USING POINT CLOUD TECHNOLOGY FOR PROCESS SIMULATION IN THE CONTEXT OF DIGITAL FACTORY BASED ON A SYSTEMS ENGINEERING INTEGRATED APPROACH

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Abstract

Currently, there is a huge potential to improve the digital factory information by using a 3D scanner to build up the digital factory environment. The results of the scanning process are point clouds which are generated with less effort yet in a very high quality. In this way, it is possible to digitalize manufacturing environments in large scales. Compared with the processes in the past, it is not necessary to build up the manufacturing and factory building information by means of CAD generated entities. This paper will first present the state of the art regarding the development of digital factory as well as the current process of utilizing 3D point cloud data within it out of a comprehensive literature survey. Based on the literature review, challenges and problems during the application of the 3D scanner and point clouds in the digital factory in respect of the corresponding processes and methods will be recognized. Moreover, taking the shortages and disadvantages of current methods in digital manufacturing into account, an improved solution approach using systems engineering will be suggested and elaborated.

Keywords: Product Lifecycle Management (PLM), Systems Engineering (SE), Design methodology

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1 INTRODUCTION

The concept "digital factory" describes the idea of a network with digital models, methodologies, and different applications that integrate the planning and design of a production system with the production process itself (Zimmermann, 2005). It represents an environment where virtual models replace reality. Virtual models enable the possibility to optimize the design of a solution and also to verify different conflicts before implementation. A virtual model is easy to present and explain to others, and it can provide a basis for planning and job descriptions for project members and outside contractors (Zimmermann, 2005).

Digital factory concerns the technology used for capturing and representing information to model manufacturing systems and its available processes in a factory (Kjellberg, 2006). During the last decade, the tools and software supporting the industrial activities have developed rapidly such as CAD, CAM, digital assembly, virtual manufacturing and other simulation tools just to mention a few (Svedberger and Andersson, 2013). However, there is a need for new processes, systems, methods and tools in order to reduce stops, insecurity, waste and errors during the development and implementation of new factory layouts and products. Recently, utilizing point cloud models from 3D laser scans for visualization of manufacturing facilities and systems in the context of digital factory provides highly realistic representations. Current developments of this technology have improved not only the accuracy of point cloud models in terms of color and positioning, but also the performance of animations and simulations in processing program (Svedberger and Andersson, 2013).

Moreover, digital factory also concerns the methodology used for mirroring a factory and its available processes in planning, simulation, and optimization of the manufacturing systems. However, current research shows that in the development of digital factory, there are problems and challenges in the level of process, data management, and product lifecycle management (PLM). Systems engineering on the other hand, is an interdisciplinary field of engineering that focuses on how to design and manage complex engineering systems over their life cycles (DAU, 2001). It deals with work-processes, optimization methods, and tools in such projects, which ensure that all likely aspects of a project or system are considered and integrated into a whole. Therefore, applying and combining the systematic and methodological systems engineering approach could be the future of digital factory. Furthermore, by means of systems engineering in a combination of digital manufacturing, there is huge potential to carry out the digitalization processes, methods and tools by utilizing 3D scan data in the pre- and post-processing steps.

Accordingly, this paper will first present the state of the art regarding the development of digital factory as well as the current process of utilizing 3D point cloud data within it. Then we will shed light on the challenges and problems related to the aspects of process, method, and system during the application of point could in digital manufacturing. And most importantly, we are going to dig deeper into the topic of feasible adoption and application of the methodological and systematic systems engineering approach to digital factory by implementing an adapted V-Model. By means of using the systems engineering approach, it is possible to do the 3D scanning process in a systematic way from requirement definition up to the scanning process itself.

2 STATE OF THE ART

2.1 Digital factory

A digital factory is a model of a hypothetical or real manufacturing system (Sivard, 2012). The purpose of the digital factory is to mirror a factory and its available processes and therefore represent the relevant information of the factory's resources and processes. On the one hand, the digital factory will be a resource model that can be used as a base for preparation, plant design as well as being a tool for layout, material flows, and analyses (Kjellberg, 2006). On the other hand, digital factory enables to test and reveal all possible production problems and shortages before the start of production.

