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# Process Model Automation For Industry 4.0: Challenges For Automated Model Generation Based On Laboratory Experiments

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**Abstract.** Driven by technological advances and increasing customer demands, the complexity in manufacturing companies is rapidly growing. To manage this complexity numerous architecture standardization initiatives are emerging in the manufacturing industry, e.g. Production Platforms, Reference Architecture Model Industry 4.0 (RAMI4.0), Industrial Internet Reference Architecture (IIRA). Large manufacturing companies are changing their approach towards managing production and are adopting the concept of Production Platforms. Production Platforms can be understood as a set of subsystems and interfaces to create a common architecture to develop both products and production systems simultaneously. The development of the models required in these platforms is often performed manually and it is perceived as very time consuming. A discipline that can support the implementation of Production Platforms is Enterprise Architecture (EA). EA is a discipline that manages the organizing logic of the enterprise and it reflects the integration and standardization requirements of its operating model. Therefore modelling the products, production systems and process is in the scope of EA when applied to the manufacturing industry. In this paper, we develop a new automated EA modelling method relevant also for manufacturing. We tested it in an Industry 4.0 laboratory. This paper is a first step for creating automated EA modelling methods that are general-purpose and applicable in different contexts. With this goal in mind, we outline future research directions based on the limitations and challenges experienced during the laboratory experiments.

**Keywords:** Enterprise Architecture, Enterprise Modelling, Enterprise Modeling, Automatic, Automated, Manufacturing, Production, Smart Production, Industry 4.0, Smart Factory, Digital Twin.

## 1 Introduction

The fundamental goals and principles of manufacturing are changing with the emergence of new paradigms. In recent years, “the ubiquitous presence of the internet and computing and availability of emerging responsive manufacturing systems” lead to the emergence of the personalization paradigm [1]. In this new paradigm, the products are personalized to the individual needs and preferences of consumers. In this approach consumers, customers, and manufacturers collaborate to create innovative products. The fourth industrial revolution, also referred to as Industry 4.0 or Smart Manufacturing, is concurrent to and enables the personalization manufacturing paradigm. As a consequence of the emergence of this new paradigm combined with the changes brought by Industry 4.0, manufacturers are experiencing a significant increase in the variety and complexity of products and production processes.

An emerging concept in the manufacturing industry that addresses the complexity of production systems is the Production Platform [2]. Production Platforms are a solution to standardize assets in production by mapping "products with corresponding production systems and developing both simultaneously" [2]. This is achieved by classifying production processes and identifying "common processes, elements and interactions across multiple production systems" [2]. Practitioners in the field reported to us that they have been using diagramming tools (e.g. Microsoft Visio) in pilot projects without finding suitable modelling tools with an object repository and the possibility to have add-on functionalities (e.g. Enterprise Architecture notations like Archimate).

A discipline that can support Production Platforms is Enterprise Architecture (EA). In this paper, we apply EA to manage the complexity in the new era of manufacturing and implement Production Platforms. Although there is no general agreement on the definition of EA, we are in agreement with Lapalme's purpose of EA being to "effectively implement the overall enterprise strategy by designing the various enterprise facets […] to maximize coherency between them and minimize contradictions" [3]. Being EA a discipline based on models, the verbs modelling and documenting will be used interchangeably. EA and Production Platforms have several points in common. Most importantly, they both involve the development of a standardized representation of process models. Based on our experience with large Danish manufacturers, when developing Production Platforms in manufacturing companies with hundreds of product variances and production processes they experience two main problems. One is the difficulty in managing the amount of information to be modelled, and the other one is the prohibitive effort required to develop these models manually[1].

Automated modelling is an emerging research stream in the field of EA that deals specifically with these challenges. Its goal is to "automate EA documentation by retrieving and maintaining relevant information from productive systems" [4]. This research stream is still in its infancy and it is significantly limited by the inability to abstract the information available in the IT systems [4]. In most cases, the information available is very detailed and often not easily understandable by non-specialists. Therefore, it is not useful to directly generate high-level EA models.

