the company. It is important to associate, characterize, and classify the “local” tools and remote agents that are available to a company.

Closure

The overarching goal in this report is to present a vision of the future of engineering design and move towards a scientific formalization of product realization. In achieving this goal, I have first developed a strategic vision of where FutureTechDME should be positioned and the partnerships that must be forged. FutureTechDME should make significant contributions in both time and money with academic research labs to shape the next generation of distributed product realization. FutureTechDME should form long-term vested relationships with academic labs through close communication, sharing case studies and first hand experiences, and cutting edge support tools and methodologies. These relationships will push FutureTechDME to the forefront of distributed product realization not only as a producer of quality products, but also as a thought leader. Additionally, a vision of the future of the world of 2020 is presented. A critical review of paradigm shifts in the past is completed and a vision of product realization over the next 20 years is proposed. Finally, a vision of the technologies needed to support distributed product realization in the next 20 years is put forth. I have proposed several In order for FutureTechDME to remain competitive and a thought leader in product realization over the next 20 years.

It is my strong belief if FutureTechDME forges the above mentioned relationships with universities, invests in cutting edge research, and positions itself at the forefront of knowledge that it will be successful over the next 20 years. I am willing and excited to stay with FutureTechDME over the long haul and invest my effort and time in helping to negotiate and navigate FutureTechDME to the forefront of product realization over the next 20 years of this century.

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