As we all know, building a brand new factory or only implement or install a new machine in an existing flow is very costly. Changes are always more expensive at the end of a project than at the beginning. Making mistakes and having to redo in retrospect must be avoided and it is important to get it right from the start. Therefore, it is more cost effective to simulate the factory in a digital environment where collisions, laws and regulations can be checked and modifications and optimizations can be done without

affecting the existing production line in operation (Svedberger and Andersson, 2013). In this way, digital factory implementation could result directly in economic as well as production indicators improvement. Generally speaking, digital factory is appropriate mainly as a support for the batch manufacturing of high sophisticated products, their planning, simulation, and optimization.
Nowadays, its main application area is automotive industry, mechanical engineering industry, aerospace and shipbuilding industries as well as electronics and consumer goods industries (DELMIA - DPE, 2008). To better fulfill the concept and application of digital factory, factories and plants in those industries can be 3D scanned and visualized in a three-dimensional world. The 3D scan technology allow a very exactly representation of the current stage of the factory. Therefore, we will explain in the next section show the technology works and what kind of scanner we have applied to digitalize the test scans at the university of the applied sciences to generate a demonstration environment for the analysis of the 3D scanner and there functionalities and the use of the scan data.

2.2 3D laser scanning technology

3D laser scanning is used for the building of 3D digital model of existing layout or by the analysis of static constructions. FARO Focus3D X 330 (Figure 1) is a good example to explain how a terrestrial 3D scanner works. With such 3D laser scanners, it's possible to capture the environment in the whole spatial angle with an accuracy of ±2mm (FARO, 2015), which makes them very appropriate for indoor applications. The result of this procedure is a discrete capture of the environment in form of a 3D point cloud. After the raw point cloud has been created, also the color information is being assigned to every point. This is carried out through a regular photo camera which is taking pictures in every spatial angle and then overlaps the pictures onto the point cloud data.

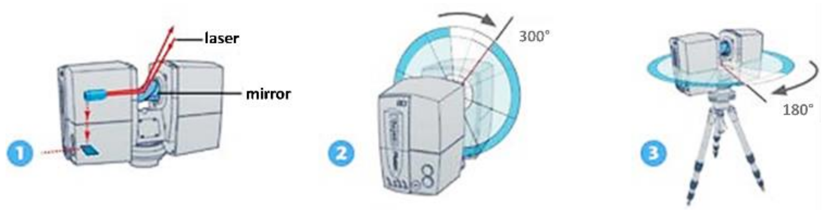


Figure 1. The functionality of terrestrial laser scanners (Function Laser Scanner n.d.)

As a matter of fact, the technology of laser scanning is not that new. However, the software has been drastically developed in recent years. The modern programs have become more efficient and have introduced new applications and the technology. They can handle larger point clouds in color, animations performance and simulations performance. Besides, they can make fast and simple planning decisions due to the possibility. Furthermore, it delivers highly accurate and photo-realistic results. Those being the case that planners' and engineers' tasks are simplified while time and effort are substantially reduced.
In this way, the planning of the digital factory is substantially improved through the possibility to scan existing facilities and the environment of the factory in three-dimensional space. However, there are also challenges during the 3D scanning process itself. It started with questions like how to define the scan positions, which method or process should be defined, how many scans are necessary, how to deal with the big size of the scan data, how to deal with the generated 3D scan data and so on. In this paper we will give some advices how to answer the above mentioned questions and how it will be possible to do systematic scanning process by adoption of Systems Engineering approach.

2.3 Application of 3D laser scanning technology in digital factory

As illustrated in Figure 2, the whole procedure of providing 3D laser scan data for a simulation in the context of digital factory is carried out in 4 steps: 3D laser scanning, scan data handling, simulation and applying results.