Moreover, EA functions in enterprises are often positioned in the IT department [3, 5] and, as industrial surveys indicate, this made the discipline detached from the business [6, 7]. To increase its contribution to the business, several authors are calling for

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[1] This information has obtained by attending events at companies that collaborate with Aalborg University.

a reconceptualization of EA to include the whole enterprise and its environment [5, 8]. Research in automated modelling is almost exclusively focused on IT aspects [9, 10]. For these reasons, further research is required to address the abstraction gap issue in automated modelling and extend automated modelling methods to be usable also to model the rest of the enterprise and not only its IT (e.g. production processes in manufacturing). This paper has the additional goal to support the implementation of Production Platforms in the manufacturing industry. Therefore, we address the following research questions: *How do automated EA modelling methods include abstraction? What are the challenges in introducing abstraction in automated EA modelling methods?*

To address these research questions and the challenges experienced by Danish manufacturers, we developed an automated modelling method that involves domain experts in structured abstraction actions. A domain expert can be understood as a person who has extensive knowledge and experience in a particular topic. While developing and applying this method, we documented the limitations, challenges and problems experienced in our Industry 4.0 research laboratory [11]. We validated its usefulness and gathered feedback by interviewing the laboratory manager. We extended automated modelling methods to not only extract information from IT systems and generate models, but also involve a domain expert to abstract information for the development of Production Platforms. Based on our experience and the interaction with several companies and researchers, we present future research directions.

The remaining of the paper is structured as follows. Section 2 presents the background literature, and Section 3 the methodology and the experimentation environment. The following section presents the new modelling method, the generated model and the results of the evaluation. Finally, the last two sections discuss the results of the research, outline future research directions and conclude the paper.

## 2 Background

We begin this section by positioning our research in the field of EA and its modelling process. Afterwards, we present automated EA modelling methods literature as well as the classification adopted for the development of Production Platforms.

### 2.1 Enterprise Architecture

The scope of this paper is limited to the documentation of ‘as is’ models when the information for creating them is available in a digital format. This is due to the fact that to automate documentation the information needs to be retrieved from an IT system (e.g. Manufacturing Execution (ME) and Enterprise Resource Planning (ERP)) and usually these systems represent only information relevant for the ‘as is’ models.

A main challenge of EA is the fact that EA functions are usually part of IT departments and its approaches have been focused on IT aspects and this caused a lack of acceptance and made EA being perceived as organizationally inconsiderate [3]. In addition, EA practices have not been able to "consistently deliver adaptation or innovation in the past" [3]. Leading researchers in the EA field stated that “EA calls for a radical reconceptualization to inform a more adaptive EA practice” [5], [8]. The same group of researchers expressed the need for EA to develop new tools and methods to provide coherence and adaptability [5]. A second challenge in the field of EA is that as a discipline it requires extensive manual effort which makes it expensive and time-consuming. According to [9] and [10], “the majority of EA practitioners rely on the manual input of changes to an EA model, without any automation of EA model updates” [11]. Therefore, “manual documentation activities pose one of the biggest challenges to EA management” [12]. Exploiting the newest technological trends, EA can improve the efficiency of tools and methods for gathering information and modeling.

### 2.2 EA modelling process

Lankhorst et al. identified the activities of EA modelling process and their logical order [12]. Figure 1 presents in the top part the activities of the EA modelling process and underneath the four actions that are part of the *creating and structuring the model* activity. The modelling process starts with *establishing the purpose, scope and focus* of the model. Each model has a goal, for example provide insight into processes, or enabling business-IT alignment. This goal restricts the part of reality that will be modelled, and guides the focus on certain aspects with a certain level of detail. The second activity of the modelling process is the *selection of the viewpoints* to create the model. This includes selecting the concepts and relations to be represented in the model to address the requirements of the stakeholders. The third activity is *creating and structuring the model*. This activity starts by gathering the information required in the model, for example through interviews with stakeholders or analysis of enterprise’s documents. To reduce its complexity the information is structured in a model. Based on the requirements of the stakeholders, the fourth activity of EA modelling focuses on *visualizing the model* in an appropriate way. Finally, the representation of the model is *used* to communicate with the stakeholders, and the iterative *model maintenance* keeps the model up to date and in line with the stakeholders’ requirements. In the creating and structuring activity, the contribution of this paper is focused on automating the *information gathering* and *structuring the model* actions, as well as create a structured *abstraction* action.

