Computer Integrated Manufacturing Architecture: A Literature Review

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Keywords: Manufacturing systems, Smart Manufacturing, Computer Integrated Manufacturing, Systems Architecture.

Abstract: The exponential technological revolution has had a positive impact on industrial companies, providing them with plenty of opportunities to improve their production flows and optimize their costs. This revolution has led to contemporary computer integrated manufacturing (CIM) that consists of linking the shop floor systems to the high business layer. And in order to do that, there has been some research to define a reference architecture to cover all the use cases. This paper presents a literature review of CIM architectures. The purpose of this review is to enumerate the different aspects covered by the different architectures in the literature and the approaches proposed to handle them.

1 INTRODUCTION

Competition and rapidly changing customer demands are calling for continuous changes in manufacturing environments. For that, the competitive companies had to effectively handle the concurrent evolution of products, processes and production systems (Farid Meziane, 2000). As a result, companies started to integrate information technologies from other fields in the manufacturing process. This change has had several names such as Smart Manufacturing (Li et al., 2019) and Computer integrated manufacturing (Thomas Hedberg, 2016).

This trend consists of two major elements: Computerizing the industrial processes, and facilitating the exchange of data. This can be achieved through integrating every system in the manufacturing process in the same architecture in order to create a fully connected plant, where every retrieved data is reusable to optimize the various business processes. This is what we call a smart factory (Li et al., 2017). To achieve that, we should ensure the connection between the different levels of the plant, from the shop floor level that contains the production machines, to the highest level of the plant where the company's strategies are established. This connection is challenged by the inherent difficulty of aggregating and applying context to data from heterogeneous systems across the production life cycle (Tolio et al., 2013). Therefore, the researches have been able to propose several solutions that are able to encompass all of the company's major IT systems into one architecture while ensuring the interchangeability among them.

In this paper, we present a literature review on the contributions regarding Computer integrated Manufacturing Architectures. The main objective of this review is to go over the literature in this field between 2015 and 2019 and to identify the number and the nature of contributions in the collected papers, as well as the different aspects covered by them. We identified six aspects that we deemed essential to handle in a contribution: Data integration, Systems integration, Security, Monitoring & Data analysis, Mobility and finally Cloud computing.

This paper is sequenced as follows: Section 2 explains the literature review methodology we will follow. In Section 3, we analyze and discuss the results found against the predefined research questions. Section 4 presents some limitations of the study. Finally, Section 5 concludes the paper.

2 RESEARCH STRATEGY

Through time, researchers have been able to propose several architectures and models for computer integrated manufacturing that can have the ability to handle multi systems data. To analyse these solutions, we decided to conduct a review of the different approaches proposed in the literature. For this purpose, we followed the same stages and steps of a Systematic Literature Review (SLR) as recommended in Kitchenham's guidelines (Kitchenham, 2007).

The SLR protocol is composed of six main steps: 1) Identification of research questions and Research Strings, 2) Search in the Data Sources, 3) Definition

Remli, A., Khtira, A. and El Asri, B.
Computer Integrated Manufacturing Architecture: A Literature Review.
DOI: 10.5220/0010148002490256
In *Proceedings of the 12th International Joint Conference on Knowledge Discovery, Knowledge Engineering and Knowledge Management (IC3K 2020) - Volume 3: KMIS*, pages 249-256
ISBN: 978-989-758-474-9

of Inclusion and Exclusion criteria, 4) Data Refinement, 5) Data Extraction, and 6) Data Analysis. The first five steps of the followed protocol are detailed in the rest of this section, while the last step is detailed in Section 3.

2.1 Search Questions and Strings

The main goal of this review is to analyse the existing studies on CIM Architectures and to scrape the different aspects covered by each architecture. For this reason, we formulated the three following questions:

- **RQ1.** What are the different architectures proposed for CIM to handle production data integration in the literature?
- **RQ2.** What are the types of contributions regarding the systems interoperability in a CIM environment?
- **RQ3.** What are the different aspects that have been covered by the existing approaches in the literature?

Based on these questions, we constructed our search string by using the main keywords of our research as well as including the synonyms and related terms. Then, we concatenated the alternative keywords using Boolean "OR" and linked the main terms using Boolean "AND". As a result, we obtained the following search string :
(Software OR Systems OR Manufacturing Execution OR MES) AND (Architecture OR Framework OR Approach OR Model) AND (Computer Integrated Manufacturing OR Smart Manufacturing OR Industry 4.0)

2.2 Data Sources

In this step, we used the constructed String as a search input in the most commonly used Digital libraries, namely IEEE Explore, Science Direct, ACM Digital Library and SpringerLink. Due to the multitude of search features provided by these digital sources, we did not use a single search string for all the Digital libraries. Instead, we derived a specific search string for each library and we carried out some additional actions to get equivalent results from the different libraries.

