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Lean Based Problem Solving using 3D Laser Scanned Visualizations of Production Systems

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Abstract— ***3D laser scanning technology holds the capability to provide accurate and realistic visualizations of production systems. These visualizations can be used as decision-support in project teams when planning the redesign of production systems. To make such decision-support effective, a structured approach for how to use the realistic visualizations in team environments is required. The purpose of this paper is to propose a structured approach of how realistic visualizations can be used to solve problems that are identified while planning the redesign of a production system. The proposed approach derives from a theoretical framework on problem solving and three industrial studies applying realistic visualizations. The result is a description of how realistic visualizations can be used in the five steps of the problem solving approach LAMDA used in Lean product development. Such approach has the potential to support project teams in making the required decision by systematic solve problems pro-actively while planning the redesign of production systems.***

Index Terms— **3D laser scanning, Point cloud, Problem solving, Production systems.**

I. INTRODUCTION

The requisite to redesign production systems could derive from different causes, such as change in market demands, new product introduction, or new production technologies. To planning the redesign involves complex processes with numerous factors and scenarios to consider, e.g. material handling, production flows, and factory logistics [1], [2]. Such processes involve project teams with key experts and competences from different areas of the organization [3]. These experts are usually responsible for e.g. facilities, maintenance, machine acquisition, material handling, or process engineering. Their focus is on deciding where and how to install new equipment or on how to implement other changes to the production system. Early decisions in planning process are usually made based on spatial limitations and other existing pre-conditions in the facility, specific machine or process capacity needs, and logistic conditions or goals.

Virtual manufacturing tools can be used to support project teams to analyze, define, document, discuss, and communicate planned redesigns of production systems [4]. An example is layout planning, where virtual representations are used as decision-support by analyze and visualize different layout alternatives [5]. If these representations are difficult to understand it may lead to misunderstandings in the project teams, which can result in problems that only are noticeable when implementing the production systems [6], [7]. However, by creating virtual representations that visualize the production system in a realistic way and are easy to understand can reduce the number of misunderstandings by enable a common understanding in project teams [6], [8]. The term *realistic* is defined as representing things in a way that is accurate and true to life [9]. Using realistic visualizations will also make it possible to include e.g. shop floor personnel in the planning process [8]. A better understanding of the redesigned production system will make it possible to identify and solve possible problems using the realistic visualization. However, to make the identification and solving process efficient a structured approach is required. In this paper, a problem solving approach will be described that can be used in combination with realistic visualizations of production systems in project teams. The aim is to reduce cost and lead-time as well as improve performance in the planning process by identifying risks and solving problems pro-actively. This aim will be reached by addressing the following research questions:

1. How can realistic visualizations support project teams when planning redesigns of production systems?
2. How can a feasible problem solving approach be adopted to support decision-making using realistic visualizations in project teams?

The research questions are addressed based on a theoretical framework and three industrial studies. These studies have been carried out in projects that were planning the redesign of production systems producing large mechanical components for aerospace industry. The production systems are characterized by discrete process steps that are

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organized in a mix of functional and product flow workshops. This paper discusses how realistic visualizations of production systems can support the decision-making by detecting and solving problems pro-actively in project teams. The realistic visualizations are created using 3D laser scanning, which holds the capability of creating realistic visualization of production system in a few hours. The laser scan data in combination with 3D computed aided design (CAD) models and simulation technology are used to generate and analyze redesigned scenarios of the production systems.

II. THE METHOD USED TO ADDRESS THE PROBLEM SOLVING APPROACH

The problem solving approach addressed in this paper is a result of lessons learned from three industrial studies along with a theoretical framework, as shown in Fig. 1. *Industrial study A* and *B* were carried out in 2011 and 2012 with the aim to use 3D laser scan data to support project teams when planning the installation of new machines in the production systems. These studies has previously been published in [8] by the authors of this paper. The experiences and conclusions from the first two industrial studies were used when designing *Industrial study C*. The aim of *Industrial study C* was to further evaluate whether realistic visualizations created from 3D laser scan data could support different expert areas and phases of the redesigning process of production systems. This with the objective to go from a static visualization considering only the spatial data of the facility to the use of 3D scan data in a simulation model, as presented conceptually in [10]. *Industrial study C* was carried out in 2013 as a collaboration between the authors and the master thesis by Jansson and Roos [11]. In this paper, a summary of the study is presented focusing on how to create a realistic visualization followed by an evaluation of the perceived benefits and drawbacks with such visualizations. The lessons learned from this evaluation in combination with those from *Industrial study A* and *B* are the main contributions to proposing the use of a problem solving approach. As the theoretical framework, a literature study was carried out to find possible approaches to match the requirements.