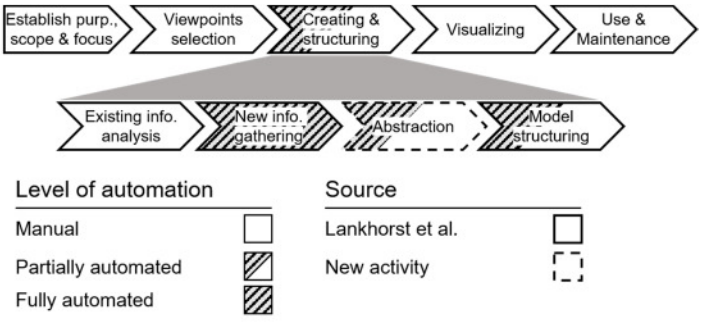


**Fig. 1.** EA Modelling process Lankhorst et al. [12] with the addition of the abstraction action.

### 2.3 Automated EA modelling methods

Research on automated EA documentation has been mostly undertaken at three research institutes in Europe. We structured this sub-section presenting the research in each institute because each institute developed its own solutions that have been applied and refined by several authors within the same institute. At the Institute of Computer Science at the University of Innsbruck, Farwick et al. [13–16] researched automated documentation methods and the required manual contributions associated with automation. In particular in their most extensive work [13], they applied situational method engineering and outlined four methods for EA model maintenance relating them to EA layers, as defined by Winter et al. [17]. Among these four methods, the automated structured data collection method is related to the content of our paper, and it is based on the concept of collecting data from "data sources that can deliver structured EA-relevant data, such as Configuration Management Database (CMDB), network scanner or Enterprise Service Bus" [18]. The same research group identified data sources for automated EA documentation [16]. The Royal Institute of Technology (KTH) in Sweden also extensively researched on automated EA documentation and modelling. Buschel et al. [19] were the ones to initiate research on this topic at KTH. They developed a "method for automatic generation of EA models with respect to the complex IT architectures of enterprises" based on network scanners applications. The same research group has also used as inputs for their models active and passive network scanners [9, 20] as well as SAP Process Integration (PI) as Enterprise Service Bus (ESB) [21]. Johnson et al. in [10] outlined dynamic Bayesian networks for automatic EA modelling and provided a list of machine-readable data sources for EA. Finally, Hauder, Matthes and Roth have lead research in automated EA documentation at the Technical University Munich (TUM). They focused on data quality aspects [21] and conflict resolution in EA models [22, 23]. In addition, they identified challenges related to automated EA documentation [4].

### 2.4 Production Platform process classification

Key elements in Production Platforms are the process and product classifications. In this paper, we focus on the process classification and we are adopting the one of Sorensen et al. [2] because it is applied in companies that collaborate with Aalborg University. Sorensen et al. developed a classification for the manufacturing industry that classifies processes in four categories: manufacturing, material handling, control and planning, and test and inspection. Their classification is organized as follows: 4 process categories, 16 process families, 53 process classes, 232 process subclasses. As an example, the *manufacturing* process category includes the *shaping* process family. In shaping, there are five process classes – *casting, molding, compacting, deposition* and *composite*. Finally, for example casting can be further classified in: *sand casting, die casting, investment casting, continuous casting,* and so on. Applying this classification is possible to identify production activities using a common vocabulary as well as abstract production activities. The elements in this classification utilize different icons that share the overall design at a *process category* level (e.g. a square for material handling, a triangle for test and inspection, and a circle for manufacturing) but have different details in the representation for *process classes*.

Concluding this section, we summarize the state of the art of research related to this paper. As a discipline, EA is transforming itself from being confined to the IT department to become more comprehensive and consider the whole enterprise and its environment [3]. In the beginning of the year 2010s the topic of automated modelling emerged in the field of EA. Since its first appearance, research in this topic has been focused on IT aspects. Acknowledging the evolution occurring in the discipline, the methods and knowledge developed in the automated modelling topic needs to progress to be relevant. To do so, the biggest challenge in automated EA documentation remains to be addressed [4], namely the abstraction gap between EA models and information in IT system. To the best of our knowledge, no researcher has addressed this challenge in this topic before. Therefore, with this paper we aim to contribute solving this challenge as well as to initiate a transformation of automated modelling methods to become general-purpose and not relevant exclusively for IT models. For this reason, we investigate the challenges related to this transformation and outline future research directions to continue this transformation.

