IJST International Journal of Science and Technology
CENTRE OF PROFESSIONAL RESEARCH PUBLICATIONS
ISSN 2049-7318

International Journal of Science and Technology Volume 2 No. 3, March, 2013

Redefining Virtual Prototyping in the Mechanical Perspective

Tariq Yasin
University of Science and Technology
Department of Industrial Engineering and Management Sciences
Taxila, Pakistan

ABSTRACT

The need to redefine virtual prototyping in the mechanical perspective has been felt in view of the widespread role and applications that the technology finds in today's industry. Especially when seen in conjunction with the recent and rapid advancement, the available definitions seem to have lagged or have been found deficient in various aspects. The modifications made in the proposed definition have attempted to bring such aspects into perspective and after having ascertained the shortcomings through a careful and methodical analysis, have filled in the gaps and voids with value additions. The additions have been scrutinized in perspective of existing definitions and justifications offered for their validity and acceptance. Uptill now, virtual prototyping has been taken to be synonymous with Digital Mockup (DMU). After having ascertained the core essentials and evolution of the technology, it has been argued that the DMU in the classical sense is a static system. More recent development in the field related to the application of kinematic laws to simulate the DMU for operational analysis is now being seen as the true essence of virtual prototyping which the available definitions were found to fall short in signifying. Moreover, quit often, a technology or terminology is known and understood more through the core capabilities that it leverages. The proposed definition also benefits from this philosophy and has made these capabilities part of the definition for quick comprehension and intuitive familiarity with the term-the crux for any definition.

Keywords: *Virtual prototyping, Digital mockup, Kinematics simulation, functional prototype*

1. INTRODUCTION

The unprecedented and exponential rise in computational power over the years has enabled this luxury to the programmers to pack greater functionality and versatility into their software packages and applications. In this regards, the area of focus in this paper is the revolutionary evolution taking place in Computer Aided Designing (CAD), Computer Aided Manufacturing (CAM) and Computer Aided Engineering (CAE) perspective and an emergent specialty of virtual prototyping where all these technologies merge at their excellence or cutting edge. Given the dynamic and flexible environment of progress, the paper professes that our perspective and definitions have to keep pace and adapt accordingly so as to remain truly realistic, meaningful and relevant. A focus on the progression and development of related terminologies can only ensure that future research is well directed and fruitful. The paper therefore examines the evolution and present status of how virtual prototyping is defined and suggests appropriate modifications to make it abreast with the current development and trends in the field. To do so, the paper selects noteworthy definitions related to virtual prototyping. The information presented in the definitions is then split and brought under suitable categories for the purpose of comparison and analysis. The proposed definition is then brought under scrutiny and each modification made with respect to earlier definitions is scrutinized and deliberated to justify as a value addition. Given the diversity of application in the realm of virtual prototyping, a basic simplification of restricting the research to the mechanical domain had to be made right at the onset. The need to redefine virtual prototyping in the mechanical perspective has been felt in view of the widespread role and applications that the technology finds in today's industry. Uptill now, virtual prototyping has been taken to be synonymous with Digital Mockup (DMU). Digital Mock-up is however a relatively older concept and literature covering all the technical aspects related to it exist in abundance and are also readily available. The DMU, being a static system in the classical sense, has stood to represent virtual prototyping for a long time given the state of technological advancement of yester years. The paper however signify that digital mock-up simulation, DMU Kinematics or functional prototyping representing dynamic systems have not been reflected in their true essence in the available definitions duly supported by the core capabilities these have to offer to the industry. These aspects, it is argued, are the very essence due to which the technology is being embraced by the industry to stay competitive and therefore mention of the same would add greater meaning and insight to the definition. The paper draws inspiration form the master's level thesis presented on "Digital Mockup Simulation for new product development in lean environment" by the author.

2. THE DEFINITION OF A DEFINITION

A definition attempts to explain a word using other words. This is sometimes challenging. Common dictionaries contain lexical, descriptive definitions, but there are various types of definition - all with different purposes and focuses. A stipulative definition is a type of definition in which a new or currently-existing term is given a specific meaning for the purposes of argument or discussion in a given context. When the term already exists, this definition may, but does not necessarily, contradict the dictionary (lexical) definition of the term. Because of this, a stipulative definition cannot be "correct" or "incorrect"; it can only differ from other definitions, but it can be useful for its intended purpose [1][2]. This is similar to a précising definition but differs in that a stipulative definition may contradict the lexical definition, while a précising definition does not [3].

