Integration of Augmented Reality Technologies in Process Modeling
The Augmentation of Real World Scenarios with the KMDL

Marcus Grum and Norbert Gronau
Department of Business Informatics, esp. Processes and Systems, University of Potsdam, August-Bebel-Strasse 89, 14482 Potsdam, Germany
mgrum@lswi.de, ngronau@lswi.de

Keywords: Augmented Reality, Process Modeling, Knowledge Modeling Description Language, KMDL, Tacit Knowledge Transfer Visualization, Cyber-Physical Market Visualization, Process Simulation Visualization, Simulation Process Building, Industry 4.0, CPS, CPPS, Internet of Things

Abstract: The integration of powerful technologies in traditional domains realizes promising potentials but mostly rises complexity and shrinks comprehensibility of underlying processes. With the aim to rise comprehensibility of non-transparent processes, a process modeling language has been transfered in 3-D and prepared to augment the real world. Definitions for a methodological proceeding have been created and were mapped to a software tool. Three scenarios then have been realized as demonstration and proof the working of drawn AR integrations. Focusing non-transparent processes, scenarios visualize tacit knowledge transfers (1), complex coordination mechanisms (2) and process simulations (3) in the domain of cyber-physical production systems.

1 INTRODUCTION

Once, new technologies are integrated in existing processes, new potentials can be established. As one takes the integration of Internet of Things technologies in traditional production systems, there can be realized customized productions and flexible, fast changing production processes based on further feedback loops between cyber-physical systems (Gronau et al., 2016a). With this, new coordination efforts among them require much more complex processes, with time-dependent system states and numerous data transfers. Since, all of them are hard to comprehend for non-experts and the current processing is hard to categorize correctly, those further are referred to as non-transparent processes. Although not limited to the domain of cyber-physical production systems, this domain is very suitable for the selection of non-transparent processes.

Since 2-D modeling approaches can be extended easily with a third dimension, new AR technologies bring in potential to increase the comprehensibility of those non-transparent processes in using available dimensions and located existing 2-D models within the real world. Hence, the following research question will be focused within this paper: "How can non-transparent processes be visualized with help of AR technologies?" This includes the process of modeling. Because of the interplay of the real world, augmented world and the more or less paper based 2-D world of common process models, lots of potentials can be realized during all process modeling phases. This paper intends not to collect an all-embracing collection of potentials rather than drawing a first way of structuring. Although several options can be realized to use three dimensions of the AR technology, the following focuses only on a spacial placement.

The research approach is intended to be design-oriented as Peffers proposes (Peffers et al., 2006) and (Peffers et al., 2007), such that the paper is structured as follows: A second section presents underlying concepts, the third sections derives objectives for an integration of augmented reality in process modeling. The fourth section provides the design, followed by its demonstration and evaluation. A final section concludes the paper.

2 UNDERLYING CONCEPTS

Starting with the selection of a modeling approach in the first subsection, the application center for industry 4.0 is identified as a promising environment for non-transparent processes since participating systems provide separate knowledge bases. Further, approaches such as the cyber-physical market require numerous non-transparent coordination efforts and provide a fruitful environment for process simulations and coordination approach benchmarks. In a last subsection, available AR technologies are discussed.

2.1 Process Modeling Areas

Since non-transparent processes shall be focused on the base of separate knowledge bases and complex conversations within Internet of Things similar structures, the following concentrates on knowledge modeling methods.

An overview of existing modeling methods and a comparison of their ability to represent knowledge can be found by (Remus, 2002, p. 216f.). Here, ARIS, INCOME, PROMOTE, WORKWARE, EULE2 and FORWISS are only some representatives. Hereunder, (Gronau and Maasdorp, 2016,) identify the Knowledge Modeling Description Language (short: KMDL) as only representative to overcome lacks in visualizations and analyses through the combination of several views (process view, activity view and communication view). Focusing on the even broader context of organizational, behavior-oriented, informational and knowledge-oriented perspectives, (Sultanow et al., 2012,) identify the KMDL to be inferior in the comparison of twelve common modeling approaches as well.

Being developed iteratively and being applied in numerous projects, the KMDL has been developed and optimized over more then ten years. An evolution of the KMDL can be found in (Gronau, 2012) and currently, the development of the version 3.0 is in progress (Gronau et al., 2016b). The KMDL has proven its benefits in numerous application areas such as software engineering, product development, quality assurance and investment good sales. It provides a fully developed research method which can be found in Figure 1 and is described by (Gronau, 2009, p. 386) in detail.

With its strengths in visualization, the KMDL seems attractive for augmenting the reality. To the best of our knowledge, so far an augmentation of the real world with spacial correct positioned process models has not been realized yet. A prototype of an AR collaborative process modeling tool augments the real world with BPMN process models, which are augmented only w.r.t. inner model relations (Poppe et al., 2011). Eichhorn et al. presented geometric 3-D Figure models in a virtual space and created statistical insights from those (Eichhorn et al., 2009).

Hence, the current paper builds on the wide spread KMDL version 2.2 (Gronau and Maasdorp, 2016,).