## 3 Methodology

We applied design science research as methodology during our project and we completed one full iteration. In particular, we chose Peffers et al. research methodology for information systems [24] because it is tailored to our research field. Moreover, design science research methodology addresses simultaneously practitioners and research problems through the development and testing of artefacts [24]. Starting from the academic side, our research is contributing to the call of several researchers in the field to extend EA's scope to include also non-IT aspects of the organization [5, 8]. Concerning the industrial aspect, our research is based on the collaboration with several large Danish manufacturing companies that are part of the Manufacturing Academy of Denmark (MADE) initiative. We informally engaged with them and acknowledged the need for an efficient approach to develop high level production process models.

The method we designed is based on Lankhorst et al. [12] description of EA modelling process. We decided to use this process since it adequately represents to our knowledge the EA modelling process. Based on their process, we identified the modelling actions to be automated, and we added an explicit abstraction action to the process. We made the abstraction action explicit to increase its importance and to better identify the level of automation of the actions, see Fig. 1.

We applied our new method at the Smart Production Laboratory at Aalborg University [11]. "This research facility is a Learning Factory [11] and it includes a fully automated small production line integrating and demonstrating various Industry 4.0 concepts and technologies" [25]. This Learning Factory replicates industrial environments and is used by students, researchers and practitioners to develop and test new technologies and solutions in the manufacturing industry. The product is a phone that is composed of five parts and requires assembly, drilling and inspection activities.

To develop EA models we leveraged QualiWare EA platform [26] because this platform provides the set of functionalities required for implementing the new method that other platforms do not offer in the standard version.

We demonstrated our method in the Industry 4.0 laboratory at Aalborg University generating the high-level production process model. Even though the production process in the Industry 4.0 laboratory has a fewer number of activities than industrial processes, the data and IT systems used are in common with industrial environments. A preliminary evaluation of the method and the model was performed by interviewing the laboratory manager. We decided to interview him because he could have best validated the usefulness of the model in the laboratory. In addition, he provided feedback on the industrial implications and requirements based on this extensive collaboration with Danish manufacturing companies. The first author interviewed the manager using open-ended questions related to the following topics: value of the abstracted model, soundness of the new modelling method and of the abstraction action. In the first part of the interview, the author presented to the manager two versions of the production process, one that was generated using the new method with the abstraction action and one that skipped the abstraction action. This second model had a uniform representation of the symbols of the production activities and it included the naming available in the ERP system, see the image of *existing information analysis* in Fig 2a.

## 4 Artefacts & Results

In this section, we present our automated method that contributes to a specific activity of Lankhorst et al. modelling process [12]. Afterwards, we describe its instantiation using QualiWare EA platform at Aalborg University's Industry 4.0 laboratory. We end this section by reporting the outcome of the evaluation with the laboratory manager.

### 4.1 New automated modelling method

The method focuses on the "creating and structuring" activity of the modelling process. Therefore, enterprise architects are encouraged to follow Lankhorst et al. modelling process as it is except for this activity. As shown in Fig. 1, this activity is structured in 4 actions, three from Lankhorst et al. [12] and the new abstraction action. We classified the actions with different levels of automation, see Fig. 1. In the remaining of this sub-section, we describe each action and the new tasks necessary for automated modelling. These tasks are organized in *meta-model* and *instance* tasks. Meta-model tasks aim to define the frames, rules, and constraints of the automatically generated models. Instance tasks focus on the development of a specific instance.

In the *existing information analysis* action, the enterprise architect analyzes existing models of the enterprise and the documentation that is made available. This action is extended with four tasks required for automation. The *meta-model* tasks include (1) specify the meta-model (e.g. industrial standards) and (2) import the meta-model in the EA platform. The tasks focused on the *instance* include (1) identify which data is available that is relevant to the model and (2) locate where are the data sources for this data. This action is completely manual because it requires the enterprise architect to interact with employees in the organization to find information, as well as analyze unstructured information.