3. VIRTUAL PROTOTYPING: THE BASIC PERSPECTIVE

Verification of the drawing made on the drawing board, especially related to assemblies, subassemblies and systems or subsystems has always been challenging. The solution was found at that time by verifying the drawings and the design intent by constructing physical mock-ups through less expensive materials and make shift means for the purpose of verification. Later, with the CAD and CAM, the constituent parts of a system started to be modelled in 3-D (digitized) and placed in their right places / orientation as per the system definition. In continuation to the physical mock-ups, the setup was categorized as a DMU. DMUs had a wider range of utility and applications as physical mock-ups needed not to be constructed saving time, cost and resources. Even at the parts level, the CAD models could be analyzed through CAE techniques such as the Finite Element Analysis (FEM), Computational Fluid Analysis (CFD) etc. This established the foundation for a new technology - the virtual prototyping, as there was lesser need now to test and qualify parts and assemblies by actually manufacturing or prototyping these. However a DMU was a static system. If these constituent parts could be made to move and function just the same way as these would when the product under design was actually manufactured and put to use, such a dynamic mock-up was said to be capable of being simulated and had even greater utility and applications compared to a static mock-up. A mechanism of this nature required that the relationship between constituent parts be assigned, degrees of freedom (DOF) be constrained other than the direction / axis in which motion is intended to be executed and the motion laws / equation be applied to DOF left free. Such a system was much closer to a truly virtual prototype and extended the applications to operational testing also, giving a greater insight into the design flaws earlier left undetected related to interferences, clearances and clashes which the constituent parts of the assembly or sub assembly experienced during its operations. So the CAE armoury could now be employed for virtually anything and this came to be known as CAx. Figure 1 shows the core accomplishments of this evolution with a greater insight presented on the y-axis of Figure 2. The x-axis of Fig 2 shows the salient landmarks achieved in the product design process as a consequence of developments on y-axis. These landmarks helped in achieving lean in the design process, may it be Design for Manufacturability (DFM), Design for Assembly (DFA), Design for Dimensional Control (DFDC), Design for Ergonomics/Environment (DFE) etc. All such terminologies are collectively designated as DFx. The entire progress and development has ultimately resulted in shortening product design and development cycle thereby reducing time to market. The product design and development cycle has therefore been made efficient and lean.