With its intention to focus on the generation of knowledge following (Nonaka and Takeuchi, 1995), the KMDL enables the modeling of tacit knowledge bases, single or numerous knowledge transfers, the socializing of several conversion partners in complex control flows and their time-dependent development. Since all can be identified as non-transparent processes, the KMDL seems attractive for the scenario design in section 4.3.

2.2 Application Center for Industry 4.0

Since the physical meaning of classical production components can be enhanced by a virtual representation, these can be considered as cyber-physical systems (short: CPS), providing more or less distinctive characteristics in abilities to perceive its environment via sensors, to interact with its environment via actuators, process data via processors and communicate via communicators (Gronau et al., 2016a). Equipped with memory, each CPS can build individual knowledge bases and can hold time-dependent states.

A cyber-physical production system (short: CPPS) integrates several CPS with the purpose to realize productions. For this, huge communication efforts are necessary and complex coordination mechanisms are required. As one of many, a cyber-physical market can realize this coordination analogous to real market mechanisms (Grum et al., 2016) such as each CPS is considered as market participant and has to negotiate with its environment before tasks are realized.

The Application Center for Industry 4.0 (short: ACI4.0) is build as CPPS, containing several types of CPS. *Machines* are surrounded by computer displays and can visualize different kind of production steps. *Conveyors* connect machines and transport workpieces. A *workpiece* is a small box surrounded by displays such that its current production state can be visualized. Next to the conveyors, *robots* or *humans* are placed, that are part of the production process. All of them are considered to be a CPS providing more or less distinctive characteristics within a cyber-physical market. Hence, the ACI4.0 is a fruitful environment for tacit knowledge transfers, process simulations and coordination efforts, which are all non-transparent processes. In section 4.3, the scenario design will therefore be based on the ACI4.0.

2.3 Available AR Technologies

As augmented reality (short: AR), the paper follows the definition of (Azuma, 1997), who identifies AR as a variation of virtual environments, which allows users to perceive the real world, superimposed and

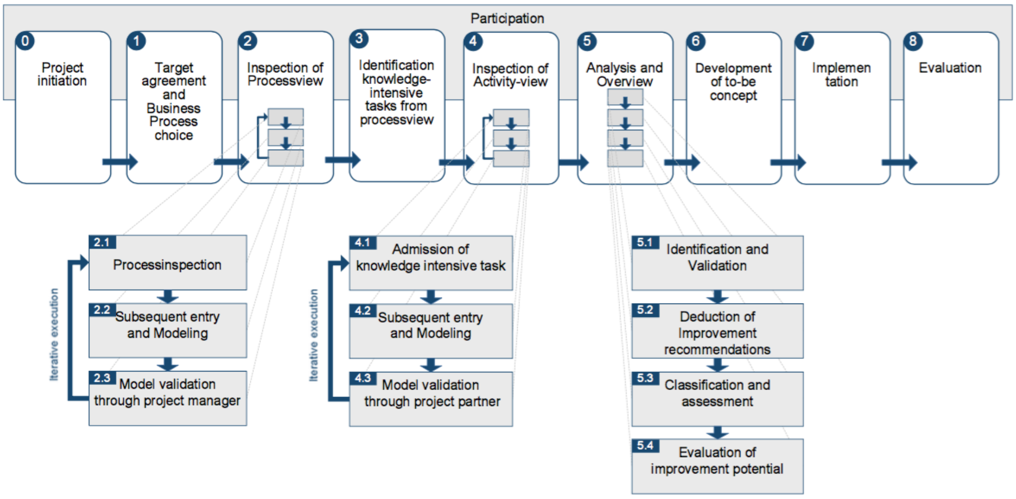

Figure 1: KMDL procedural model.

composited virtual objects such that users have impression those worlds would coexist. Therefore, AR systems have the following characteristics:

- a real world and a virtual world is combined;
- an interaction with both worlds is possible in real time;
- objects are registered in 3-D.

Following (Schart and Tschanz, 2015), the visualization can be realized with help of screen displays, mobile devices (handhelds), head-up displays, head-mounted displays and contact lenses. Here, head-mounted displays (HMD) were focused because of the intention to quickly hand over the visualization technique from person to person and do not limit their interaction via hands during the production process.

HDM gadgets are available as optical see-through HMD and closed-view HMD. While the first variant lets the user see the real world directly, the second variant does not allow any direct contact with the real world. Each brings individual advantages and (Jannick et al., 1994) discusses tradeoffs. The following focused optical see-through HMD with the intention to choose the most realistic system. Here, *Google Glass*, the Epson *Moverio BT-200* and the Microsoft *HoloLens* were compared with respect to the following criteria: price, processor performance, battery runtime, RAM, field of vision size, display solution, usability and availability. Here, the AR glasses from Epson were selected since other products did not provide a handheld control unit.