Afterwards, in the *new information gathering* action, the enterprise architect collects additional information to create the models. In this case, two new tasks focused on the instance are required. These tasks are (1) connect the data sources (e.g. API, databases) to the EA platform and (2) when this is not possible export the data from the data source in a format that can be imported in the EA platform (e.g. Microsoft Excel). Contrary to the previous action, this one is fully automated because it is possible to import information in the EA platform by using "connectors" that handle the interaction with the IT systems identified in the previous action (e.g. SAP, SharePoint connectors).

The third action of the method is the new *abstraction* action where a domain expert (e.g. manufacturing architect, production manager) is contacted through the EA platform to add the required information (e.g. by e-mail). He or she is expected to verify if the information extracted is aligned with his or her knowledge. In case of errors in the raw information, corrected information should be inserted by the domain expert preserving the original one. For example, in excel it can be added a dedicated column where the domain expert can insert corrections. The reasoning behind this approach is that in this way the wrong information will be more easily identifiable, and the manual corrections can be replicated also in the future without the need for the domain expert to reinsert them. Afterwards, it is time to perform the classification. In this case for each information imported the right classification is applied. Manual work can be further reduced in two ways. If a classification at a detailed level is inserted the more high-level ones can be assigned automatically. On the other hand, if a high-level classification is inserted, the range of available classification at the lower levels can be shortened and only the relevant ones can be displayed. Finally, the domain expert has the opportunity to edit the name displayed in the model. The default value is the most detailed classification value. This action has three tasks. The *meta-model* task consists of generating the environment for the abstraction task (e.g. Microsoft Excel file with headings and formatted columns). The *instance* tasks are (1) request the contribution from the domain expert who receives the information and the input interface to perform the abstraction, and (2) import the outcome of the previous task in the EA platform. This action is partially automated. The preparation and import of the abstraction task are automated, while the abstraction and eventually correction tasks are performed by the domain expert.

Finally, the *model structuring* action consists in creating objects in the EA platform and arranging them in a visual representation of the model. In this last action, the *meta-model* task focuses on specifying the structure of the model in the EA platform:

its development, vertical, horizontal or circular; and the presence of layers. Based on this information, the *instance* tasks can be executed. The tasks are the following, (1) instantiate the objects in the EA platform (e.g. an activity in a workflow model) with all the related information/attributes, and (2) generate the model following the structure specified and the meta-model rules and constraints (specified in the first action). This action is mostly automated and the only tasks performed by the enterprise architect are specifying the structure of the model and eventually correct the placement of the object in the model.

### 4.2 Empirical study

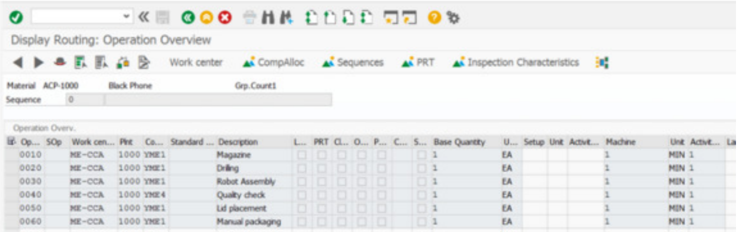
In the following section, we present the application of the method in the laboratory. We documented each action with screenshots in Fig. 2. We focused on the production process of the product variance that is mostly manufactured at this facility. First, we imported the Production Process classification metamodel in QualiWare Platform by extending the existing object "Activity". Afterwards, we analyzed the data available in SAP ERP system and FESTO ME system, the two systems managing production at this facility. Continuing with the new information gathering action, we exported in Microsoft Excel the information about the production process from SAP ERP system (precisely, the *routing operations overview* table of the product) as well as the production sequence from FESTO ME system (that specifies in which sequence the production operations are executed). These data were combined in a single Microsoft Excel sheet using the operation ID as key (information to merge the information). Afterwards, we added to the Microsoft Excel file the columns required for the abstraction action. Subsequently, the authors filled the information required for the abstraction and the file was uploaded in QualiWare platform. At this point, the platform modelled the workflow model on the horizontal axis, as shown in Fig. 2d. We manually added start and end events. Having said so, this can be automated and the names of these events can be decided by the domain expert.