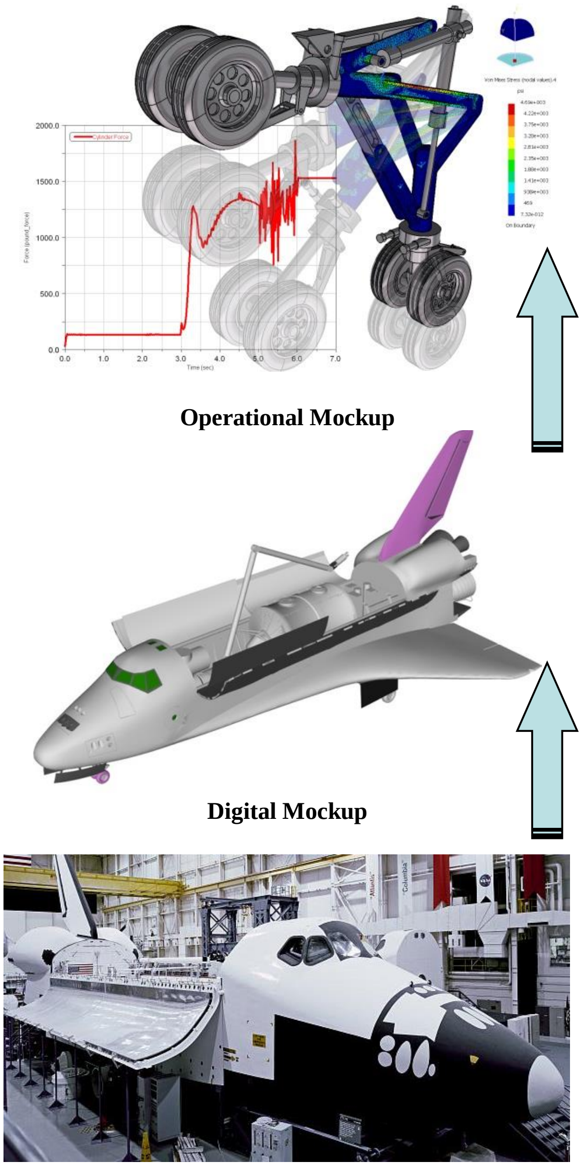

Fig 1: Mockup Evolution-Physical to Digital to Operational

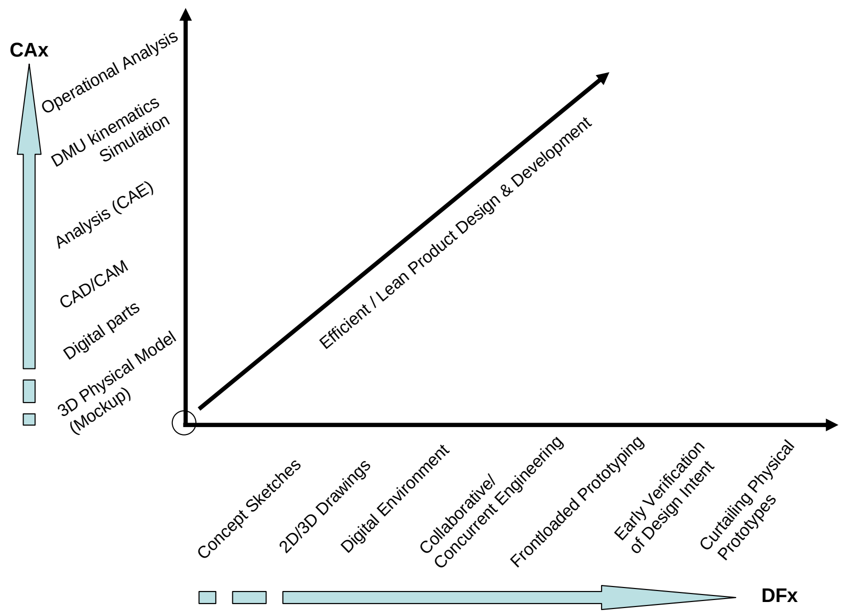

Fig 2: The Evolution and Dividends of Virtual Prototyping Related Technologies

The technology helps to authenticate the relationship of interacting mechanical parts in the product with regards to its fitment, tolerances, constraints and functionality thereby indicating to the designer the adequacy or otherwise of the product design. Deficiencies can be easily detected analyzed and fixed enabling the subsequent development phases complete in lesser iterations and short time. The product is made to perform its intended design movements and functions in the controlled but artificial environment of computer so that any interference or clash amongst the parts can be noted. The operational DMU therefore acts as a design concept demonstrator, verifying and demonstrating the mechanical design and obviating the need of manufacturing an actual product to do this. In a conventional product development process, a prototype is usually constructed to prove design concepts, evaluate design alternatives, test product manufacturability, and often just to present a product [4]. With the goal of replacing physical prototype electronically, the DMU must first serve the same functions and even more of a physical prototype, regardless of which techniques are used. In light of this, a DMU should be able to “test” a product’s form and performances, and be used for training and other studies. In addition, a physical prototype usually allows human beings’ sensory evaluation of a product, such as color, form, aesthetic features, feel, fitness, and so on. Product’s ergonomics is also of an increasing concern. The concept is of special significance in concurrent or collaborating engineering environment where multi disciplinary cross functional teams dispersed geographically, culturally and linguistically across the globe are deputed to work on a joint project by providing a common digital language / platform. Functionality to accomplish all these tasks was initially available in only high end CAD software’s. However in view of the significant advantages that the DMU simulation has to offer, this functionality is now being embedded to varying extent in virtually all CAD software’s.

4. EVOLUTION OF DEFINITIONS LEADING TO PROPOSED DEFINITION

As the case with any scientific and engineering terminology, their comprehension and definition are subject to modifications and alterations based on latest research, technological innovations and developments. In this regards, some of the most noteworthy and significant definitions in chronological sequence reflecting the evolution of terms related to virtual prototyping were selected for analysis out of many definitions found in the literature. These are presented below with the proposed definition place at the last:-

“A computer based simulation of a system or subsystem with a degree of functional realism that is comparable to that of a physical prototype”, Haug et al, 1993 [5]

"The process of using a virtual prototype, in lieu of a physical prototype, for test and evaluation of specific characteristics of a candidate design”, Garcia,Gocke, and Johnson 1993 [6].