The Epson *Moverio BT-200* is available for about EUR 700 and provides two miniature projectors which are placed on each glasses side piece. The projection surface is positioned within the field of view and transparent, such that it is possible to perceive both, the real world and projected world directly. Being equipped with a dual core processor (1300Mhz) and one gigabyte RAM, the AR component is sufficient for first augmentation purposes. A GPS module beside software computer vision components can be used for the placement of the AR glasses within space.

3 OBJECTIVES OF AN AUGMENTED REALITY INTEGRATION IN PROCESS MODELING

Since a modeling language shall augment the real world, objectives of three domains have been identified: The modeling language itself, the context for the modeling language as well as the augmentation technique.

Aiming to prepare the KMDL for the purpose to augment the real world, the following set of requirements has to be considered:

- the augmentation has to build up on an existing version of the KMDL;
- existing shapes have to be mapped to 3-D;
- the augmentation has to be included within the methodological approach of the KMDL;
- the augmentation of the KMDL has to go along with the extension of the corresponding modeling software, which is *Modelangelo*[1];

[1]http://www.kmdl.de/en/node/46

- time-dependent visualizations have to be considered, since process models can change on an abstract level and the content of modeled items can change as well on a concrete level;
- fast time-dependent visualizations have to be slowed down so that the human perception is able to deal with.

With respect to the scenario creation, the following objectives have been identified:

- a real world tacit knowledge transfer has to be visualized;
- the communication of heavily complex processes has to be visualized;
- the simulation of processes has to be visualized;
- all three, the *activity view*, *process view* and *communication view* shall be visualizable;
- process modeling phases shall be supported.

Focusing on the hardware selection, the following criteria were relevant additionally to AR technique inherent requirements such as the positioning within an area, performance issues, etc.:

- AR glasses shall be used within closed rooms;
- AR glasses shall be used within the outdoor area;
- AR glasses shall cost less than Euro 1.000;
- AR glasses shall bring programming libraries for free and ideally open source;
- AR glasses shall realize free movements;
- AR glasses shall consider real physics so that obstacles cover shapes in the background;
- AR techniques shall be used on base of common cameras, so that persons who currently do not wear AR glasses can see the augmented world on a projector;
- AR glasses shall realize interactions with the augmented world.

Each identified objective of those three domains has been relevant for the augmentation of non-transparent processes and serves as input for the following sections.

4 DESIGN OF AN AUGMENTED REALITY INTEGRATION IN PROCESS MODELING

The design of AR integration in process modeling is presented with help of four subsections. For the first, the KMDL is augmented, then the method is expanded. Afterwards, three scenarios are built and finally, software tooling issues are designed.

4.1 Augmenting the KMDL

On base of existing shapes of the KMDL as it was selected in section 2.1, items were mapped to three dimensions, which were required by the scenarios and can be seen in the modelings of subsection 4.3. Those items were constructed with Autodesk *Fusion360* and can be found in Figure 2.

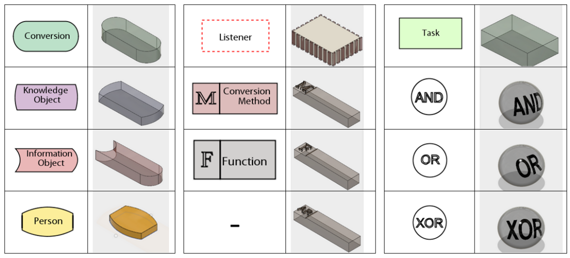

Figure 2: Mapping of existing KMDL shapes to three dimensions.

Here, mostly simple extrusions and colored glass materials were used because of their transparent characteristics in the augmentation.

Since those shapes shall be located within the real world, the following new attributes have to be brought in the KMDL:

A set of *origin coordinates in x-, y- and z-axis* define the global point of origin within space. A set of *coordinates in x-, y- and z-axis* with respect to a point of origin locates the center of any body within space. Initially, the global point of origin is selected but those coordinates can consider the position of other bodies as a relative point of origin as well, such that easy spacial movements are possible. A set of *size in x-, y- and z-axis* manages the spacial requirements and is ideally automatically adjusted in relation to other bodies' sizes. A set of *rotation in x-, y- and z-axis* can assure the optimal angle with respect to a person wearing AR glasses, such that bodies and texts can be identified easily. Since each item can hold a 3-D model, a *filepath* to this model and a checkbox for the standard *KMDL shape visualization* and a checkbox for the *3-D model visualization* shall switch them on or off.

For the modeling, only a single shape has been introduced, which looks similar to the shape of the *conversion method* but holds an "AR" on it. This shape indicates a proper prepared AR perspective and saves previously mentioned 3-D information. Since the same knowledge conversion can be visualized in different views, the modeling can hold several of them.

All together, those extensions are the basis for the augmentation of the real world with process modeling languages.

4.2 Expansion of the Methodological Appraoch

Faced with a well described procedural model of the KMDL as can be seen in Figure 1, the following describes the integration of AR technology. For this, the numbers within the Figure serve as orientation.

Phases from the *project initiation* (phase 0) until phase 2.1 can be realized as usual.