2.3 Data Selection

The main idea of the systematic review is to collect relevant papers regarding a specific subject. Accordingly, we used a staged selection process that follows a number of predefined criteria. In the first stage, a paper was included only if:

- It was a full article, a book, a chapter or a thesis.
- The title or the abstract of the paper contained the keywords related to the search.

After the first stage, the number of papers found was 4073, distributed as follows, 1737 from IEEE Explore, 1776 from Science Direct, 402 from SpringerLink, 158 from ACM Digital Library. In the second stage, we kept only the papers that introduced a solution for Computer integrated manufacturing architecture. As a result, we had 1462 papers left at this stage. During the third stage, we excluded papers that does not meet the following criteria :

- The paper is written in a language other than English.
- The publication date is previous to 2015.
- The paper is a short article, a standard, a poster, an editorial, a tutorial.
- The paper is duplicated.

After the third stage, we obtained 74 papers. To refine our study, we had to follow through a quality based selection on the remaining papers. For that, we defined two additional criteria :

- Number of citations : We defined a minimum number of citations required that varies for each year.
- Work continuity: If the work described in the paper does not have a continuity in recent papers, then the paper is excluded.

We investigated each of the 74 papers, and after applying the quality based selection, we kept the 29 papers presented in table 2.

2.4 Data Extraction and Synthesis

We fully read each of the 29 papers in order to extract the required data. To help us answer the predefined questions, we had to formalize the extracted data, hence we defined a set of attributes to fill for each paper. These attributes are : 1) Paper title, 2) Authors of the paper, 3) Publication year, 4) Paper type (i. e. Journal paper, conference paper, thesis, book, chapter, workshop paper), 5) Database (i. e. IEEE, ACM, SpringerLink, Science Direct, Google Scholar), 6) Source (e. g. Journal name, conference name), 7) Research type (e. g. Review, Approach evaluation, Solution proposal, Experiment, Case study), 8) Keywords specified in the paper, 9) Short description of the paper, 10) Contribution (e. g. Model, Framework, Tool, Method, Algorithm), and 11) Domain of application.

3 RESULTS AND ANALYSIS

3.1 Demographic Data

Demographic data consists of the metadata of the selected papers. In our review, we focused on three types of metadata: the database, the year of publication and the source.

Data Source

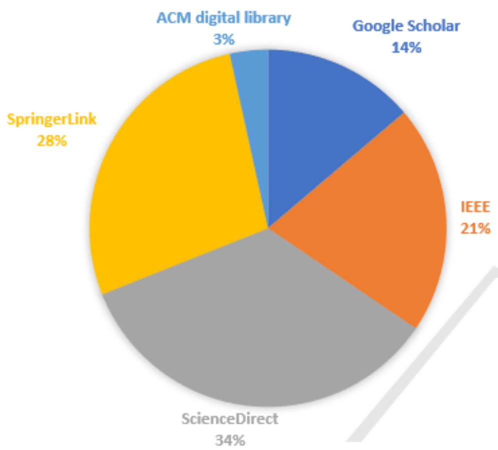

Figure 1: Papers distribution per Data source.

Figure 1 represents the percentage of papers per database. Among the 29 papers selected using the staged process, we identify 1 paper from ACM digital Library, 4 papers from Google Scholar, 8 from Springer, 6 from IEEE and finally 10 from Science Direct. We can clearly notice that Science Direct is the database with the largest number of relevant papers with a percentage of 34%. Springer comes next with a percentage of 28%, which can be explained by the number of papers initially retrieved from these two databases (402 for SpringerLink and 1776 for Science Direct). For the other databases, we can notice that Google Scholar kept the same percentage in the end, 14% compared to the first selection, and the same thing goes for ACM Digital Library with 3% in the beginning. For SpringerLink, in the beginning, the initially selected papers represented only 9%, but in the end they represented 28% from all the papers.

Two conclusions can be drawn from this first analysis. First, the quality of papers is not proportional to the initially selected number. In fact, a database may contain a huge number of papers related to a specific area, but most of them cannot be qualified as relevant. Second, the search engines proposed by the selected databases are not perfect, which is why the initially selected papers do not correspond to our search String.

