

Enabling Industry 4.0 with holobuilder

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Abstract: Industry 4.0 denotes the emergence of smart factories with a strong focus on communication between humans, machines and products, which is supported by cyber-physical systems [HPO15]. Among such systems are augmented reality applications, which have great value for the assembly, monitoring and maintenance of machines. Yet, to date there are no convenient means for end-users to create augmented reality content in a simple manner. We introduce *holobuilder*—a novel platform for the creation of interactive instruction manuals in Industry 4.0 settings. Additionally, the created augmented reality scenarios can be enhanced with OPC UA capabilities, which enables communication between devices displaying holobuilder content and the monitored machines. We assess our platform against six design principles for Industry 4.0 systems and show that all of them are successfully met. Moreover, we demonstrate the effectiveness and feasibility of holobuilder in two real-world case studies involving a thermostat as well as a machine handling gears in an assembly line.

Keywords: 3D, Augmented Reality, Cyber-Physical Systems, End-User Design, Industry 4.0, Interactive Instruction Manuals, OPC UA, Smart Factory, Virtual Reality

1 Introduction

Industry 4.0 (German: Industrie 4.0) is a term originally coined by the German federal government in the context of their *High-Tech Strategy 2020 for Germany* [HPO15, Hi15]. It is used to describe the fourth—and currently happening—industrial revolution. At the core of this revolution stands the *smart factory* in which humans, different machines and products communicate with each other [PI15].⁵ Based on a recent and comprehensive literature review, [HPO15] define Industry 4.0 as follows:

“Industrie 4.0 is a collective term for technologies and concepts of value chain organization. Within the modular structured Smart Factories of Industrie 4.0, [cyber-physical systems] monitor physical processes, create a virtual copy of the physical world and make decentralized decisions. Over the [Internet of Things], [cyber-physical systems] communicate and cooperate with each other and humans in real time. Via the [Internet of Services], both internal and cross-organizational services are offered and utilized by participants of the value chain.”

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⁵ Original: “Im Mittelpunkt der Industrie 4.0 steht die intelligente Fabrik, die Smart Factory, in der Menschen, unterschiedliche Maschinen und Produkte miteinander kommunizieren.” [PI15].

As can be seen, Industry 4.0 strongly focuses on more efficient machine-to-machine (M2M) as well as human-machine communication that lead to added value in the process chain. Along with the first specific definition of the term above, [HPO15] describe six *design principles* for Industry 4.0 intended for both, researchers and practitioners.

Among the core components of Industry 4.0 are *cyber-physical systems* (CPS) [HPO15], i.e., systems that result from a “fusion of the physical and the virtual world” [Ka14]. One type of such CPS are Augmented Reality (AR) applications, which are “a live direct or indirect view of a physical, real-world environment whose elements are *augmented* (or supplemented) by computer-generated sensory input such as sound, video, graphics or GPS data.”⁶ An example application of AR would be the Cologne Cathedral that is being viewed through the camera of a user’s smartphone that at the same time automatically displays information about the building. Also in industrial contexts, one can greatly benefit from AR systems, e.g., when it comes to the assembly, monitoring and maintenance of machines in smart factories. Yet, there is still a lack of adequate solutions enabling the simple creation of AR content for end-users without specific training.

We introduce *holobuilder*—a novel web platform that allows end-users to create and share arbitrary AR content in terms of “3D projects”. Thus, we enable *end-user design* for AR content in analogy to end-user programming. While *holobuilder* is intended as a *general* platform, in the context of Industry 4.0 it is particularly suited for the following two use cases:

Interactive Instruction Manuals, which allow users to view a machine through the camera of their mobile device, with context-aware instructions automatically displayed through AR means.

OPC UA, the *Unified Architecture* (UA) developed by the *Object Linking and Embedding for Process Control* (OPC) Foundation. That is, a protocol for M2M communication described as “the interoperability standard for the secure and reliable exchange of data in the industrial automation space and in other industries” [OP15].

Regarding these use cases, our platform has demonstrated its effectiveness and feasibility in two case studies. First, we have implemented a fully working interactive instruction manual for a thermostat using *holobuilder* alone. Second, we have successfully created an OPC UA-enabled *holobuilder* project for monitoring a machine handling gears in an assembly line.