The modeling (phase 2.2) can be enriched by 3-D information as was required in section 4.1, can be simplified with help of a *ground plan* and *sketch plan* as is described in section 4.4, and is visualized as can be seen in Figures 10 and 11.

The *model validation* (phase 2.3) can be enriched with the spacial observation within those plans as well as with a look on the augmented reality as it is described in subsection 5.3.

Phases from the *identification of knowledge intensive tasks* (phase 3) until phase 4.1 can be realized as usual.

Analogous to modeling and validation steps before, 3-D information can enrich the activity modeling with help of a *ground plan* and *sketch plan* as is described in section 4.4, and is visualized as can be seen in Figures 6 and 7 as well as in Figures 8 and 9.

The *model validation* (phase 4.3) can be enriched with the spacial observation within those plans as well as with a look on the augmented reality as it is described in subsection 5.1 and 5.2.

The work of analysts can be enriched by the impression of the collection of created plans and real world augmentations (phase 5).

Phases 6-8 can be enriched in AR visualizations of a static to-be concept and non-static simulation visualizations as they can be seen in all three scenarios. Hence, is- and planned-to-be comparisons can be realized, the working of an implementation can be tested. Further, comparisons of planned-to-be and realized-to-be can be realized.

All together, those methodological expansions serve as guideline and show how to integrate AR technology in the process modeling. The following was realized considering those extensions and demonstrates its working.

4.3 Integration of AR Technology

The integration of AR technology in process modeling shall be visualized with help of three scenarios. All can be located within the ACI4.0, which was described in section 2.2.

A laser manipulation scenario shall visualize the tacit knowledge transfer in complex, multi-interaction partner settings. As can be seen in Figure 3, a situation has been designed within the CPM, wherein a robot manipulates a workpiece with a laser cutter. The workpiece stands on top of a conveyor and is observed by a human worker. The worker's task is to control the production progress and interfere when necessary. For this, basic knowledge in laser manipulation and the experience gained from former production is considered as tacit knowledge.

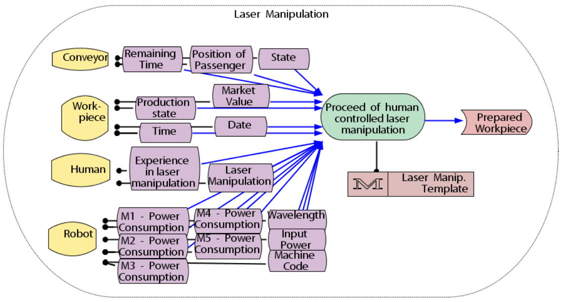

Figure 3: Current activity view of the laser manipulation task (laser manipulation scenario).

A negotiation scenario shall visualize the complex interplay of numerous CPS during a negotiation within the CPM following (Grum et al., 2016). Here, four CPS socialize and update themselves with price value, amount and duration information.

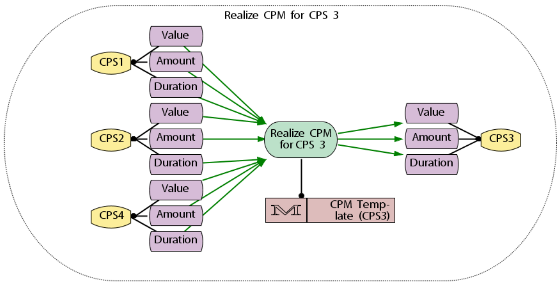

Figure 4: Current activity view of the negotiation task from CPS3 (negotiation scenario).

A process variation scenario shall focus process variations during process simulations within CPPS. As becomes clear in Figure 5, a selected workpiece can be produced following alternative process options. Either, a closely situated robot is used for human controlled laser manipulation (see scenario 1), or robots are used that are located in greater distances so that the workpiece requires further transport steps to reach the robot. Place holder tasks showing "..." visualize the idea that neither the entire production process of the workpiece nor all process options are visualized in this Figure.

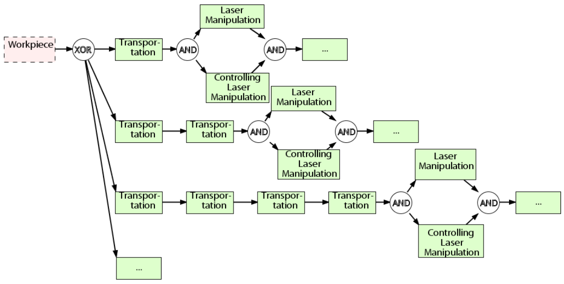

Figure 5: Simplified current process model of a workpiece within a CPPS simulation (process variation scenario).

Since more than one workpiece is produced within CPPS simultaneously, this Figure only shows a very limited insight in the current process simulation model.

All together, those three scenarios serve as fruitful context to integrate AR technology with the purpose to visualize non-transparent processes.

4.4 Extending the Modelangelo Modeling Tool

With help of a modeling tool called *Modelangelo*, the following software design supports the integration of AR in process modeling, as it was designed in section 4.2.

In section 4.1 identified attributes are introduced in the properties space of *Modelangelo*.