Year of publication

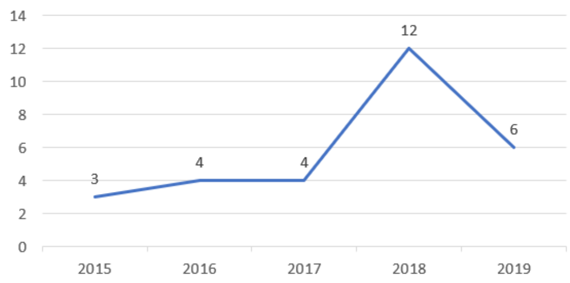

Figure 2: Papers distribution per publication year.

As mentioned before, the search was carried out for the period 2015-2019. The diagram presented in Figure 2 shows the number of papers published per year. We can clearly notice that the number of publications has been changing from 3 to 4 publications per year between the year 2015 and 2017. The peak year was 2018 with 12 publications.

Publication Source
After analysing the data sources of the selected papers, their types and the number of papers for each source, we have found that there are 25 sources; 13 conferences and 12 journals. The number of papers published in all the conferences is 17, which represents 58.62%. The Springer Confederated International Conferences, *"On the Move to Meaningful Internet Systems"* alone has 3 papers. There are 2 conferences for which we can find 2 papers: *"Springer Business Modeling and Software Design"* and *"Science Direct International Federation of Automatic Control"*. For journals, we have 12 papers selected; which represents 41.37%.

3.2 Contributions Analysis

After carefully reading each of the 29 papers, we focused our study on the papers content and the proposed contributions. As a result, the first remark we have had is that 26 papers give a proposition; which represents 89.66 % of the selected papers. The 3 remaining articles are reviews and analyses of existing approaches.

Table 1 sums up all the types of contributions proposed by the selected papers, in addition to the number of papers associated with them. For papers that propose solutions, we can distinguish 4 types of contributions: Tools/Prototypes, Frameworks, Architectures and Models/Meta-models.

Table 1: Papers per Contribution types.

Type of contribution	Number of Papers	Papers
Review and Analysis	3	(Li et al., 2019), (Li Da Xu, 2018), (Lia et al., 2018), (Wei Zhao, 2018)
Tools / Prototypes	4	(Ding et al., 2019), (Sherwin Menezes, 2018), (SangSu Choi, 2018), (Mohammed et al., 2018)
Frameworks	5	(Li et al., 2017), (Zhang et al., 2019), (Tao et al., 2018), (Fei Tao, 2019), (Alessandra Caggiano, 2016)
Architecture	12	(Leitão et al., 2017), (Emanuel Trunzer1 · Ambra Calà2, 2019), (Kavakli et al., 2018), (Thijs Franck, 2018), (Jiang, 2017), (Tang et al., 2018), (Theorin et al., 2017), (Jeon et al., 2016), (Lane Thames, 2016), (Michael P. Papazoglou, 2015), (Bousdekis et al., 2015),(Li et al., 2019)
Models / Meta-models	5	(Khakifirooz et al., 2018), (Müller et al., 2016), (Tae Hyun Kim, 2019), (Dennis Weihraucha, 2018), (Timothy Sprock, 2015)

3.2.1 Review and Analysis

Many researchers have attempted to sum up the current state of research on a particular topic related to CIM architectures. For instance, Xu and his colleagues presented a state of art on Industry 4.0, the new technological trends and the architectures that are related to it (Li Da Xu, 2018). Li and his colleagues did an overview on the smart manufacturing standard frameworks and models, and they listed some of the standardization roadmaps such as Integration of Industrialization & Informatization (iI&I), Manufacturing 2025 and Industry 4.0 of Germany (Li et al., 2017).

3.2.2 Tools / Prototypes

Many papers have provided tools and prototypes in order to validate the solutions they proposed. These tools can address a specific use case or several use cases. For example, Menezes and his colleagues presented a Real Time RFID-enabled MES dedicated to medium and small businesses. This tool provides the capability to write and read manufacturing data (Sherwin Menezes, 2018). Choi and his colleagues came up with a Web-based Platform based on third party technologies and services for smart manufacturing assessment in order to improve planning, with the capability to learn and recommend improvements (SangSu Choi, 2018).

3.2.3 Frameworks

Some studies propose a 'semi-complete' or special purpose architectures that can be specialized to produce custom systems, or what we call "frameworks". In this sense, Caggiano and his colleagues' Cloud Based Framework enables smart monitoring of machining in order to offer real time diagnosis (Alessandra Caggiano, 2016). Tao and his colleagues presented the Data-Driven Smart manufacturing Framework which enables the usage of the data collected through the manufacturing process in order to increase its efficiency (Tao et al., 2018).