In the following, we will give an overview of important background concepts and related work in Section 2 (**Background & Related Work**). Particularly, the six design concepts for Industry 4.0 described by [HPO15] will be introduced in detail. The subsequent section (**holobuilder**) presents *holobuilder* and gives details about the platform’s architecture and implementation. Moreover, it elaborates on particular design choices to improve usability and user experience for end-users. Section 4 (**Evaluation**) evaluates our platform against

⁶ http://www.wikiwand.com/en/Augmented_reality (accessed 2015/04/23).

the Industry 4.0 design concepts ([HPO15]) to substantiate its feasibility and particular usefulness for Industry 4.0 scenarios. Subsequently, Section 5 (**Case Studies**) in detail describes the two case studies mentioned above before discussing our approach and giving concluding remarks in Section 6 (**Discussion & Conclusions**).

2 Background & Related Work

The following gives an overview of existing work and research that is related to our platform, specifically in the areas of interactive instruction manuals and OPC UA.

2.1 Interactive Instruction Manuals

REFLEKT ONE [RE15] is a general software for creating AR applications in industry, which include interactive instruction manuals. The software allows to re-use existing 2D and 3D content and caters for the process of “linking traditional content and diagnostic data to CAD and 3D animations” [RE15] and “Connect[ing] virtual content to real world objects” [RE15]. In contrast to holobuilder, REFLEKT ONE is not realized in terms of a web application that can be utilized for creating 3D content with a modern web browser alone. Hence, it is oriented at specific industry solutions rather than (general) end-users. In particular, the software does not offer predefined 3D objects and animations. Rather, it focuses on transferring existing 3D content (e.g., from CAD applications) into an AR setting that can thus be arbitrarily customized.

*NGRAIN*⁷ have cooperated with *Lockheed Martin*⁸ for providing an AR-based *computerized maintenance management system* (CMMS) for airplanes [He15a]. That is, Lockheed Martin’s engineers are provided with virtual real-time information that allow them to maintain planes in a shorter amount of time with less potential for errors [He15a].⁹ Compared to our system, this is a very specific and individual industry solution, particularly because it involves very large 3D models of Lockheed Martin airplanes [He15a]. [He15a] as well states that “real-time updates on factors like temperature, pressure and other indicators are available, including dynamically-changing parts colouring”. However, whether this happens through OPC UA does not become evident from the article.

The *Plant@Hand*¹⁰ project of the *Fraunhofer IGD* institute provides a suite of solutions for different tasks in the context of Industry 4.0. Among other things, these include interactive instruction manuals (*Plant@Hand Montage Assistent*), which are context-sensitive and support novel devices such as smart watches. Moreover, the *Plant@Hand3D* sub-project aims at optimizing process flows through 3D visualizations of production data. Yet, these solutions are not particularly aimed at or built on AR scenarios.

⁷ <http://www.ngrain.com/> (accessed 2015/04/28).

⁸ <http://www.lockheedmartin.com/> (accessed 2015/04/28).

⁹ “‘In short, our customers use our technology to equip their mobile workers with access to the right data at the right time on the right device,’ says Director of Product Management Barry Po. ‘We provide real-time assistance and allow them to access all the information they need to do their jobs to the fullest extent possible.’” [He15a].

¹⁰ <http://www.igd.fraunhofer.de/node/2387> (accessed 2015/04/28).

*ioxp*¹¹ provide interactive AR manuals that display necessary steps in terms of semi-transparent video overlays. That is, the correct execution of the step is recorded beforehand while the system analyzes the state of the workplace before and after the execution. Based on automatic task segmentation they provide a solution that does not require the user to indicate when a step is finished and gives automatic feedback on whether the execution was correct or not [PS12]. Yet, for robustness it is optimal to record the same step multiple times [PS12]. The process of creating *ioxp*'s AR manuals is fundamentally different from *holobuilder* since it is strongly focused on the involved video captures. Furthermore, they make no statements about the integrability of their solution with OPC UA. OPC UA will be addressed in detail in the following section.