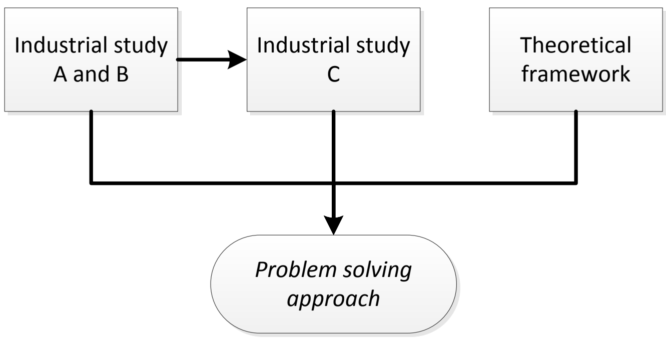

Fig. 1: Relation between the industrial studies, theoretical framework, and the problem solving approach

III. STATE OF THE ART

In the last decades, there have been several attempts to use virtual representations when redesigning production systems. Visualizing the virtual representations in a realistic way has shown to be important in such attempts [7]. The term *Virtual factory* is used to describe an approach of working virtually with planning factories, including digital visualizations of current or planned production systems [12]. Such visualizations are primarily used for decision-support, but examples can be found where they aspire to become the blueprint of the real factory [13]. The decisions are made with support from the analysis of conditions that are currently not present, e.g. for different market demand behaviors or with added or removed equipment. Hence, the virtual representations can be used as decision-support when predicting the future performance for a well-defined set of changes [12].

A. 3D laser scanning to capture and visualize factory spatial data

A number of production-engineering problems can be solved by access to accurate spatial data of production systems. For example, if adding equipment to production systems the production engineers needs to know the physical properties of the current system. These physical properties can be accessed either in real system environment or in virtual representations such as drawings of the system. Many times, such drawings are missing, out of date, or of too poor detail and accuracy to be used. A solution is 3D imaging, which is a field within measurement science that deals with the capture of spatial data. There are many different technologies for that

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purpose, see e.g. [14] or [15] for an overview. One such technology is 3D laser scanning, or LiDAR as it is often termed, which has been used in this research effort. This technology is currently used across a number of fields, e.g. heritage documentation, forensics, and tunnel mapping [14], [15].

3D laser scanners typically have close to 360 degrees field of view and are capable of sampling tens of millions of measurement data points in only a few minutes [16], [17]. The scanner operates by emitting laser light and recording its returned reflection to gauge the travelled distance [17]. Each recorded reflection represents a sample of the surface of the closest object along the measurement direction. By systematically recording reflections in all directions from the scanner, a comprehensive geometrical representation of the surrounding environment is generated [16]. Such a sampling sequence is referred to as a *scan* and its resulting data set, a *point cloud*. The point cloud can be complemented by an RGB imaging sensor to add color for enhancing the visualization of the data [16]. The size of the data set depends on the resolution settings in the scanner and may vary between a few thousand to hundreds of millions of individual measurement points. The resolution will also affect the duration of the data capturing. With the scanner used in this research, a typical setting for an indoor scan will result in 20-40 million measurement points in RGB color and duration of five to seven minutes. To capture a factory with its many interior objects such as machines and material facades it is necessary to scan from several positions. For reference, a 2500 square meter section of a factory resulted in close to 500 million measurement points. The corresponding file size is around 4 gigabytes and duration of data collection was about 4 hours in total for all positions. It should be noted that the size and level of detail is directly correlated to the intended purpose of the date capture. In the mentioned example, the purpose was to assess alternative layout options for the positioning of machining equipment, see [8] for further details.

The point clouds can be made sparser by filtering away a percentage of the points. This reduces data size and can be done to various degrees depending on the target application and processing performance. To be able to use the data for purposes beyond visualization of static backgrounds, manual intervention is necessary. Typical operations performed on production system point clouds are object based selection and teaming of subsets of points. This could e.g. be used to separate a machine body from the collected data and save it as a stand-alone point cloud file. Most applications designed to work with point clouds also have the capability of rendering or editing CAD models. There are ongoing efforts to standardize testing and assessment of both measurement equipment and data formats for storing and transferring the measurements [18].