3.2.4 Architectures

A system architecture is the conceptual model that defines the components, the structure and the behavior of a system (Clements, 1996). Among the analyzed papers, twelve have proposed architectures in relation of our research. For example, Sprock and his colleagues proposed an architecture for smart manufacturing to bridge the gap between system data and analysis models (Timothy Sprock, 2015). Tang proposed the Cloud-Assisted Self-Organized Architecture (CASOA) to build a vertically enabled system for data consolidation (Tang et al., 2018).

3.2.5 Models / Meta-models

Systems modeling is the interdisciplinary study of the use of models to conceptualize and construct systems in business and IT development (Wegmann, 2007). An example of the models proposed in literature is the one introduced by Khakifirooz and his colleagues. The objective of this system dynamic model is to describe links between the components of "Industry 4.0" and how they influence each other (Khakifirooz et al., 2018). Kim and his colleagues also presented a conceptual model; the Smart-MES (S-MES) dedicated to rolling stock manufacturing (Tae Hyun Kim, 2019).

3.3 Aspects Discussed

Based on the 29 analyzed papers, we extracted six aspects that were taken into consideration when proposing a CIM architecture. These Aspects are: Systems Integration, Data Integration, Security, Monitoring & Data Analysis, Mobility and Cloud Friendly. Figure 3 shows the aggregation of papers per aspects.

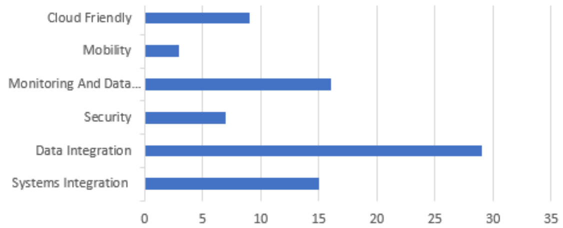

Figure 3: The number of papers by artefact.

Table 2 presents a comparison between papers depending on the aspects they cover.

3.3.1 Systems Integration

System Integration is the capability of a solution to ensure the integration and the cooperation between different IT systems in the same architecture. In works dealing with systems integration, the systems are sometimes limited to MES due to the crucial role it plays (Wei Zhao, 2018),(Mohammed et al., 2018),(Sherwin Menezes, 2018),(Tae Hyun Kim, 2019). The other contributions deal with IT systems in a general overview. Among the solutions proposed in this context is Service Oriented Smart Manufacturing (SOSM) Framework.It aims at facilitating the integration of smart manufacturing systems based on service-oriented technologies (Fei Tao, 2019). To validate their approach, the authors provided a use case on Milk industry. Thames and Schaefer proposed the Software-Defined Cloud Manufacturing (SDCM), a networked model that exploits on-demand access to a shared collection of diversified and distributed manufacturing resources (Lane Thames, 2016).

3.3.2 Data Integration

Data integration consists of applying context to data from heterogeneous systems across the production life cycle. We can remark that this aspect has been covered by all of the 29 articles. In this vein, the PERFORM system architecture was proposed to establish an adequate middleware in order to connect industrial field devices with upper IT systems (Leitão et al., 2017). Theorin and his colleagues proposed an event Driven Architecture called LISA (Line Information System Architecture) for rapid integration of smart services in the manufacturing environment (Theorin et al., 2017).

3.3.3 Security

Security is the ability of the proposed solution to provide secured connection for systems' integration and data exchange. This aspect has been covered in 7 contributions, however, it has been just highlighted as a prerequisite and there have been no propositions on how to implement it (Lane Thames, 2016) (Mohammed et al., 2018) (Lia et al., 2018).

3.3.4 Monitoring and Data Analysis

Monitoring and data analysis consists of utilizing collected manufacturing data to improve productivity. In this aspect, we can distinguish two types of data. The first one is Real-time Data used generally for monitoring. This data type is covered in all MES-related contributions due to the real-time monitoring functionalities the MES provides. The second type is Historic Data used for Data analysis. Among the contributions that cover this type is the architecture proposed by Kavakli and his colleagues.It supports decision making in the context of disruptive events in manufacturing (Kavakli et al., 2018). Bousdekis and his colleagues proposed a model to integrate real-time Data and to store it, in order to be used as an historic data for predictive maintenance (Bousdekis et al., 2015).