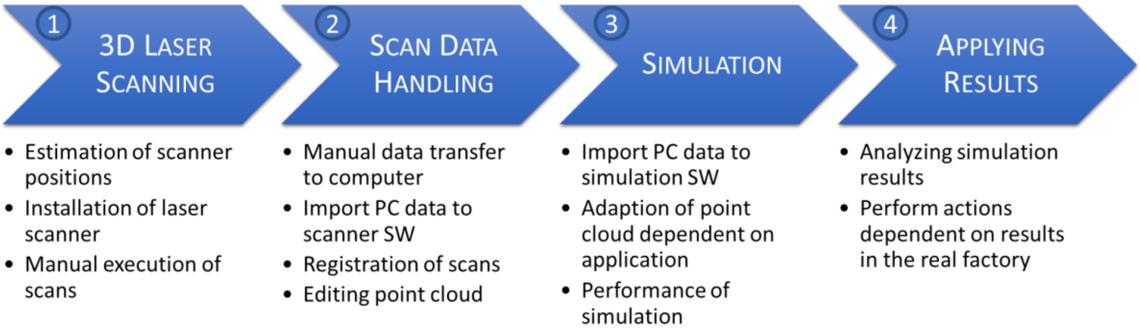


Figure 2. State of the art process of performing a simulation based on point clouds

1. *3D laser scanning:* A laser scanning system is to capture the fabrication environment. Therefore first we need to plan the scanning and reference objects positions to ensure that all necessary data can be captured. In this way, multiple scans are manually being carried out on different positions in the room. For good results, it is important that the scanned environment remains motionless throughout the scanning process.
2. *Scan data handling:* Register the scans to align into one data set and clean the data from any unwanted artefacts. The scans are manually being transferred to a computer system and software-aided structured to each other.
3. *Simulation:* Based on the generated 3D point cloud data it is possible to build up the simulation environment, the simulation of digital manufacturing could take place. In out use case we worked with process simulate.
4. *Applying results*: The results of the simulation have to be analysed, dependent on this; actions have to be performed in the real factory to optimize the production processes.

From above mentioned procedures, we could easily find out that the profits gained with the 3D laser scanning approach in the development of digital factory is considerable. This technology has the great potential to generate savings in time and money compared to traditional methods of digitalising. According to Greaves (2009), the reduction of the cost and schedule by using the 3D scan technology could be up to 7%, while the efforts of contingencies for rework are being reduced to less than 2%. And some advantages could be summarized as following:

- Fast capturing of a detailed 3D environment information
- No generation of 3D CAD models related to the facilities in factory necessary
- Replace current method of measuring
- Reduce travel costs for capturing the factory information
- Increase understanding and communication on a inter disciplinary level

Figure 3. An example of 3D-models in a point cloud environment within a digital factory

Nowadays more and more companies use laser scanning for modern plant construction projects (Digital factory and plant construction, [no date]). An example is showed in Figure 3 of an automotive company when it comes to using and developing the concept of digital factory with laser scanning technologies. Many other companies are working actively with laser scanning today as well, such as BMW, Toyota, Mercedes and Ford. Their focus is e.g. to scan robot cell. This section showed that there are different challenges related to the 3D scanning process. Below we will discuss the challenges from different perspective.

2.4 Challenges with current methods

With using the traditional methods of providing 3D laser scan data in the context of visualization, modelling and simulation several problems can emerge in regard of data, processes and systems. A manual preparation process without any prescribed methodology of the to-be-scanned area, could potentially be a source of errors due to redundancies and inconsistences which could appear within several process steps. Figure 4 shows the challenges during the current scanning process by means of testing the technology in the university environment.

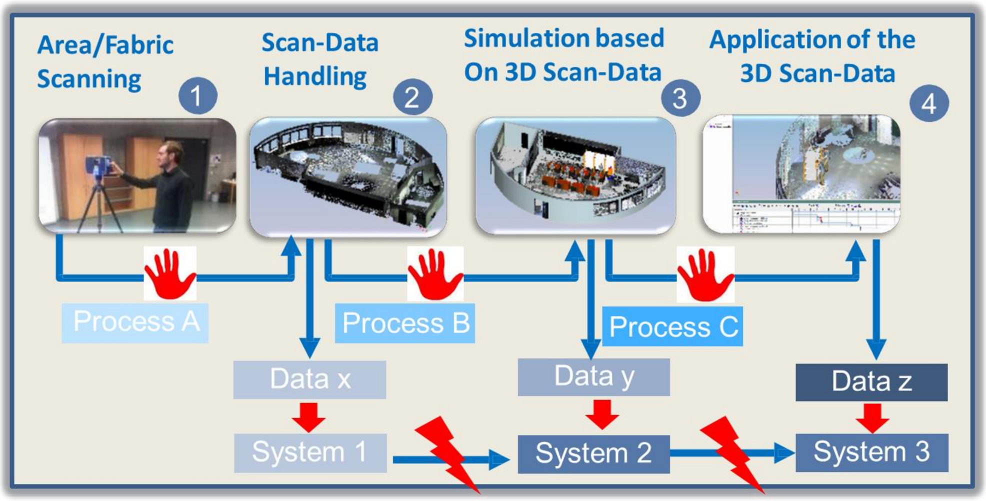


Figure 4. Challenges with current methods regarding processes, data and systems

The challenges can be divided into the process, data and PLM system level (see Figure 4).