There are a number of approaches available to visualize the 3D scan data. The two main approaches are either to visualize the scan data as a spherical 360 degrees image from each scan position or as 3D point clouds. Visualizing the scan data as spherical images could be compared with the popular street view function implemented in the online map system Google maps. By virtually assuming the actual scan position, it is possible to make measurements and study the environment in detail. The data could be provided in standalone desktop applications or as a web server application. Visualizing the data as 3D point clouds enables the possibility to move freely through the model and analyze the data in more detail. This solution also has the possibility to visualize changes in the model by modifying positions of objects or by adding new 3D CAD models.

B. Problem solving approaches

There are numerous approaches and techniques for problem solving in production system development [19]. Several of those are used for specific non-conformances or deviations from specifications or even functional errors or accidents. These can occur in e.g. pre-production or serial production phases and are solved by approaches using both data and facts. During design and development of products or production systems there is a need to solve technical issues and challenges to achieve the intended functions and, especially important, to foresee any future potential problems [20]. For this purpose various approaches for risk analysis is used as well as analytical methods and simulations [21], [22].

Lean production is a management philosophy originating from the Toyota Production System (TPS) [23]. Within the Lean philosophy an important aim is to 'make it simple and keep it visible', which is achieved through available principles and tools [24]. One such main principle in Lean production is Continuous improvements, which is supported by the four-step approach of the PDCA (Plan-Do-Check-Act) cycle [19]. The purpose with the approach is to learn-by-doing through iterating the cycle over time to continuously improve and solve problems within the

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production system. In Lean product development, PDCA is extended into the LAMDA (Look-Ask-Model-Discuss-Act) approach [25], [26]. This approach focuses on finding the root cause, analyzing it and then solving it to remedy the problem. This is close to how Toyota works with problem solving and can be described with the LAMDA cycle; see Fig. 2 [25]. The LAMDA cycle should be repeated until all problems are solved, which can be seen as a perpetual movement towards an improved system design [26]. The five steps of the cycle are described in more details below, according to Ward [26].

Look – go and see for yourself,
Ask – get to the root cause,
Model – using engineering analysis, simulation, or prototypes,
Discuss – with peer reviewers, mentors, and developers of interfacing subsystems, and
Act – test your understating experimentally.

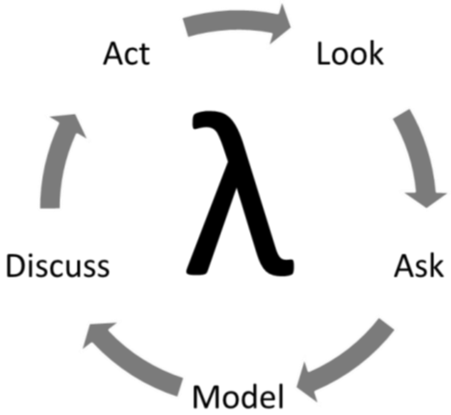

Fig. 2: The LAMDA cycle [26]

IV. CREATING AND EVALUATING THE REALISTIC VISUALIZATION

Industrial study C was carried out in the same workshop area as *Industrial study A*, where a robotic cell for automated x-ray inspection of products had been installed since the previous study. To reach the production volume goal, an identical cell was planned to be installed later the same year. The industrial aim was to evaluate where to locate the cell based on conditions such as available space, materials handling, and operator work environment. A simulation based realistic visualization of the workshop area was created as a tool to solve the problem. The process of creating and evaluating the realistic visualization is presented in this section. As presented in Fig. 3, the process is separated into two main phases and six sub-phases.

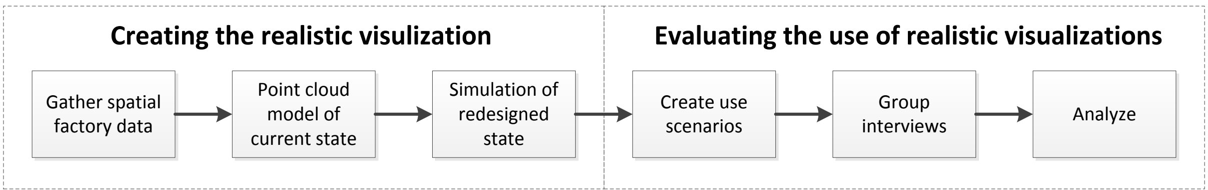

Fig. 3: Summary of the method used in Industrial study C

A. Creating the realistic visualization

The realistic visualization was created from using a 3D laser scanning of the existing production system. The resulting point cloud from the scanning was combined with the point cloud from *Industrial study A* and 3D CAD models of the robotic cell. In this section, the process of how the spatial factory data was captured with the 3D laser scanner is presented along with how that data was used to create the visualization.

