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An architectural view to computer integrated manufacturing systems based on Axiomatic Design Theory

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ABSTRACT

The emergence of the globalization paradigm in manufacturing industry has changed the markets' circumstances, and accordingly manufacturing systems need to be compatibilized with these situations. There are many solutions to assist manufacturing systems for this purpose. Computerized systems and their related solutions were being the most attractive ones for manufacturing systems in recent decade. Developing such systems and exploiting from the advantages of such solutions requires a consistent foundation. Computer Integrated Manufacturing (CIM) emerged as a philosophy to provide such foundation, and to assist the computerized manufacturing solutions. Despite of the high potentials of the CIM philosophy, the related works lack in many aspects. The absence of a thorough look to exploit the high potentials of the CIM philosophy to consider different aspects of the manufacturing systems, and the complexity which exists in the nature of the designing of such systems are the major concerns. These concerns lead us to afford them fundamentally with an architectural view. The architectural view of the paper is because of architectures are the basis for designing and future development of the systems, and synthesizing solutions that satisfy the system requirements. Accordingly, the architecture of the system is considered as a basis for creating desired changes and resolving the mentioned concerns. Therefore, the paper proposes a layered architecture which covers five critical aspects of a CIM system. Physical, Functional, Managerial, Informational, and Control aspects are the five critical aspects which are assigned to five layers of the architecture. The manipulated architecture assists manufacturing systems to audit their Physical, Functional, Managerial, Informational, and Control aspects based on a proposed set of ISO standards in order to compatibilize and align themselves with the necessities of the globalized manufacturing industry. The layered architecture expected to be well-structured and to resolve the concerns. The expectations have been investigated through a promising tool for designing and analyzing complex systems, known as Axiomatic Design (AD) Theory. The AD-based design and analysis are according to two axioms, known as Independence Axiom and Information Axiom. Moreover, the AD Theory approaches have been used to reach a set of standard guidelines for exploring and achieving realization operands for the architecture. By analyzing the results with the AD Theory axioms, appropriateness of the design has been approved. Finally, a roadmap for future works is delineated.

1. Introduction

Nowadays, globalization has changed the ways that manufacturing systems work [1,2]. Globalization has caused manufacturing systems to face with modern challenges like customized customer demands, high quality product, trends for lower product development costs and shortened product life cycle [3–5]. These concerns, in manufacturing environments, need to be satisfied by some effective solutions and ideas. These solutions and ideas inevitably must be effective and efficient to develop and establish manufacturing systems in a well-structured manner [6–8]. Researchers have suggested the application of Information Technology (IT) for fulfilling the aforementioned requirements [8–14]. Computer Integrated Manufacturing (CIM) paradigm stands as a prominent philosophy which helps to achieve numerous advantages of computerized manufacturing. CIM emerged as a philosophy in manufacturing systems and relevant designing in the late 1970s. CIM philosophy revolutionized the manufacturing environments, and reached to its maturity till 2000 [15,16]. CIM philosophy opens a vast field for researches and studies to develop various IT-based solutions. These solutions concluded to incredible results and improvements in the manufacturing systems [17–20].

Many researches have been suggested the Virtual CIM (VCIM) as one of the effective solutions for todays' globalized manufacturing systems [21–23]. The word "Virtual" is a prefix for CIM to express the

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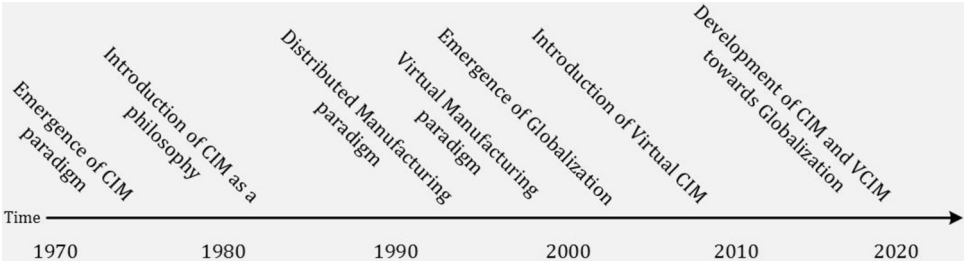

Fig. 1. The historical development of CIM philosophy.

Virtual Manufacturing and Distributed Manufacturing aspects within the CIM philosophy and systems. So, VCIM could be introduced as an evolvement of CIM philosophy which considers some of the new paradigms of the manufacturing in the CIM philosophy [21,23,24]. In Fig. 1, the historical formation and development of the modern CIM philosophy and systems, are illustrated.