Beside the normal modeling environment, two further modeling surfaces are introduced, that simplify the model enrichment with required 3-D information. Those take existing model information and transfer them in a *sketch plan* and a *ground plan*. Here, the modeling is not realized w.r.t. the reading direction from left to right (see Figure 3-5), but locates existing shapes within space per drag and drop. Figure 6 and Figure 7 visualize this difference w.r.t. the laser manipulation scenario. Before the positioning of items within space, white rectangles have been used to model realistic dimensions and distances easily. Then, items were placed and resized.

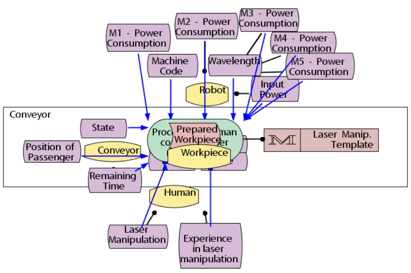

Figure 6: Ground plan of the laser manipulation scenario.

Having a detailed look on Figure 7, shape overlaps can be identified because of the spatial arrangement.

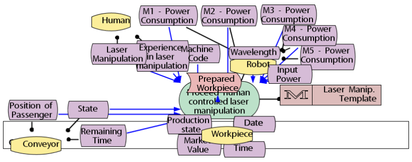

Figure 7: Sketch plan of the laser manipulation scenario.

The creation of the ground plan and sketch plan of the negotiation scenario was realized similarly to the positioning of the laser manipulation scenario and can be found in Figure 8 and Figure 9.

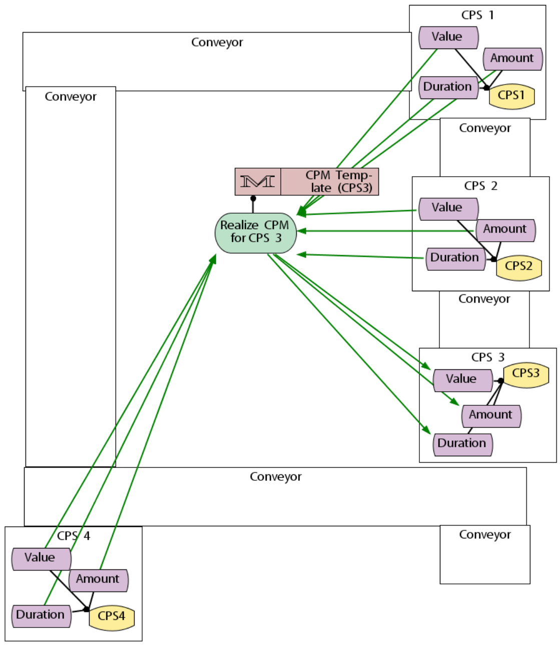

Figure 8: Ground plan of the negotiation scenario.

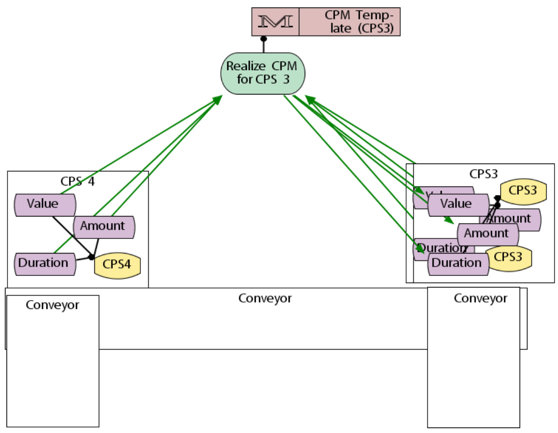

Figure 9: Sketch plan of the negotiation scenario.

Further, a *KMDL Augmentor* is introduced, that translates existing KMDL models to the selected AR glasses (Epson *Moverio BT-200*), such that models can be visualized easily. For this, the *Vuforia* framework has been chosen. KMDL models that lay on the department servers serve as interface and can be augmented easily.

Further, the *KMDL Augmentor* can be connected via interfaces, such that models can visualize time dynamics. Then, real world sensory data e.g. coming from the ACI4.0 or connected simulation frameworks can be displayed. Since tasks can hold repetitive machine components, three-dimensional visualizations can be attached directly to modeling items and optionally displayed by activating the *3-D model visualization*. Hence, quickly huge production settings can be build. Figure 10 and Figure 11 visualize this by indicating task elements displaying its three-dimensional components in blue.

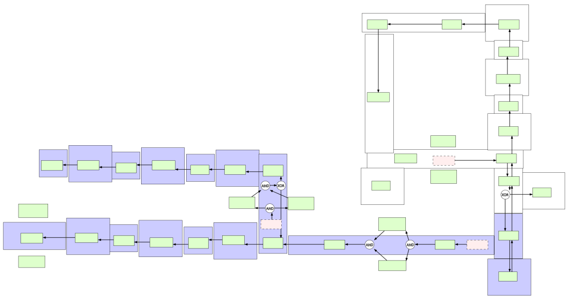

Figure 10: Current ground plan of the process variation scenario.