1) Capturing spatial factory data

Spatial data of the factory environment was captured using a FARO Focus3D 120 phase shift laser scanner set to a resolution of 1/5, quality of 4x and speed of 122 000 points per second. Two types of scanning reference objects were used, 139 millimeters white spheres and 150 by 150 millimeters black and white checkerboards. During

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Industrial study A, fastener plates were mounted throughout the factory building to positioning the reference spheres. Three of these plates were re-used in this study to align the data with that of the previous study. Tripods and other fastening equipment were used as well to mount added reference objects. To acquire sufficient data points, the scanner was placed in 13 different positions. The average time between the start of each scan was 12 minutes including approximately 6-7 minutes for the actual scanning in each position. Total data capture time including planning and preparations was 4 hours. The scan data was processed in the vendor specific application, which semi-automatically identifies the reference objects and aligns the data from all 13 scans into one point cloud. The resulting point cloud consisted of approximately 325 million points, each point consists of x, y, z coordinates and RGB color codes. A rough estimation of the duration of the data processing is 4 hours, equal to the data capture duration as presented in Table 1. The data of this stage can be used to visualize the current state of the production system, as point cloud or as spherical pictures from each scan as described in section 3.1.

Table 1: Summary of the scan process

Factory area	**Number of scans**	**Time for data capturing**	**Time for data processing**	**Number of persons**
1500 m^2	13 scans	4 hours	Approx. 4 hours	4 persons

2) Modeling the realistic visualization

The redesigned state of the production system is presented in a point cloud based realistic visualization created in two steps. First, the point cloud was modified according to the existing layout proposal. The current robotic cell was duplicated and positioned at the proposed location, as presented in Fig. 4. The proposed location currently held office space, so an adjacent work area, with similar configuration was superimposed and used to represent the proposed location. The adjacent section was taken from the point cloud captured in *Industrial study A*.

Fig. 4: Point cloud of proposed layout, future layout outlined on the left hand side

Second, the point cloud of the layout proposal was used to create a simulation model of the redesigned state. The simulation model included products, operators, work tasks, material handling equipment, and process related parameters. The simulation application required 3D CAD models for representing moving objects such as material wagons, fixtures, and products. These models where created manually in 3D CAD format according to measurements from the point cloud. Predefined models of humans were used to represent the machine operators. The point cloud was used as to represent the building and static objects in and around the two robotic cells. The result is a realistic visualization created as a simulation model with point clouds and 3D CAD models, as presented in Fig. 5.

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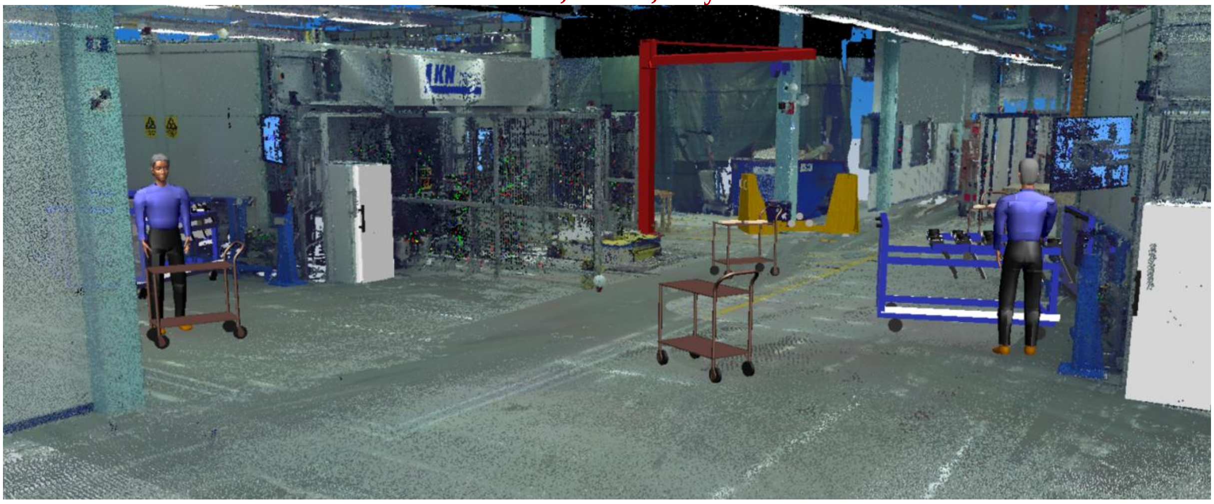