### 4.3 Outcome of the evaluation

We evaluated the model and the method interviewing the laboratory manager. During the interview, he expressed that in the model automatically generated without abstraction the representation of the activities was both not clear and very limited. On the other hand, he thought that "going from the raw model to the one with the classifications is a big step for the industry because they get much more information into the same model". In addition, he explained that the classification of the activities of the production process transforms information in the ERP and ME systems, that can be understood only from people that worked with these systems, to more readable and understandable information for people who have not worked with these specific applications.

Moreover, the manager proactively presented a list of extensions to the method. He recommended to create a production process model for each product variance since each product variance has limited alternative routes. These models are easy to verify and to understand. Once the models for all product variances have been developed, he recommended to create a production line or generic production process model that overlaps the activities in common in the different models and represent distinctively the ones specific to a product variance. “This would we valuable if you want to know if these ten products can be produced on the same production line”. Finally, the laboratory manager outlined also three main challenges that have been included in the discussion section.

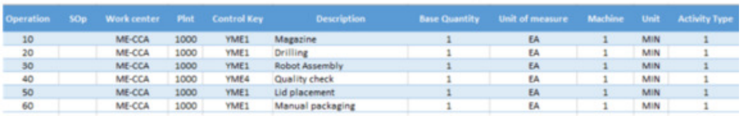
a. Existing information analysis



Material ACP-1000 Black Phone Grp.Count1
Sequence 0

| Op... | SOp | Work cen... | Plnt | Co... | Standard ... | Description | L... | PRT | Cl... | O... | P... | C... | S... | Base Quantity | U... | Setup | Unit | Activt... | Machine | Unit | Activt... | La |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 0010 | | ME-CCA | 1000 | YME1 | | Magazine | ☐ | ☐ | ☐ | ☐ | ☐ | | ☐ | 1 | EA | | | | 1 | MIN | 1 | |
| 0020 | | ME-CCA | 1000 | YME1 | | Driling | ☐ | ☐ | ☐ | ☐ | ☐ | | ☐ | 1 | EA | | | | 1 | MIN | 1 | |
| 0030 | | ME-CCA | 1000 | YME1 | | Robot Assembly | ☐ | ☐ | ☐ | ☐ | ☐ | | ☐ | 1 | EA | | | | 1 | MIN | 1 | |
| 0040 | | ME-CCA | 1000 | YME4 | | Quality check | ☐ | ☐ | ☐ | ☐ | ☐ | | ☐ | 1 | EA | | | | 1 | MIN | 1 | |
| 0050 | | ME-CCA | 1000 | YME1 | | Lid placement | ☐ | ☐ | ☐ | ☐ | ☐ | | ☐ | 1 | EA | | | | 1 | MIN | 1 | |
| 0060 | | ME-CCA | 1000 | YME1 | | Manual packaging | ☐ | ☐ | ☐ | ☐ | ☐ | | ☐ | 1 | EA | | | | 1 | MIN | 1 | |

b. New information gathering



| Operation | SOp | Work center | Plnt | Control Key | Description | Base Quantity | Unit of measure | Machine | Unit | Activity Type |
|---|---|---|---|---|---|---|---|---|---|---|
| 10 | | ME-CCA | 1000 | YME1 | Magazine | 1 | EA | 1 | MIN | 1 |
| 20 | | ME-CCA | 1000 | YME1 | Drilling | 1 | EA | 1 | MIN | 1 |
| 30 | | ME-CCA | 1000 | YME1 | Robot Assembly | 1 | EA | 1 | MIN | 1 |
| 40 | | ME-CCA | 1000 | YME4 | Quality check | 1 | EA | 1 | MIN | 1 |
| 50 | | ME-CCA | 1000 | YME1 | Lid placement | 1 | EA | 1 | MIN | 1 |
| 60 | | ME-CCA | 1000 | YME1 | Manual packaging | 1 | EA | 1 | MIN | 1 |