Similar to Figure 7 and 9, task overlaps can be found in Figure 11 because of the spatial arrangement.

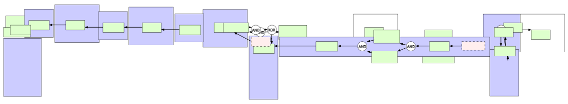

Figure 11: Current sketch plan of the process variation scenario.

A zoomed version of those Figures considering correct denominations can be found in the appendix.

All together, those software extensions help to locate model items easily per drag and drop in real spacial dimensions, transfer existing 2-D process models on AR glasses and help to connect further simulation frameworks.

5 DEMONSTRATION

The following subsections show the realization of selected scenarios with help of the *Vuforia* Developer Libary and the *Moverio BT-200*. Full videos are available at following links and complete the here presented screenshots. Videos have been cut with *PowerDirector* of CyberLink.

5.1 Scenario 1

The positioning of knowledge modeling entities, such as the KMDL proposes, can be seen in Figure 12. As the robot manipulates the workpiece, the conveyor holds the workpiece and pauses the movement of its rolls. Observed by a human worker currently wearing the AR glasses, the worker's experience is considered in the externalization as well. So, a controlled laser manipulation can be realized.

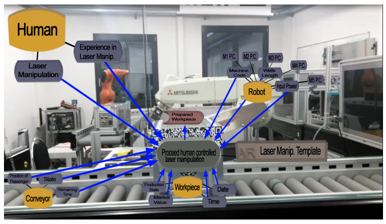

Figure 12: A potential look through AR glasses on the augmented KMDL modeling (using Epson Moverio BT-200).

The prepared "AR Manipulation Template" can be seen in Figure 13. As the human worker observes transparently arranged knowledge objects, a more detailed view can be realized because of a manual activation of a virtual button by a cyber-physical contact with the worker's real hand. This is the way, a well-grounded decision to interrupt the observed laser manipulation can be found. Since this decision has to be realized continuously, relevant knowledge modeling entities update in the video, of course.

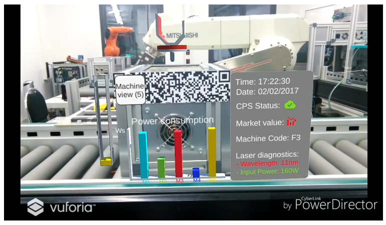

Figure 13: A look through AR glasses on the AR laser manipulation template (using Epson Moverio BT-200).

The corresponding video is available at https://mediaup.uni-potsdam.de/Play/7230.

5.2 Scenario 2

The positioning of knowledge modeling entities of the negotiation scenario, can be seen in Figure 14. Since available CPS are communicating via the CPM and are exchanging value, amount and duration information, green arrows indicate a socialization.

As relevant knowledge modeling entities are not required within the "AR CPM Template of CPS3", Figure 15 visualizes the conversion on a minimal base. The CPM is visualized by the red planet. Since

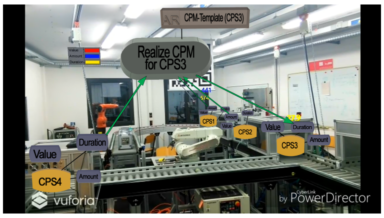

Figure 14: A potential look through AR glasses on the augmented KMDL modeling (using Epson Moverio BT-200).

the communication direction changes over time, the video shows bidirectional and changing communication partners, of course.

The corresponding video is available at https://mediaup.uni-potsdam.de/Play/7231.

Figure 15: A look through AR glasses on the AR CPM template of CPS3 (using Epson Moverio BT-200).

5.3 Scenario 3

Figure 16 shows the positioning of knowledge modeling entities of the process variation scenario. Here, a process view is realized considering tasks, logical operators and current control flows. Since not only real world elements can be augmented, here, the focus lays on the virtual extension of the physically available production setting within the ACI4.0.

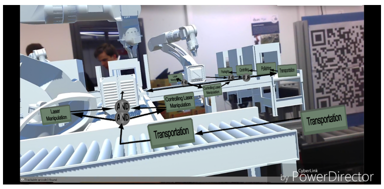

Figure 16: A potential look through AR glasses on the current KMDL simulation setting (using a common camera).

The simulation can be nicely regarded as knowledge modeling entities are not visualized (Figure 17). Hence, the video shows the simulated production of numerous workpieces on the left next to real, physical productions on the right.

The corresponding video is available at https://mediaup.uni-potsdam.de/Play/7232.

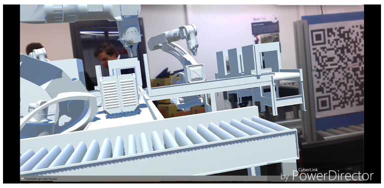

Figure 17: A look through AR glasses on the current simulation setting (using a common camera).

6 EVALUATION

Considering the presented demonstration, the objectives identified in section 3 could be met with respect to three objective groups.