Fig. 5: Simulation model created from point clouds and 3D CAD models

B. Evaluating the use of realistic visualizations

The use of realistic visualizations was evaluated using two use scenarios representing possible alternatives for using the visualizations to solve industrial problems. These scenarios used the realistic visualization describe above in different context. The first scenario handled layout and workflow planning of new equipment in different phases of the planning process. In the earliest phase, a point cloud of the factory building was used in combination with simplified CAD model to approximately evaluate the location of the robotic cell. The complexity of the CAD model was subsequently increased to mimic the planning process ending in a simulated model of the production system. The second scenario was using the realistic visualization to evaluate how new equipment could be installed in an existing production system. This was demonstrated according to the process described in section 4.1.2. The two scenarios were discussed in four semi-structured group interviews. The interviewees were working either directly with the studied production system or in the project team responsible for planning and installing the system. At the interview sessions, the interviewers presented the two scenarios to the interviewees. During the ongoing presentation, possible benefits and drawbacks were discussed. This enabled collection of immediate reflections based on the use scenarios. The reflections have been sorted as problems with the current tool along with benefits and drawbacks with using realistic visualizations. These reflections are summarized in the following sections. For the complete evaluation, see [11].

1) Problems identified with current layout planning tool

The current used tool for layout planning at the company was described as using 2D CAD models for evaluating and visualizing different layout proposals. In these models, objects such as power cables, pillars, and machine equipment are not always at right position or even included at all. This causes potential problems during the implementation phase of the system build or change. Another problem described with these 2D CAD models is for everyone included in the planning process to understand them correctly. This results in difficulties to communicate and discuss layout proposals with other persons within the organization or with machine suppliers. The solution to this problem was usually manual measurements in the real production system to provide machine suppliers with necessary information. It was seen as a too time consuming process to update CAD models with correct and accurate information.

2) Perceived benefits from using 3D laser scan supported layout planning

The interviewees found that realistic visualizations would enable accurate layout planning when redesigning production systems. Realistic visualizations would make it possible to compare layout proposals against each other by thoroughly investigate each proposal before taking any decisions. The realistic visualization makes it faster to evaluate if equipment will fit in a specified area of the factory compared to using the current tools. Making this process faster will lower the risk of working to long with a layout proposal that cannot be realized. The realistic visualizations will also provide decision-makers with easy-to-understand presentations, enabling decisions based on correct information. It will also support different functions in project teams to align their understanding of how a layout proposal actually works, looks, and interacts with other parts of the factory. This will make it easier to

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involve and educate operators and production technicians in the early phase of the planning. Besides these persons, it will be less time-consuming to include e.g. workers' union representatives and safety protection agents in discussions regarding work place design in the same phase of the planning process.

3) Perceived drawbacks from using 3D scan supported layout planning

The interviewees stated that working with realistic visualizations might increase the risk of spending too much time on creating the visualization, which can create a risk of losing the potential time gain of the visualization. For example it might be time-consuming to simulation the workflow for each project and not always necessary. The implementation of using realistic visualization was also deemed critical by the interviewees, due to the risk of it not being used. To get a good interest and acceptance in the organization, it is important to explain the benefits and make sure that the right people get to work with it. The interviewees foresee that it could be difficult to determine who should be the owner of the data and who should be authorized to edit the different models. It was also perceived that the 3D scan data has a slightly limited area of application compared with CAD models. This perception is related to the fact that the selection of software suites that handle point cloud data is still rather limited.

V. THE PROBLEM SOLVING APPROACH

The result from *Industrial study C* indicates that realistic visualizations created from 3D laser scan data have the potential to support the planning when redesigning production systems, which verifies the lessons learned from *Industrial study A* and *B*. These studies showed that realistic visualizations would make it possible to increase the common understanding of the redesigned state of production systems in project teams. This common understating is critical when identifying and solving possible planning problems of the redesigned state of production systems. In the industrial studies, the problem identification and solving were made using the realistic visualizations without any well-defined approach. To make the process more effective the LAMDA problem solving approach can be applied. By using this approach, it is possible to solve problems by evaluating the realistic visualizations in project teams and improve visualization of the redesigned state. The five steps of the approach are applied within the context of the industrial studies by reflecting on lessons learned in these studies, as presented in Table 2.