“Digital mock-up (DMU) as a realistic computer simulation of a product with the capability of all required functions from design/engineering, manufacturing,

product service, up to maintenance and product recycling", Dai, F. and Reindl, P., 1996 [7]
"In the mechanical engineering definition of virtual prototyping (VPME), the idea is to replace physical mock-ups by software prototypes. This includes also all kinds of geometrical and functional simulations, whether or not involving humans", Antonino and Zachmann, 1998 [8]

"Virtual prototype, or digital mock-up, is a computer simulation of a physical product that can be presented, analyzed, and tested from concerned product life-cycle aspects such as design/engineering, manufacturing, service, and recycling as if on a real physical model. The construction and testing of a virtual prototype is called virtual prototyping (VP)", G. Gary Wang, 2003 [9]

"Virtual prototyping is the realization of 3D Computer Aided Design modeling which can be rendered, tested and analyzed using Computer Aided Engineering / Manufacturing to verify fit, form, function, manufacturability and aesthetical aspects as per the design intent whereas at the assembly level the process is extended to a static digital mockup for ergonomic analysis and to simulated DMU through application of kinematics laws for operational testing. Industries embrace the technology to advance prototyping process early into the product design and development cycle (frontloading) making it efficient, short and lean through early detection of design flaws, concurrent handling of engineering functions and curtailing physical prototyping". (Proposed)

Table 1: Comparison of Similar Aspects of Selected and Proposed Definition

	Realization Process	**Role**	**Capability / Applications**			
			Core Capability	**Level**	**Ergonomics**	**Fit, Form Function**
Haug et al, 1993	Computer based	Provide degree of functional realism comparable to physical prototype		System or subsystem		
Garcia,Gocke, and Johnson 1993		Using a virtual prototype, in lieu of a physical prototype	Tests and evaluates specific characteristics of a candidate design			
Dai.F, Reindl.P, 1996	A realistic computer simulation	Digital mock-up (DMU)	Capability of all required functions from design /engineering, manufacturing, product service, up to maintenance and product recycling	Product related		
Antonino and Zachmann 1998	Replace physical mock-ups by software prototypes		All kinds of geometrical and functional simulations		Whether or not involving humans.	
G. Gary Wang, 2003	Virtual prototype, or digital mock-up, as a computer simulation of a physical product	Can be presented, analyzed, and tested as if on a real physical model	Caters for concerned product life-cycle aspects such as design/engineering, manufacturing, service, and recycling			
Proposed	Realization of 3D CAD model extended to static or kinematics simulation of DMU at assembly level	Rendering, testing and analyzing thru CAM/CAE, extending to operational testing at assembly level	--Verifying design intent/early detection of flaws --Frontloading prototyping --Curtailing physical prototyping --More efficient product design/ development	Extends to specific capabilities enabled at assembly level	May include ergonomics at assembly level	Fit, form, function, manufactura bility, aesthetics, extending to ergonomics and operational

			cycle			testing

5. ANALYSIS

Refer Table 1. Analysis of selected definitions and the information presented in these enables suitable headings or categories to be formulated under which the information could be split and placed. By doing so, each aspect of the information presented in various definitions could be compared and analysed with similar aspects presented in other definitions. The system therefore offered effective scrutiny of the existing and proposed definition. These categories included the realization process, role, and scope/applications. The scope/applications were further split into core capabilities, ergonomics and fit, form, function etc.

5.1 Realization Process

It becomes evident form the tabulated analysis that considering "realization process" as an essential part of the definition has been important in a number of ways. Primarily, it acts as a first filter and narrows down to only the relevant techniques for virtual prototyping. Analysis of the first two definitions in Table 1 would show that while Garcia,Gocke, and Johnson applies no filter here, the filter used by Haug et al is too course to let many other technologies to pass through which are not strictly virtual prototyping techniques especially in the mechanical perspective such as virtual reality or augmented virtual reality inclusive of both immersive and non immersive techniques. Dai,F. and Reindl, P has however explained that the outcome of a realistic computer based simulation should be the digital mockup which has been listed under the "role" column in Table 1. It may be noted that the computer graphics can also generate a photo realistic depiction of digital mockup such as the cars and airplane used in the gaming industry. Although such applications can be utilized to an extend for aesthetics and feel, these are not geometrically accurate to the extent of generating a code for assigning to a CNC machine for manufacturing and do other CAE analysis such as the FEM, CFD etc and therefore such mock up are not brought under the virtual prototyping domain in the mechanical perspective. The parametric CAD modeling based mockups, in contrast can also be rendered (made photo-realistic). This is why "rendering" has also been added in the proposed definition as a possible utilization of CAD modeling along with testing and analyzing in purview of virtual prototyping. The proposed definition has also added other techniques being presently utilized to get maximum dividends out of virtual prototyping. The definition therefore makes mentions of 3D CAD modeling as the realization process extended to static or kinematics simulation of DMU at assembly level. By doing so the definition has retained the earlier related techniques and includes the emerging trends in the field thereby laying down a more comprehensive and steady foundation for the definition.