- The challenges in the level of process include: 1) difficulty in selection of the correct 3D laser scanner for the implementation of digitalization and 3D laser scanning capture; 2) a cross-domain application of a consistent, interdisciplinary development methodology which considers the special demands of utilizing 3D laser scan data; 3) hardly support of a cross-domain integration, configuration and change management; 4) manually carried out working steps for the whole 3D laser scan processes; 5) redundancies and gaps between the process steps; 6) availability of the target data and actual data with interconnection of mobile clients such as tablets, smartphones, smart glasses.
- The challenges in the level of data management include: 1) impossibility of a cross-domain and continuous utilization of 3D laser scan data and the product and production structure; 2) redundancy and partly inconsistent storage of 3D laser scan data in different departments. 3) non-support of cross-domain and coordinated change and editing of 3D laser scan data, functions and systems which built at one another; 4) conditionally or hardly possibility of a cross-domain release of 3D-Laserscan data as well as their functions, systems and components due to the broken information flows between the different disciplines; 5) inappropriate application of a cross-domain production information based on 3D laser scan data.
- The challenges in the level of system, to be more specific - PLM system, include 1) incapability of enabling a clear storing, versioning and alternating of 3D laser scan data; 2) absence of a suitable data model for the coupling between the 3D laser scan data and the PLM system product structure; 3) impossibility of the editing of 3D point cloud in existed PLM system.

For tackling all of the above-mentioned challenges, a solution approach has been developed by means of the adoption of the V-Modell in systems engineering. The next section will explain the developed approach.

3 CASE STUDY - APPLICATION AND ADOPTION OF THE SYSTEMS ENGINEERING APPROACH FOR THE DIGITAL MANUFACTURING OF A MECHATRONIC DEVICE USING POINT CLOUDS

In this section, we will demonstrate the development of an assembly line simulation within a point cloud environment in the context of digital factory. Based on the literature review, the challenges and problems has recognized due to the lack of a holistic and sustainable methodology of digital manufacturing through current strategy. Thus, a solution approach is being suggested within the framework of an adopted systems engineering approach.

3.1 The background of V-Model in systems engineering

The V-Model (Figure 5) is one of the procedure models in the systems engineering approach and belongs to the plan-driven methods. The Association of German Engineers (Verband Deutscher Ingenieure - VDI) adapted the V-Model as a methodology for the system development lifecycle of mechatronic products in the guideline 2206. The "V" in the V-Model arises from the shape of the graphical representation of the model. It combines a top-down and a bottom-up approach. In top-down approach, customer objectives are being translated into technical requirements and specifications in a view of the whole system and later on transferred for the related subsystems and concepts. Subsequently, the development of the subsystems is being carried out in a bottom-up approach, which then can be integrated into the whole system. The central part of 'V' deals with the three domains - mechanical engineering, electrical engineering and software development. Simultaneously the verification is taking place in view of a comparison with the requirements defined at the left side. The upwards iterations are ensuring the technical fundamentals. Especially that the developed solution is able to cover the user requirements (Haberfellner, 2012). Accordingly, the complete system can be validated in respect of the original goals of the development (VDI, 2004). However, current research has not set deeper foot into the topic of how to implement systems engineering in digital factory.