Objectives of the KMDL augmentation have been met as follows: Time-dependent visualizations have been considered in all three scenarios. Since a trigger such as an information exchange started a visualization, the speed of that visualizations was adjusted on base of the human perception. Since the concrete content of the scenarios (scenario 1 and 2) and the abstract process models (scenario 3) changed, all time-dependent objectives were met. Building up on the model items of KMDL (version 2.2) and extending its shapes with a third dimension, the first two objectives were considered as well. The extension of *Modelangelo* has been met with the integration of the ground and sketch plan, the identified set of properties as well as the integration with the selected AR framework.

Objectives of the scenario selection have been met as follows: An activity view has been realized in the laser manipulation scenario, a communication view has been realized in the negotiation scenario. A process view has been realized in scenario three. Hence, all objectives have been met.

Objectives of the hardware selection have been met as follows: All three scenarios have been realized within a closed room with help of the computer vision technique of the *Vuforia* framework. For this, three QR codes have been placed within the production setting, so that each scenario has been identified easily. The objective to move freely was met but has to be limited: The identification was only possible when the QR code was detected by the camera system. Hence, the degree of freedom was limited and dependent on the size, position and viewing angle of the QR code relative to the AR glasses. Hence, the design of each scenario was optimized w.r.t. the position of the intended QR code relation. Although an outdoor arena has not been part of any scenario, one can proceed on the assumption that all three scenarios would have worked there with the aid of the QR code as well. Further, a GPS signal could have been used additionally so that greater movements were possible. With about Euro 700, the price objective was met by the selection of the Epson *Moverio BT-200*. The performance was acceptable although the hardware was not powerful enough to carry all three scenarios within one common application. Each scenario has had to be realized as separate application. Since the room was not scanned and 3-D modeled by the AR system, augmentations did not consider physical obstacles so that the objective to consider real world physics has to be limited. Augmented parts, which should not be visible because of real world elements, were visualized although. Hence, the design of each scenario was optimized w.r.t. the position of the intended QR code. Interactions with the augmented world were possible on behalf of the camera system of the AR glasses. The results of a look through a common camera (scenario 3) were very good so that further parties will be able to enjoy a persons perspective on a display.

7 CONCLUSIONS

In this paper, an integration of AR technologies in process modeling has been drawn and realized on behalf of the KMDL. Main contributions and scientific novelties are the following: A modeling language has been prepared for augmenting the real world. This includes the building of three-dimensional shapes of the KMDL, the identification of required shape properties and the definition of AR required modeling techniques such as the ground and sketch plan. An expansion of an methodological approach for augmentations has been drawn. On that base, three non-transparent process scenarios have been designed on behalf of the KMDL and brought to a time dynamic realization. With this, the drawn integration could have been applied and proven. Hence, the research question was answered and the following potentials are suitable next steps:

The realization of an outdoor scenario was attractive in order to get insights about the precision of augmentations. Further, the comparison of AR glasses of the same price level was attractive as well as the comparison with more powerful AR glasses. Still promising is the deepening of the AR integration in process modeling phases such as the bidirectional interplay of modeling within the augmented world and the two dimensional process model world. For example a process model could be created while standing on a real world position and dropping model items. Further, process optimizations could be realized within the augmented world in grabbing and moving certain process steps. Here, a systematic research considering all modeling phases as shown in Figure 1 was attractive. In presented approaches, given three dimensions were interpreted as spacial dimensions but the use of further meanings can rise comprehensibility as well. Considering further dimensions in created scenarios, those can be tested quantitatively through surveys that shall identify a rise in comprehension.

REFERENCES

Azuma, R. T. (1997). A survey of augmented reality. *Teleoperators and Virtual Environments*, 4(6):1–48.

Eichhorn, D., Koschmider, A., Li, Y., Strzel, P., Oberweis, A., and Trunko, R. (2009). 3d support for business process simulation. *Computer Software and Applications Conference COMPSAC09. 33rd Annual IEEE International*, 1.

Gronau, N. (2009). *Process Oriented Management of Knowledge: Methods and Tools for the Employment of Knowledge as a Competitive Factor in Organizations (Wissen prozessorientiert managen: Methode und Werkzeuge für die Nutzung des Wettbewerbsfaktors Wissen in Unternehmen)*. Oldenbourg Verlag München.

Gronau, N. (2012). *Modeling and Analyzing knowledge intensive business processes with KMDL - Comprehensive insights into theory and practice*. GITO mbH Verlag Berlin.

Gronau, N., Grum, M., and Bender, B. (2016a). Determining the optimal level of autonomy in cyber-physical production systems. *Proceedings of the 14th International Conference on Industrial Informatics (INDIN)*.

Gronau, N. and Maasdorp, C. (2016). *Modeling of organizational knowledge and information : analyzing knowledge-intensive business processes with KMDL*. GITO mbH Verlag Berlin.

Gronau, N., Thiem, C., Ullrich, A., Vladova, G., and Weber, E. (2016b). Ein Vorschlag zur Modellierung von Wissen in wissensintensiven Geschäftsprozessen. Technical report, University of Potsdam, Department of Business Informatics, esp. Processes and Systems.