5.2 Role

The definition of a term can also benefit by narrating its role. An analysis of the chronological evolution of selected definitions as given in Table 1 indicates that the concept made a humble beginning. Even if it provided some degree of functional realism comparable to that of the physical prototype, Haug et tal considered it a virtual prototype. The term "functional" here is of special interest and would be deliberated in greater detail later in comparison to the term "operational". Other authors have seen virtual prototyping role as an in lieu for physical prototype and as a means of presenting, analyzing, and testing as if on a real physical model. A simpler approach however, as used by Dai,F. and Reindl, P is to straightaway equate a virtual prototype to a DMU utilizing an advantage often sought in the definitions to benefit from other terms that are already understood or whose definitions are easily obtainable or demonstrable.

5.2.1 The Circularity Error

While defining virtual prototyping on the basis of DMU, caution had to be made so as not to invoke an error generally termed in the "fallacies of definitions" as the circularity error. This would happen if the term DMU on the basis of which the term virtual prototyping is intended to be defined by the author is not already well understood. This is somewhat similar to circular reasoning. However, in this case the term "mock-up", as explained earlier, has been in use for a long time and the fact that when a physical mock is digitized using CAD; it is termed as a digital mock-up is also well understood. As such, there was good enough reason to assume that its usage would not induce circularity error.

The proposed definition keeps CAD and CAE at the centre stage as both play a key role and are central to the theme or philosophy of virtual prototyping. The proposed definition further elaborates that these technologies enable rendering, testing and analyzing which is further extended to operational testing at the assembly level. The "realization process" part has earlier explained that the operational testing is achieved through kinematics simulation. The coverage of "role" in the proposed definition can therefore be summarized as "rendering, testing and analyzing thru CAM/CAE, extending to operational testing at assembly level", whereas the CAD part was covered under the "realization process".

5.3 Capability/ Applications

The inclusion of capability / applications into the definition results in a greater comprehension of the term. Moreover just like other criterion such as the "realisation process" and the "role", it helps to filter out and narrow down the potential terms which could qualify as virtual prototyping. It becomes evident form the "capability/applications" column in Table 1, that as per the definitions given form time to time in a chronological sequence, the core capability of virtual prototyping continues to be seen as a more powerful, versatile and enabling technology in the industry. Garcia, Gocke, and Johnson have considered virtual prototyping to be capable of testing specific characteristics of a candidate design. Later an inclinations of explaining virtual prototyping through its capability of dealing with all phases of the product life cycle or Product Lifecycle Management (PLM) has also been noted in the definitions provided by Dai,F, Reindl, and G. Gary Wang. Special focus has been given on design, engineering, manufacturing, servicing and recycling. Antonino and Zachmann have indicated that all kinds of geometric and functional simulations form the core capability of virtual prototyping.

The proposed definition has added many aspects in definition with regards to the scope/applications. The ideas were not just to make the definition lengthy but to make the virtual prototyping concept easier to comprehend through explanation of the core and other key capabilities. In contrast to other definitions, the proposed definition, however does not consider virtual prototyping to be covering all facets of PLM, starting from design to recycling. This is based on the fact that this theme is more akin to PLM than to virtual prototyping. In the industry, PLM is the process of managing the entire lifecycle of a product from its conception, through design and manufacture, to service and disposal [10]. The proposed definition has therefore focussed on the core capacities of virtual prototyping on the basis of which industry is embracing this technology to leverage a competitive advantage. These include, verifying design intent, frontloading the prototyping process for early detection of design flaws, curtailing the need of physical prototyping and consequently achieving greater efficiency in the product design and development cycle. Since "frontloading" is also a less understood terms its usage could have induced a circularity error. The term has therefore been used in descriptive form in the definition as being a process of advancing the prototyping process earlier into the product design and development cycle. The proposed definition adds further depth by clarifying that these core capabilities offer form, fit, function, manufacturability and aesthetical testing which can be extended to ergonomics and operational testing at the assembly level. The definition therefore makes the statement more palatable to the reader in explaining the concept in sync with the same theme in which it has evolved.