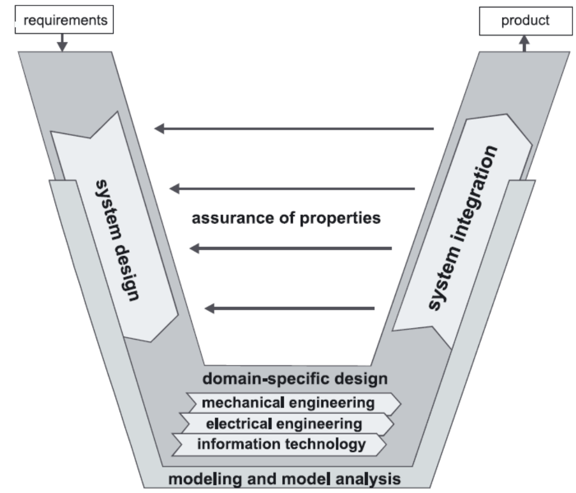


Figure 5. The V-Model according to guideline VDI 2206 (VDI, 2004; Gausemeier and Moehringer, 2003)

3.2 Solution approach based on adoption of using systems engineering

With the intention of a continuous improvement of the whole fabrication system, the scan methods so far are not satisfying. As a basis of a systematic process to capture, automatically handle and store the current geometrical boundaries with taking version, variant and validity into account and providing it in the view of a long-term use for further applications, there is a sustainable methodology missing. The current challenges in regard of processes will be solved with the implementation of an advanced and adapted V-Model. The aim is to provide a consistent methodology which prescribes the proceeding. Since the V-Model is based on the systems engineering approach, which only deals with the three domains - mechanical engineering, electrical engineering and software development. The view onto production is until now not being considered in an appropriate way.

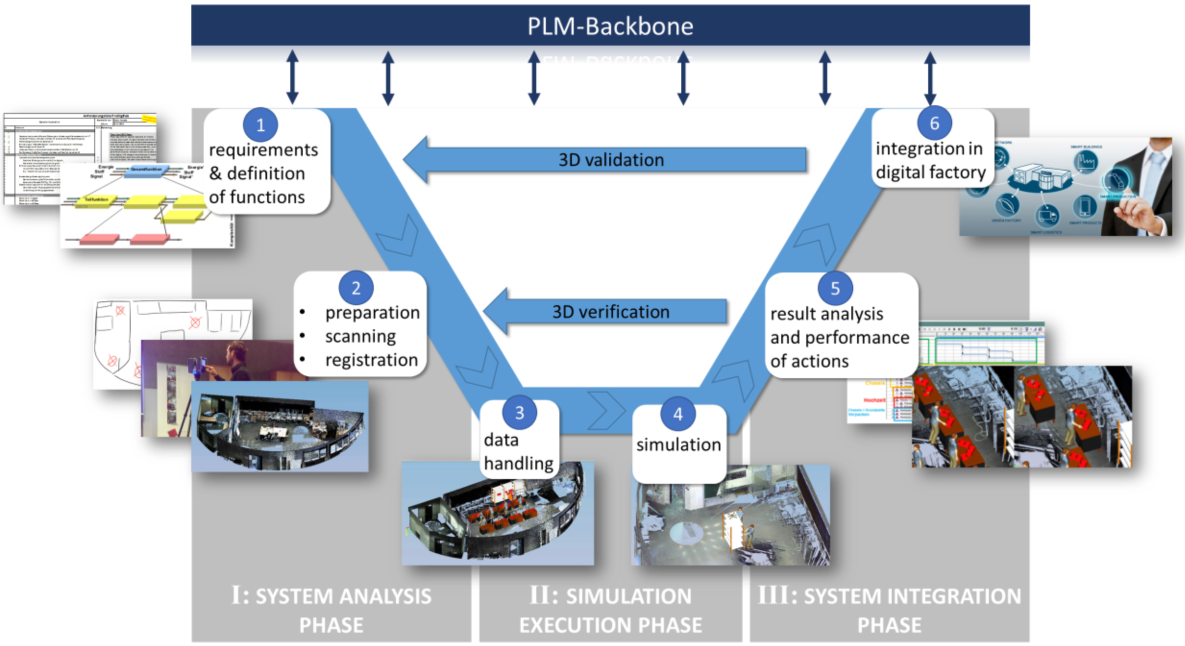
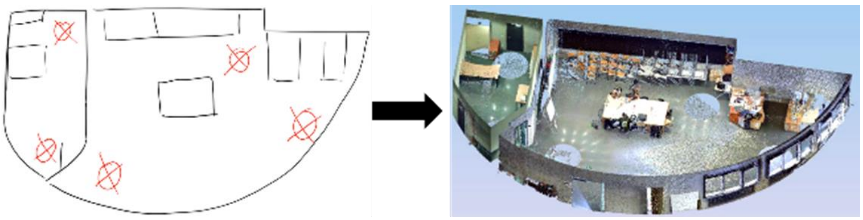