2.2 OPC UA

OPC UA is short for *OPC Unified Architecture*, a standard for machine-to-machine communication developed by the *Object Linking and Embedding for Process Control* (OPC) Foundation¹². The main goal of the standard is to provide a protocol that is independent of the manufacturers of the communicating machines [Bi14]. In order to support a wide range of available systems, OPC UA is based on three core functionalities: *transport*, *meta model* and *services* [Bi14]. According to [Bi14] “Transport and Services provide the protocol (the ‘How’) which is used to exchange data, while the Meta Model can be understood as the information (the ‘What’) that has to be transmitted.” Based on the meta model we can describe arbitrary physical systems as OPC UA models that are based on a specified, generic OPC UA object [Bi14]. Such OPC UA models can then be represented by a corresponding OPC UA server [Bi14]. In the context of *holobuilder*, we have to define such a server in terms of the following standardized scheme to be able to create OPC UA-enhanced AR content:

```
opc.tcp://MyServerPcName:4840
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The server itself is XML-based and transfers data to the client via TCP [He15b]. It uses a secure, reliable and service-oriented architecture to ultimately deliver machine and process data to the monitoring and controlling systems [He15b].

In [He15b] the use of OPC UA in industry scenarios—particularly in combination with novel wearable devices—has been coined *HMI 4.0*, i.e., Human–Machine Interaction 4.0. This refers to the fact that with the help of OPC UA and wearables, smart factories can reach a new level of interaction between machines and mechanics/engineers. While AR enables a *visual* fusion of the real and the virtual world, the additional use of OPC UA furthermore leads to a fusion on the *information* level. Hence, one core aim of *holobuilder* is to leverage the advantages of AR-driven interactive instruction manuals *and* OPC UA in Industry 4.0 settings.

¹¹ <http://www.ioxp.de/> (accessed 2015/04/28).

¹² <https://opcfoundation.org/> (accessed 2015/04/28).

2.3 Design Principles for Industry 4.0

In their working paper, [HPO15] present the six core design principles for Industry 4.0, which are based on a recent and comprehensive literature review of 51 academic publications. These design principles are summarized in the following [HPO15]:

Interoperability It is crucial for all parties involved in Industry 4.0—i.e., people, companies and CPS—to communicate among each other. For this, it is necessary to provide adequate standards, e.g., OPC UA.

Virtualization “CPS are able to monitor physical processes” [HPO15]. For this, one requires appropriate interfaces between the virtual and the real world for creating corresponding mappings.

Decentralization Machines are controlled and act autonomously in a smart factory. The need for centralization is reduced to a minimum, i.e., the case of failures [tHO14].

Real-Time Capability “For organizational tasks it is necessary that data is collected and analyzed in real time.” [HPO15]

Service Orientation Services enabling Industry 4.0 are provided internally as well as externally, i.e., they can be used by other participants in the context of Industry 4.0.

Modularity Industry 4.0 is also enabled by modularized systems that can react flexibly to changing contexts, e.g., “in case of seasonal fluctuations or changed product characteristics” [HPO15].