Grum, M., Dehnert, M., Vollmer, F., and Zhao, M. (2016). The conception of a cyber-physical market model as coordination instrument for production systems. Technical report, University of Potsdam, Department of Business Informatics, esp. Processes and Systems.

Jannick, R., Holloway, R., and Fuchs, H. (1994). A comparison of optical and video see-through head-mounted displays. *SPIE Proceedings, Telemanipulator and Telepresence Technologies*, 2351:293–307.

Nonaka, I. and Takeuchi, H. (1995). *The knowledge-creating company: How Japanese companies create the dynamics of innovation*. Oxford university press.

Peffers, K., Tuunanen, T., Gengler, C. E., Rossi, M., Hui, W., Virtanen, V., and Bragge, J. (2006). The design science research process: A model for producing and presenting information systems reseach. *1st International Conference on Design Science in Information Systems and Technology (DESRIST)*, 24(3):83–106.

Peffers, K., Tuunanen, T., Rothenberger, M. A., and Chatterjee, S. (2007). A design science research methodology for information systems research. *Management Informations Systems*, 24(3):45–78.

Poppe, E., Brown, R., Johnson, D., and Recker, J. (2011). A prototype augmented reality collaborative process modelling tool. *9th International Conference on Business Process Management*.

Remus, U. (2002). *Process-oriented knowledge management. Design and modelling*. PhD thesis, University of Regensburg.

Schart, D. and Tschanz, N. (2015). *Augmented Reality*. UVK Verlagsgesellschaft Konstanz, München.

Sultanow, E., Zhou, X., Gronau, N., and Cox, S. (2012). Modeling of processes, systems and knowledge: a multi-dimensional comparison of 13 chosen methods. *International Review on Computers and Software (I.RE.CO.S.),*, 7(6):3309–3320.

APPENDIX

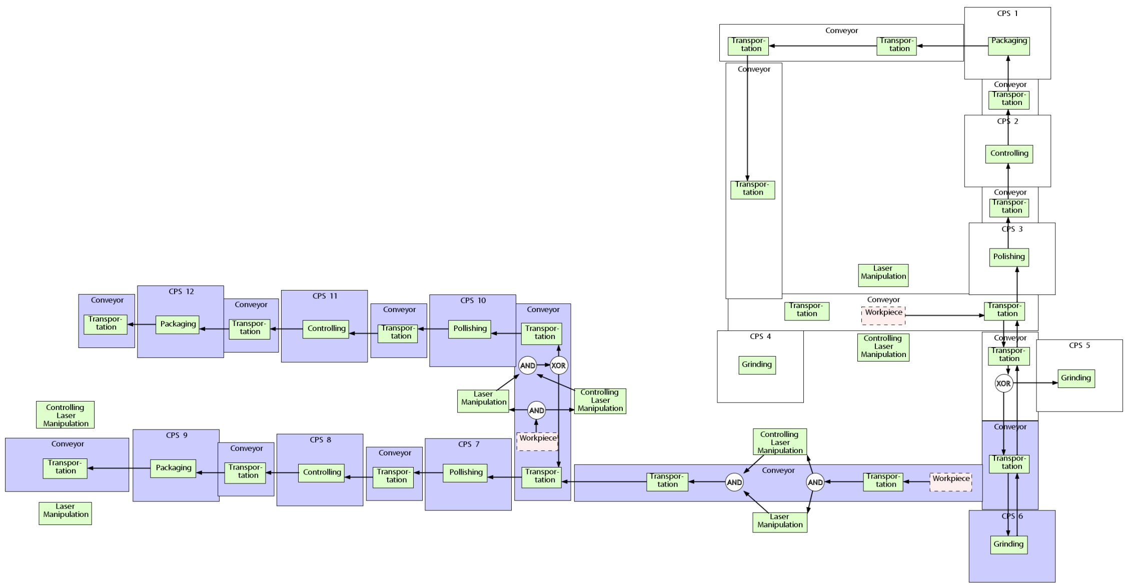

Figure 18: Zoomed current ground plan of the process variation scenario.

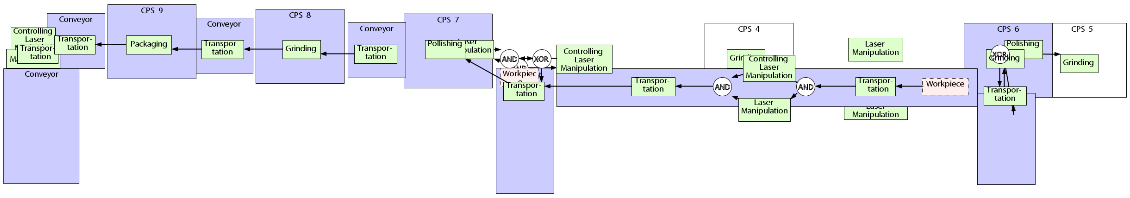

Figure 19: Zoomed current sketch plan of the process variation scenario.