Figure 6. Modified V-Model for Manufacturing (Salehi, 2016)

As can be seen in figure 6, the whole process of the original V-Model is divided into three major phases: 1) system design, 2) domain-specific design and 3) system integration. Since there is no intention of developing a specific mechatronic product, the 'domain-specific design' phase is being replaced with the new and for present procedure adapted phase - 'simulation execution' and the 'system design' is being changed to 'system analysis'. With the 'system integration', actions based on the results of the simulation have to be initiated in the real factory. This process of 3D laser scan capture has very likely to be repeated throughout the factories' lifecycle periodically to always be able to provide current data. Throughout the whole methodological process, a consistent data transfer into the PLM system of the fabrication has to be maintained. Every created data has to be stored instantly in the intended sector. This data transfer interface should preferably be in the form of a wireless connection and the storage in best case on a cloud based server. In regard of the data processing, an automatic validity and version management must be ensured.

3.2.1 System analysis phase

As part of the system analysis, first all requirements have to be setup. Those requirements could be regarding for instance the laser scan system (FARO Focus3D X 330), the data interfaces (MicroSD) and formats (.fls, .fws, .pod, .stp, .stl), the used software tools (Faro SCENE, Siemens Process Simulate, Teamcenter) and related interconnections to other software systems, the environmental boundaries of the fabrication facility like surface properties, area size and objects within the area (fig. 7), the purpose of the performed simulation (time and material flow), temporal framework conditions of the project, shift changes of the employees to avoid disruptive factors, how often 3D laser scans have to be performed, what level of quality the point cloud should fulfil and so on.
Afterward, the functions have to be defined dependent on the simulation target and present environment, which is comparable to the "what"-question in the V-Model approach. In this step, the basic framework of the scanning procedure is being developed. It is defined which specific areas of the facility have to be scanned to satisfy the desired simulation purpose. Besides, boundary conditions have to be considered such as what data is already existent, from which machines CAD files are available, onto which PLM system the processes have to be connected to and what data formats are then emerging.



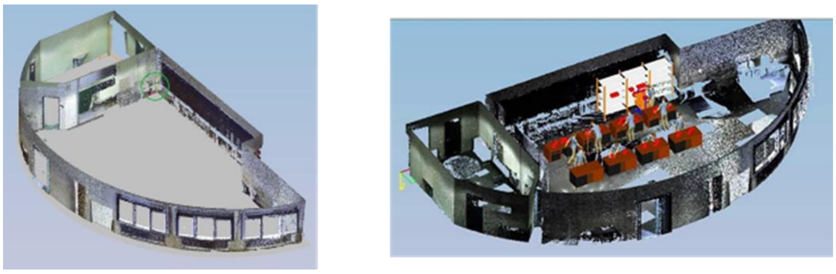
(a) *(b)*

Figure 7. (a): two-dimensional layout draft of scan positions, (b): related point cloud data

In the following step the scanning procedure is carried out. With the implementation of all necessary preparations for the scan process, the "how"-question is being clarified. To entirely scan an indoor environment of facilities, there is a necessity to execute multiple scans at different positions inside the building to ensure that emerging shadows of objects can be covered with additional scans. This circumstance must be considered in advance before starting the 3D scan project, to guarantee a satisfactory result of the point cloud data. Therefore first, the actual state is being identified and based on this a two-dimensional layout is created in which every object within the scan area is being considered and thus the positions of the scanner can be determined as shown in Figure 7. During the scanning procedure, great value must be placed on a calm scene to avoid unpleasant display of pedestrians in the point cloud. The amount of scan positions and the corresponding density is directly influencing the settings of the scanner in regard of scanning resolution and necessary accuracy of the laser distance measurement. After a successful execution of all scans, the emerging data bases must be structured to each other within the registration process by the execution of the so called *iterative closest point* algorithm.