c. Abstraction

| Process category | Process families | Process classes | Process subclasses | Name in QualiWare (the most detailed value available in the classification) |
|---|---|---|---|---|
| MaterialHandling | Handling | ChangeQuantities | Allocate | Allocate from Magazine |
| Manufacturing | Separating | Cutting_Chips | Drilling | Drilling |
| Manufacturing | Joining | Assembly | Lay&PutOn | Lay&PutOn Components |
| Test&Inspection | Inspection | CheckProperties | | CheckProperties Components placement |
| Manufacturing | Joining | Assembly | Lay&PutOn | Lay&PutOn Lid |
| MaterialHandling | UnitLoadFormation | Packaging | | Packaging manual |

d. Model structuring

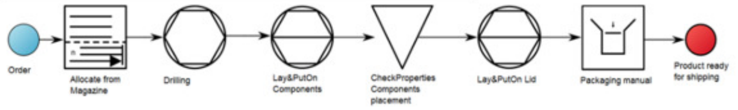


**Fig. 2.** Empirical case at the Industry 4.0 Laboratory at Aalborg University.

## 5 Discussion

Previous studies on automated EA modelling developed and applied methods for generating IT models. Researchers in the field used almost exclusively network scanning tools to generate detailed network models. The high level of detail of these models combined with the lack of abstraction limited the application of these methods outside the IT domain [4]. In this paper, we presented a new automated method for generating EA models that abstract the information available in the IT systems. Our method is aligned with the other automated modelling methods for the automated data gathering and automated model structuring and instantiation. It is unique in its abstraction action that involves a domain expert.

We identified two main implications of our research for EA researchers and practitioners. Our results outline a new vision for the EA documentation process. In this new vision, the enterprise architect is still engaging with stakeholders as described by Lankhorst et al. [12] but, at the same time, he introduces to the stakeholders industry specific meta-models and they all collaborate to customize the meta-models to address the enterprise's needs. Afterwards, the enterprise architect instead of manually creating the models from a blank sheet, he takes advantage of automated modelling methods to generate the first version of the models. This would allow the enterprise architect to become more efficient and the first version of the models would include a complete information set extracted from the production systems. The other implication is the involvement of domain experts in the modelling process. This aspect is important due to the potential lack of industry specific knowledge of enterprise architects. Since EA discipline emerged from IT architecture, the educational background of enterprise architects has traditionally been in the IT domain. Complementing the lack of knowledge with domain experts can increase value and acceptance of enterprise architects' work.

At a more general level, our research is contributing to the extension of the scope of EA. As previous literature has stated [3, 5], EA discipline needs to consider not only the IT aspect and its relation with the rest of the organization, but it should include the concerns of different departments in the organization. We are contributing to this change by providing a generic automated modelling method and by demonstrating its application to the core of manufacturing, namely production processes. Finally, our research is also answering to the call in the field to increase the adaptability of EA discipline [5, 8]. Our method could be potentially applied also to support the management of complexity in the environment of an enterprise.

Moving on to the implications of our research for the manufacturing industry, the new method contributes in several ways to the implementation of Production Platforms. The first way is that it provides a structured approach for gathering information. The second one is that once the connection with the IT systems is in place, it automatically gathers information, potentially also at different points in time. Third it generates the models without requiring a human operator to create them. Even though the method has been applied to model production processes, we expect it to be valuable also for modelling information related to products as well as manufacturing assets. In our opinion, the emerging topic of Industry 4.0 can also benefit from the outcome of our research. An architecture initiative in this domain that is becoming more and more popular is the Reference Architecture Model Industry 4.0 (RAMI4.0) [27]. RAMI4.0 structures the description of the different aspects of an asset [27]. Without entering in the details of the standard, based on our previous experience with RAMI4.0 [25] we envision the modelling of Industry 4.0 components in EA platforms using the method we presented in this paper. Furthermore, we plan to improve our method to automatically gather detailed information about the elements in EA models (e.g. using the ISA-95 standard). For example, configuration information and status information of Industry 4.0 components. To achieve this outcome, we plan to adapt the existing automated EA modelling methods focused on IT and eventually create new ones. With this addition, it will be possible to gather and model information on a recurrent basis, therefore enabling the availability of EA models constantly up to date.

Based on our experience and relevant literature, we present future research directions to significantly improve the value of automated EA modelling methods.