These well-founded principles are intended as a starting point for the implementation of Industry 4.0 scenarios as well as further research [HPO15]. Yet, they also make it possible to assess the suitability of systems for Industry 4.0.

3 holobuilder

holobuilder is intended as a general web-based platform for the creation and consumption of arbitrary AR content by end-users. This means, in analogy to end-user programming, our particular focus is on good user experience and usability for users with no special training in creating AR content. In the context of Industry 4.0, engineers and mechanics responsible for the assembly, maintenance and monitoring of machines in smart factories acquire the position of such end-users, as is implied by the original use case of our platform (Fig. 1). First, in terms of users that *create* AR content, e.g., in the form of an interactive instruction manual. Second, in terms of users that *consume and apply* the AR content created with holobuilder.

Our platform allows end-user to create “3D projects”, which can be seen as a 3D analogy to presentations created with, e.g., *Microsoft PowerPoint*; however, with three-dimensional

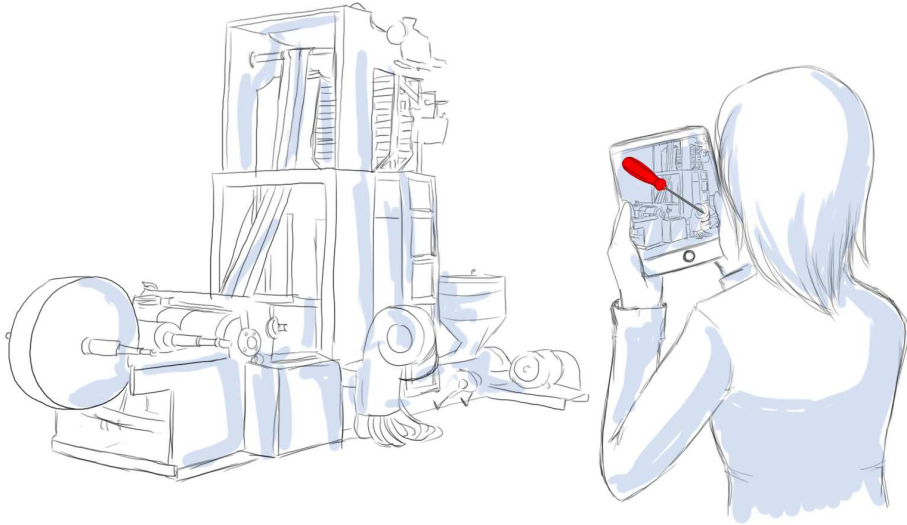


Fig. 1: Early design concept of the original use case of holobuilder: The user views a machine through the camera of his mobile device. The view of the real world is automatically augmented with 3D objects indicating the next step necessary for maintaining the machine.

rooms instead of two-dimensional slides [Sp15]. Yet, if 2D information is required in a project, holobuilder as well supports two types of slides along its 3D rooms, i.e., *text* and *checklist* slides. holobuilder acts as both, the *editor* for creating and the *player* for consuming 3D content and can switch between these two modes at any time.

Interactive Instruction Manuals For creating AR content like interactive instruction manuals, a marker has to be added to an empty room. This marker could be, e.g., a bar code or QR code that is placed on a machine to be maintained (in this case the marker would be a 2D object). Alternatively, holobuilder supports 3D markers, which would be a point cloud of the machine. This point cloud has to be obtained beforehand by scanning the machine using an appropriate 3D scanner. Subsequently, all virtual 3D objects added to the room, e.g., a screwdriver, are placed in relation to the given marker. Since holobuilder recognizes the marker in the real world¹³, in this way it is possible to place 3D objects at the exact necessary position in the AR scene. For instance, the exemplary screwdriver can be placed above the screw that needs to be removed. Since they are placed in relation to

¹³ Using simultaneous localization and mapping techniques (SLAM; cf. http://www.wikiwand.com/en/Simultaneous_localization_and_mapping, accessed 2015/04/28).

the marker, all 3D objects added to the room remain at their assigned global coordinates as the mechanic moves their mobile device around the machine in the real world. Furthermore, the virtual objects can be animated (rotate, bounce, spin etc.) in order to indicate the exact way in which the mechanic should use the tools shown. Also, it is possible to attach click events to the inserted objects, which then show additional information, open a given website URL or send an e-mail, among other things.

Each step in an interactive instruction manual has to be realized as a separate room in the 3D project. The mechanic has to indicate when a step is finished and is subsequently presented with the next room by holobuilder.