Table 2: A description of how the realistic visualization can be utilized in the steps of the LAMDA cycle

Step	Description of use in industrial settings
Look	The realistic visualization enables everyone in the project team to get a common understanding of the redesigned production system.
Ask	Using the realistic visualization will make it possible to make a qualified assessment of the situation, ask relevant questions, and identify problems or risks.
Model	Changes are made to the model based on identified problems or risks. These changes could be moving machines or other equipment by modifying the point cloud or adding CAD models.
Discuss	The updated model is used as basis for discussion to define and analyze the solutions and arrive at alternatives to improve.
Act	The defined solution is implemented in the final model, which is visualized in the project team to verify the effectiveness. The process is then repeated until no future problems or risks are identified.

VI. DISCUSSION

The industrial studies have uncovered an interest to use realistic visualizations to plan the redesign of production systems. In these studies, realistic visualizations where used for evaluating the required space for machines and material handling processes. The evaluation process of *Industrial study C* indicated that to implement realistic visualizations in the daily work, an approach of how to work with the visualizations is required. The LAMDA problem solving approach could be one such way of working with realistic visualizations. Other approaches may also be adapted to the visualizations and has the possibility to be useful for different applications. As described in the evaluation process, the acceptance of the application by the personnel is critical. It is important that everyone involved is aware of the benefits and possibilities, otherwise it may not be used to the right extent. To increase the acceptance, the realistic visualizations should be adapted to project teams making it possible to include decision-makers in the process. This may be an important step for reaching overall acceptance and garner support for upcoming changes to the production system.

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The use of 3D laser scanning technology is relatively new and undeveloped within the area of production systems. Creating realistic visualizations of the factory environment with such technology has shown to be a time effective process. For example, in *Industrial study C* where less than a working day was spent in the factory capturing the scan data and about the same amount of time was used to process the data. In this phase, the data is a very accurate and realistic visualization of the current state. This could be compared to making manual measurements to create 3D CAD models of the same factory environment, which would have required decidedly larger amounts of time. The accuracy and level of detail in 3D CAD models created in such manner could also be questioned.

The realistic visualization presented here can provide decision-support also in other redesign activities besides layout planning. It could be used in the daily work tasks on changing and maintaining production systems. Having a realistic and accurate virtual representation of the existing system could be an important support in the daily work and save valuable time. One example is production engineering meetings, where the participants are not agreeing about the actual situation in the factory. With this support, it is possible to study the current system using the visualization without leaving the room. The main goal should be to support the planning process with up-to-date information, to reduce the number of problems and misunderstandings and reduce the overall planning time and cost.

A. Reflection upon the research questions

This section returns to the research questions posed in the introduction of this paper and attempts to address them in the light of the work that has been presented.

How can realistic visualizations support project teams when planning production systems?

- Realistic visualizations can be used early on in decision-making process to gather input from future users of the systems.
- It is possible to use realistic visualizations to answer questions raised regarding both the current and the redesigned production systems.
- Realistic visualizations are more inclusive in terms of who can understand them, thus enabling a wider cross-organizational expertise in the decision-making process.
- Using realistic visualizations enables quick evaluation of alternative solutions.

How can a feasible problem solving approach be adopted to support decision-making using realistic visualizations in project teams?

- Employing the LAMDA approach as described in section 5 seems to be a promising approach to be used for systematic problem solving when redesigning production systems.
- The problem solving approach could continuously be used during different phases of the redesign process to ensure that all problems are eliminated and that the right decisions are made.

VII. CONCLUSIONS

The three industrial studies have shown that 3D laser scanning is effective for capturing spatial data of production systems. The resulting data can be used for generating point clouds with sub-centimeter accuracy, which can be modified to create realistic visualizations of redesigned of production systems. By supporting project teams with such realistic visualizations will enable an increased common understanding about redesigned production systems. With a common understanding, it is possible to use the realistic visualizations as support for problem solving and decision-making. This support requires a structured approach, such as the LAMDA problem solving approach applied in this paper. Applying such an approach, while redesigning production systems, has the potential to improve the teamwork quality by working pro-actively with identifying possible risks and problems. This will provide better decision-support, resulting in production systems with higher performance.

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