Researches emphasize [20,22,25,26] on the role of IT-based solutions for achievement of integrated manufacturing systems which have concluded to remarkable capabilities. However, the vast domain of IT-based solutions, requires a systematic approach to insure satisfaction of the new emerged challenges, like integration and interoperability among proposed solutions [27,28]. In a better word, achievement to computerized manufacturing advantages, requires exploitation of CIM philosophy in an appropriate and well-structured manner for developing CIM systems. CIM philosophy helps manufacturing systems to utilize from computerized systems and their applications in the manufacturing environments in an integrated manner.

There is a need to structure the CIM philosophy within an architecture which is compatible with todays' manufacturing characteristics and requirements. But there are some concerns which hinder researchers to use CIM philosophy for designing computerized manufacturing systems or developing CIM systems. One of these main concerns, is CIM philosophy's thorough look which covers and affects almost entire aspects of manufacturing and production. This thorough look of CIM philosophy, makes it burdensome for researchers and practitioner to develop and design manufacturing systems based on it [29,30]. Moreover, the complexities which exist in the nature of the designing of such systems [31] are the other concern that prevents to consider CIM philosophy to be used for designing CIM systems. Complexity of design and complexity of implementation both affect the complexity of CIM systems in theoretical and practical view. Manufacturing systems could be regarded and designed as complex systems [32]. So, it is important to consider principles of complexity in this issue [33]. The paper will explain the recognized reasons, and will illustrate their roles in developing an architecture for CIM systems in the following. As well, the paper will provide a thorough investigation over previous works which have been done along developing CIM systems, architecturally.

The complexity of designing CIM systems and its implementation were the other major concern. Existing numerous tools and technologies to help CIM systems, are a great advantage that increase the degree of freedom in designing for architects and engineers to realize their goals. But, existing some negative correlations may cause many limitations. In another word, the tools and technologies within a CIM system could be coupled to each other. Hence, by designing a solution without considering the architecture of the system, with a single purpose or partial look, could not be a panacea. For example, from a control perspective, to achieve a promising control and supervision over a manufacturing system with CIM considerations, it is so good to exploit from intelligent control and smart technologies [34]. But, from the infrastructural perspective reaching this level of technology for control, needs high-tech and expensive hardware and connections that could not be compatible with the state of the art of the industry [35]. Existing such negative correlations in the designing of the manufacturing systems according to CIM philosophy are numerous [36,37] which need to be regarded. Exploiting from complex systems principles and tools could be beneficial to satisfy such limitation and concerns [38,39].

Also, CIM systems lack an architectural view to help the researchers and practitioners with a perspective that considers different aspects of a CIM system. Almost, all researches in this field are single purpose and focused in one or few aspects of CIM systems [40–42]. Generally speaking, these researches have focused on some operational principles of CIM philosophy to integrate hardware and software aspects of a manufacturing system, or satisfying information requirements. Albeit, the CIM philosophy encompasses a vast domain of manufacturing systems designing aspects, and it is hard to consider such vast domain in a research or practice, thus it emphasizes to provide an architectural view with a general look for designing such systems. Also, architectural design synthesizes solutions that satisfy system requirements [43].

In the other hand, to settle aforementioned concerns. The authors propose an architectural view to satisfy the recognized reasons. As the architecture of a design has roots in both theoretical and practical aspects, the enhancement in the CIM architecture is expected to lead us toward a fundamental enhancement in the CIM philosophy for application and designing of CIM systems. The architecture has been believed as the backbone of a system which synthesize a solution that satisfy the system requirements. Moreover, the architecture of a system addresses the way how to implement, and run it. Also computerized systems has their own architectures and considerations.

By tying computerized systems with manufacturing systems, the CIM paradigm comes through. So, the CIM paradigm needs his way of implementing and running, or in a better word, needs an architecture. Merging computerized systems with manufacturing systems broadened the philosophy of computerized manufacturing and the vision of CIM systems. The architecture of the system should cover all the related aspects away from any complexity.

In the next sections, the paper will follow these requirements by proposing an architecture to cover all aspects related to computerized manufacturing systems and CIM systems. This architecture is manipulated in order to assist manufacturing organizations in auditing to align themselves to improve or enhance with the standards that helps organization to survive and compete in the manufacturing globalized market. The architecture will be presented briefly to provide a perspective for reviewing related researches in the next section. After that, the related researches will be classified and discussed through the proposed architecture perspectives. This section will illustrate that prior works only focused on integrating a few number of CIM system's aspects. In the third section, the paper will introduce the Axiomatic Design (AD) Theory as a tool to study and validate such designing in a formal and systematic manner. The applications of the AD Theory in the manufacturing will be presented and discussed. In the fourth section, the proposed architecture will be studied according to zigzag approach in AD Theory. This section delineates the details of the architecture in different aspects. In the fifth section, the paper will be discussed about implementation related details of the architecture. And at last, the sixth