OPC UA Similar to the above, it is possible to enhance holobuilder's 3D projects by adding OPC UA capabilities. That is, for a machine to be monitored, one has to set up a corresponding AR scenario including the aforementioned markers. Then, in analogy to the click events that can be attached to 3D objects, one can define OPC UA events if the project is OPC UA-enabled and has a valid server set. For instance, the color of an inserted object can be changed depending on the state of a boolean variable (that is communicated by the monitored machine via the given OPC UA server). This could be a green 3D arrow for a positive state and a red one for a negative state. To give another example, it is possible to add dynamic information, e.g., in terms of a virtual text object displaying the current temperature of the machine.

This kind of information flow as well works into the other direction, which means that variable changes can be triggered by the holobuilder project. For instance, a certain component of the monitored machine could be augmented with a virtual button. Upon clicking that button a boolean variable could be toggled that switches the component on or off. This variable change would be communicated to the machine via the given OPC UA server and then take effect. In this way, holobuilder does not only cater for the monitoring of machines via OPC UA, but also enables remote control capabilities.

3.1 Design Decisions

Since holobuilder is intended as a general tool for *end-users* to create 3D content, our platform is based on a number of core design decisions ensuring an optimal experience for users with no specific training in this domain.

Enhancement of Known Concepts holobuilder builds on familiar concepts to acquaint end-users with creating 3D content. We adopted the core principle of *Microsoft PowerPoint*—creating slides that can have different types and layouts and interconnecting them—that is already well-known to the majority of users¹⁴ and transferred it into the three-dimensional setting [He15b].

¹⁴ <https://infogr.am/PowerPoint-usage-and-Marketshare> (accessed 2015/04/27).

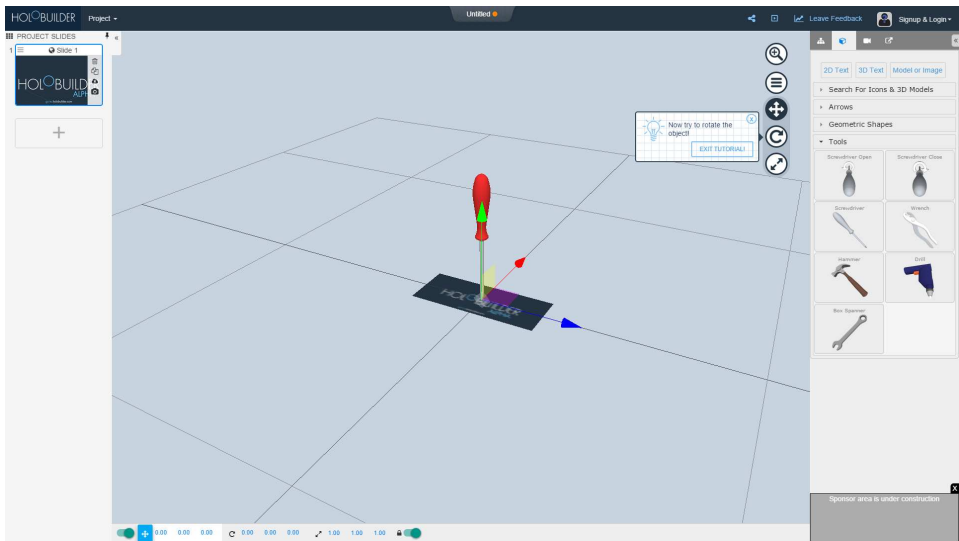


Fig. 2: Screenshot of the holobuilder UI showcasing a tutorial tooltip as well as a selection of the available built-in 3D objects for Industry 4.0 use cases.

First User Experience A step-by-step tutorial guides first-time users through all steps of the process from starting a new project in holobuilder to adding, manipulating and animating virtual 3D models (Fig. 2). The project created in this tutorial serves as a prototype from which more advanced projects can be derived.

Tooltips & Hints Since dealing with 3D content is not a trivial task for end-users, tooltips and hints are present across all stages in the process of creating a project (Fig. 2). Particularly, guidance is necessary when it comes to adding the correct marker type to a room, or when uploading custom 3D objects, as particular file types are required.

Predefined Objects & Animations We provide users with a set of predefined 3D objects and animations that cover major use cases (Fig. 2). Among the provided objects are custom text, arrows, screwdrivers as well as a variety of geometric shapes. As a part of future work, we intend to extend our collection to a “clip art gallery for 3D content” through both, internal and external input. In case a desired object is not provided by holobuilder, users are given the possibility to upload arbitrary 3D models from their computer.

3D Object Search Since not all necessary objects for all use cases can be covered by our gallery (or are present on users’ computers), we have included a search for arbitrary 3D objects. This search has been realized using an external API¹⁵ through which we ensure that only objects with the correct file format can be imported into holobuilder.