Certain definitions in the perspective of the capabilities of virtual prototyping have also commented on the level (part, assembly, system or subsystem) at which the technology is applied. In this regards, the first definition considers it applicable at system and subsystem level whereas Dai.F and Reindl.P considers it to be product related. The proposed definition, however starts with a singular note i.e assumes to include all the level, but later makes certain exceptions to indicate capabilities and applications that are only realized at the assembly or at product level. In doing so the definition is envisaged to be constructed following the sequential basic building blocks approach sounding more synchronous and rhythmic.

6. USAGE OF TERMS "FUNCTIONAL" VS "OPERATIONAL"

The proposed definition uses the two terminologies in deferent perspective. This can be better understood through an example. A "link rod" may be used in any suspension or other structural assembly intended to transfer the load from one point to the other. Although the link rod may be a stationary part of the assembly with zero degrees of freedom, but would be subjected to dynamic loading and considered as a "functional" part of the system. The word "functional" has therefore been utilized in the first part of the first sentence in the proposed definition stating, "Virtual prototyping is the realization of 3D Computer Aided Design modeling which can be rendered, tested and analyzed using Computer Aided Engineering / Manufacturing to verify fit, form, function, manufacturability and aesthetical aspects as per the design intent". However, in the second part of the definition, the movement of the assembly or subassembly in the six degrees of freedom on application of kinematic laws has been denoted by the word "operational'' so as to distinguish it from "functional". The second part of the first sentence in the definition therefore states that, "whereas at the assembly level the process is extended to a static digital mockup for ergonomic analysis and to simulated DMU through application of kinematics laws for operational testing".

7. CONCLUSION

After having ascertained the core essentials and evolution, the paper has brought to scrutiny some of the common misperceptions about virtual prototyping especially in the mechanical perspective. To do so, the methodology is based on taking the example of and analysing noteworthy definitions in the field. The paper professes that any term representing a technology which has undergone rapid and exponential advancements is also ought to adapt and adjust to the latest trends and changes so as to shed such misconceptions and reflect the term in the true essence in which it is being contemporarily applied. This is also essential for the future research to be well directed and meaningful. The proposed definition is lengthier so as not to lack clarity on the basis of other terms in the definitions that may not sound very familiar to the reader to induce circularity error. This is why the definition is inclusive of explanation to concepts like "frontloading" and "concurrent engineering". The inclusion of such terms has been found to be compulsive as most technologies or terminologies are more known for their core capabilities or benefits accrued rather than their theoretical details and as such prudence demands their inclusion in the definition. The definition therefore presents a comprehensive and wholesome theme and concept about the technology, naturally constructed in the same sequence that the concept has evolved for quick comprehension and intuitive familiarity to even a casual reader not very familiar with the field.

REFERENCES

[1] http;//atheism.about.com/od/logical arguments/ s / def _stipulative.html

[2] A Concise Introduction to Logic, Patrick J. Hurley. 2007.

[3] Critical Thinking: A Student's Introduction, Bassham, Gregory; Irwin, William; Nardone, Henry; Wallace, James M. 2002. New York: McGraw Hill.

[4] "Virtual Prototyping – An Approach Using VR-technique," Dai, F., and Göbel, M., 1994, Proceedings of the 1994 ASME Computers in Engineering Conference, Minneapolis, MN, 1994.

[5] Virtual Prototyping for Mechanical System Concurrent Engineering. Concurrent Engineering: Tools and Technologies for Mechanical System Design, Haug, E. J., J. G. Kuhl, et al. (1993

[6] "Virtual Prototyping Concept to Production", A. B. Garcia, R. P. Gocke and N. P. Johnson, , Defense System Management College, Ft. Belvoir, 1993.

[7] Dai, F. and Reindl, P., 1996, "Enabling digital mock up with virtual reality techniques – vision, concept, demonstrator," Proceedings of 1996 ASME design engineering technical conference and computers in engineering, Irvine, California August 18-22.

[8] Antonino, G. S. and Zachmann, G., 1998, "Integrating Virtual Reality for Virtual Prototyping," Proceedings of the 1998 ASME Design Technical Conference and Computers in Engineering Conference, DETC98/CIE-5536, Atlanta, Georgia, September 13-16..

[9] Definition and Review of Virtual Prototyping, G. Gary Wang, Assistant Professor Dept. of Mechanical and Industrial Engineering University of Manitoba Winnipeg, MB, R3T 5V6 Canada

[10] "About PLM", www.cimdata.com/plm.html. Retrieved 18 February 2013.