3.2.2 Simulation execution phase

With previous step, the system analysis has been concluded and the simulation execution phase can be continued. This is where the specific simulation takes place. The point cloud data has to be imported and then edited and adapted for the desired simulation in Siemens Process Simulate. Additionally, existed CAD-models of manufacturing units or assembly lines are intended to be integrated into the point cloud environment. Then the simulation of time and material flow can be carried out.



(a) *(b)*

Figure 8. (a): integrated ground plane; (b): CAD generated assembly stations in the point cloud environment

3.2.3 System integration phase and validation

At last, the present generated point cloud data can be validated in respect to the requirements which had been defined in the first step. At the next scanning procedure, possible incorrect captured areas can be considered and re-captured in terms of a constantly growing data base of the digital factory. With the integration of the simulation results in the previous step, actions in the real factory have to be carried out to enhance an improvement of the entire production process. The decisions which have been made then can be revised and thus, the simulation can be validated with consideration of the real production process. This all leads to the final intention - the development of maintenance process in digital factory (Figure 9).

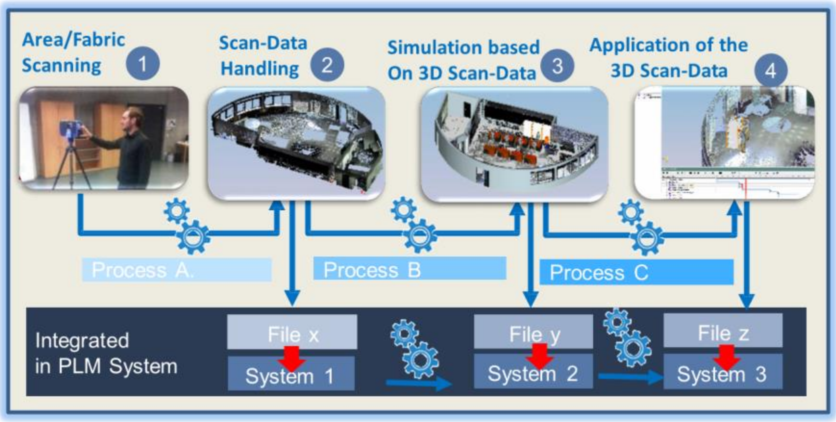


Figure 9. Organized and consistent scanning process with related PLM Backbone

Beside those procedural improvements, another field of the solution approach is regarding data related problems. At current state of technology, the version, editing and variant managements are not been carried out in a satisfying way. A sustainable and easy-to-maintain digital image of the fabrication facilities does necessitate a coupling of the laser scan data to an adapted PLM system to guarantee a long-term application with less effort for maintenance. As described in chapter two, the data today is being stored on hard drives or in a more advanced process onto cloud servers. So far this data is not interconnected to the related fabrication structure. Hence, an automated information exchange cannot be guaranteed and the scan data is not reliable in regard of valid and especially current state of information. This leads to redundancies with respect to validity, revision status and versions of the laser scan data and thus, there is no insurance which laser scan data currently is being used. Today, data of factory simulations are being stored and managed in PLM systems. With presented solution approach, this procedure is being extended to allow a coupling of 3D laser scan data and the PLM system such as SIEMENS Teamcenter as well. That way, automated processes can be generated within the PLM tool, which guarantees a consistency in the point cloud data handling as compared to CAx, ECAD and software data. By implementation of the data into a PLM system, gaps in the systems can be prevented. A holistic procedure is being enabled which also allows interdisciplinary cooperation with using point cloud data.

4 CONCLUSION AND DISCUSSION

In this paper, the focus has been directed towards the two aspects. First, the challenges and problems regarding the process, method and system during the application of point could in digital factory have been recognised. Second, taking the shortages and disadvantages of current processes in digital factory into account, the potential adaption and application of the systems engineering approach by implementing an adapted V-Model in digital factory process have been suggested and presented. By means of using the Systems Engineering approach, it was possible to do the 3D scanning process in a systematic way from requirement definition up to the scanning process itself. Furthermore, the factory planer is enabled to think about the possible 3D scans and the scanning process before scanning. This work shows that a pre-phase of preparing the scans is very important. In the future, the developed approach will be applied in an industrial company context for gaining more experience on how the method will be performed.

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