*1. How is the interaction with the domain expert improved? In what steps of the process should a domain expert be involved?*

Research in this topic is required because little or no evidence on how domain experts or in general employees that are not part of the EA group are involved in automated modelling. The work of Farwick et al. [13] represents the most detailed analysis of these aspects. In their work, they identify several context factors of documentation, distinguish between six documentation roles, and finally present four semi-automated model maintenance techniques. Having said so, empirical data on the application of these techniques are very limited. Therefore, further application of these methods is required to evaluate and improve them.

*2. How to involve multiple people in the abstraction action? Which collaboration techniques can be applied?*

While it might seem enough to rely on a single domain expert, it would be more robust to involve multiple people in the abstraction action. There are multiple options on how to involve different people as well as how to control this action. Different solutions might require the extension of automated modelling methods with new actions.

*3. How to include different data sources for automated EA modelling?*

As we have also experienced in our project, relaying on a single data source is usually insufficient to create EA models. Valja et al. [9] addressed this concern with their requirements based approach for IT architecture modelling. Having said so, further research is required to find solutions that to combine multiple data sources to create a rich information set to facilitate the abstraction action, as well as extend this approach to non-IT models.

*4. How to manage and display changes in reality in the models?*

Based on our experience in the Industry 4.0 laboratory and the vision of a constantly changing production environment, we expect to be challenges in how to maintain the models aligned with reality and how to visualize the changes in a timely and effective manner.

We conclude this section with four further development points for EA to better support Production Platforms:

1. Develop a feature in the EA platform to identify and classify patterns in processes. This feature should also enable the application of these pattern in new models. In this way, EA tools would provide an end-to-end solution to the implementation of Production Platforms. This feature would extend the catalog of automated analysis methods in EA from Florez et al. [28].
2. Generate aggregate views for product families by combining the production processes of the different product variances. This allows to visualize which products

can be produced on which production line and how much does the production process and production line need to change to be able to produce new products.

3. Support automated modelling of the other two “pillars” of Production Platforms: product and production equipment architectures.
4. Find a solution to deal with overwhelming information (e.g. 100 production steps). New research should investigate how to create further abstraction layers.

As mentioned in the introduction, the abstraction gap between the information available in IT systems and the content of EA models is the major challenge for automated EA modelling methods. Therefore, further research on this challenge is required to be able to spread automated modelling in the field and enhance EA practice.

## 6 Conclusion

In this paper we addressed the major challenge of automated EA modelling, namely the lack of abstraction, by developing a new modelling method that includes abstraction activities. We applied it in an Industry 4.0 laboratory for generating high-level process models. We evaluated the method and the generated model with the manager of the laboratory. In the manufacturing industry, companies are realizing that it is crucial to develop simultaneously product and production systems. This is a concept also advocated by Industry 4.0. This is enabled by production platforms that include high-level Production Process models, like the ones generated by our method. This model provides an understanding of the production processes and in the same model product and production equipment can be related to each other. In addition, the production process model can be used as a framework for the development and introduction of cyber-physical systems in manufacturing facilities.

Our research is at an initial stage and it presents different limitations. Starting with the context of application, even though the Industry 4.0 laboratory is created with the specific goal of replicating industrial production environments, the products and their production processes are less complex than most of the manufacturing processes in the industry. In our case we have a linear production process with no branches. When modelling the production process in the industry we might experience model structuring challenges caused by the presence of several branches in the production process. Afterwards, another limitation is the fact that the method has been applied only by the authors and therefore it needs to be validated by practitioners from the industry. Finally, part of the automated solution presents minor shortcomings that have not been solved at the time of writing.

We plan to address these limitations by focusing on two main aspects in our future work. The first one is to evaluate the new method in the industry. The second one will be to improve the conceptualization of the meta-models used. The classification of Production Platform provides a meta-model of each process category and family. Further work is required to extend the meta-model to include product and equipment elements. In addition, particular focus will be reserved in creating the connections between the elements and the process since at the moment this is missing. Furthermore, to improve the modelling of system properties we are planning to investigate the applicability of Systems Modelling Language (SysML), a general-purpose modelling language for system engineering. In this way, we might be able to document systems' properties in a structured way. In addition, adopting SysML would also further increase the level of abstraction of the models.

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