3.3.5 Mobility

Mobility is the ability to integrate IT systems on phones and tablets, generally for data monitoring. Among the papers that cover this aspect, the RFID-enabled MES integrated to an android-Based interface was proposed by Menezes and his colleagues to write and read real time manufacturing Data. The tool they proposed is dedicated especially to small and medium sized manufacturing enterprises (Sherwin Menezes, 2018).

3.3.6 Cloud Computing

This aspect concerns the capability of the solution to ensure the usage of cloud computing for some or all the functionalities. For example, Weihraucha and his colleagues propose a model to enhance agility and productivity using a Cloud-Based Platform (Dennis Weihraucha, 2018). Caggiano and his colleagues presented a Cloud Based Framework to enable smart monitoring of machining in order to offer real time diagnosis (Alessandra Caggiano, 2016).

Table 2: Comparison between approaches according to Aspects.

	Systems integration	Data integration	Security	Data Analysis	Mobility	Cloud Friendly
(Bousdekis et al., 2015)		X		X		
(Timothy Sprock, 2015)		X				
(Michael P. Papazoglou, 2015)		X		X		
(Lane Thames, 2016)	X	X	X	X		X
(Alessandra Caggiano, 2016)		X				X
(Müller et al., 2016)		X				
(Jeon et al., 2016)	X	X		X		
(Theorin et al., 2017)	X	X		X		
(Tang et al., 2018)		X				
(Jiang, 2017)	X	X		X		
(Fei Tao, 2019)	X	X		X		X
(Mohammed et al., 2018)	X	X	X			
(Tao et al., 2018)		X		X		X
(Wei Zhao, 2018)		X				
(SangSu Choi, 2018)		X		X		
(Thijs Franck, 2018)		X				
(Lia et al., 2018)		X	X			X
(Sherwin Menezes, 2018)		X		X	X	X
(Dennis Weihraucha, 2018)		X			X	
(Khakifirooz et al., 2018)	X	X	X		X	X
(Kavakli et al., 2018)	X	X		X		
(Li Da Xu, 2018)	X	X	X	X		X
(Li et al., 2019)	X	X				
(Zhang et al., 2019)		X	X	X		
(Ding et al., 2019)	X	X		X		
(Tae Hyun Kim, 2019)	X	X		X		
(Emanuel Trunzer1 · Ambra Calà2, 2019)	X	X	X	X		
(Li et al., 2017)	X	X				X
(Leitão et al., 2017)	X	X				

4 LIMITATIONS OF THE REVIEW

In this review, the main idea was to select the maximum number of pertinent papers regarding Computer integrated manufacturing architectures. Nevertheless, the results of the review could have been affected by some limitations. First, the search systems of the different databases are not fully accurate; a huge number of papers initially retrieved are not related to the review scope. As for the data selection process, the application of exclusion and quality assessment criteria have caused us to ignore some interesting approaches, because they were not well cited, or because they were published in short papers.

5 CONCLUSIONS

Nowadays, it has become a must for industrial companies to digitize their processes, in order to keep up with the customers' demands and to optimize their costs. This digitization is done trough connecting the real world to the virtual one, using cyber physical systems, data sensors and IT Systems. However, the usage of several systems and technologies in the same environment is very challenging, due to the dissimilarities between them and particularities of each one of them. For that, researchers have been able to propose architectures that are capable of encompassing every system in the CIM context. In this paper, we presented the results of a literature review whose main objectives were to investigate the different approaches proposed to handle computer integrated manufacturing architecture between 2015 and 2019, to identify the nature of contributions in this area and to determine the different aspects covered by them. At the beginning, we identified 4073 papers retrieved from four digital libraries. Based on a set of exclusion criteria and quality assessment criteria, 29 relevant papers were selected.

Several findings have been drawn from this review. First, we noticed that 58% of the contributions propose a Design oriented solution such as architectures or models. We believe that tools and framework must be given more attention, because without proper tools, it is difficult to validate the proposed approaches. Concerning the aspects covered by the selected papers, all studies have covered the data integration aspect. Data analysis and monitoring have also been covered by 16 papers and Systems integration comes third, with 15 papers. We think it is normal that these two aspects are the most covered aspects, due to the fact that computer integrated manufacturing is all about connected systems, data interchangeability and reusability. Cloud computing has been covered as well by 9 contributions, which is less than what we expected, in view of the opportunities that are allowed by it. Thus, much work remains to be done to cover other aspects of CIM. As for Security, little attention has been given to this aspect in research. Yet it is a crucial prerequisite to ensure the sustainability of the business. Mobility has been covered the least, with only 3 contributions, despite it has being an important aspect in the era of industry 4.0, which makes it besides security potential research areas.

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