¹⁵ <https://www.yobi3d.com/#!/> (accessed 2015/04/27).

3.2 Architecture & Implementation

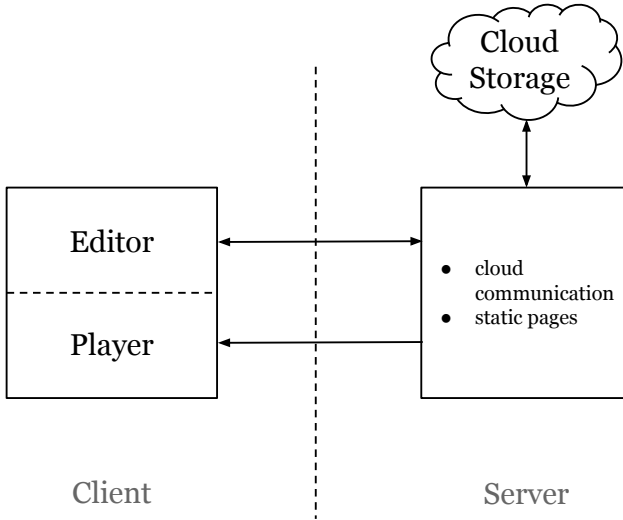


Fig. 3: High-level architecture of the holobuilder platform.

Our platform comprises a number of components on the client as well as the server side. In particular, there are two separate components for creating (*Editor*, Fig. 3) and consuming (*Player*, Fig. 3) 3D projects. The player is commonly used on mobile devices—particularly in AR scenarios—but is not restricted to that class of devices.

holobuilder has been implemented in terms of a *web application* to ensure that simply a modern web browser is required for end-users to create 3D content. The architecture of the platform is highly oriented at the asynchronous paradigm, which means that most of the core logic resides on the client side (Fig. 3). Hence, the implementation of the platform is mainly based on *Backbone.js*¹⁶ in combination with *RequireJS*¹⁷ and *WebGL*¹⁸. In this way, a slow or unstable Internet connection does not affect the actual use of the holobuilder editor. The server-side components come into play when loading (*Editor*, *Player*) or storing (*Editor*) 3D projects (Fig. 3). All projects created with holobuilder are stored in the cloud to guarantee worldwide availability, but can be alternatively downloaded to the users' computer (in terms of a `.holo` file that can be interpreted by the holobuilder player). Therefore, the holobuilder server is mainly responsible for communication with the cloud provider and serving a number of static pages (such as different landing pages). Its implementation is based on *Java Servlets* in combination with *JSP*.

The live version of holobuilder can be accessed at <https://www.holobuilder.com/>.

¹⁶ <http://backbonejs.org/> (accessed 2015/04/27).

¹⁷ <http://www.requirejs.org/> (accessed 2015/04/27).

¹⁸ <https://www.khronos.org/webgl/> (accessed 2015/04/29).

4 Evaluation

In the following, we assess holobuilder against the six design principles for Industry 4.0 defined by [HPO15] (cf. Sec. 2).

- ✓ **Interoperability** holobuilder supports interoperability on two levels of abstraction. First, our platform enables machine-to-machine communication through OPC UA. Second, holobuilder itself has been realized as a web app running in any modern web browser. Hence, any appropriate mobile device can be used to monitor machines in a corresponding holobuilder-based AR scenario.
- ✓ **Virtualization** Since our platform enables the use of AR in smart factories, it clearly fuses the physical and the virtual world (which characterizes CPS according to [Ka14]). Moreover, it leverages the advantages of OPC UA for monitoring physical processes by communicating with the monitored machines.
- ✓ **Decentralization** holobuilder supports the decentralization of smart factories since, e.g., interactive instruction manuals can be created separately for each machine (optionally with OPC UA capabilities). This facilitates decentralized monitoring and maintenance.
- ✓ **Real-Time Capability** Naturally, AR scenarios such as interactive instruction manuals are applied in real time since the corresponding machine is viewed live through a camera. Also, in the case of an OPC UA-enabled holobuilder project, machine parameters are communicated in real time.
- ✓ **Service Orientation** Projects created with holobuilder are not specific to a machine *and* factory. That is, as long as the same marker is being detected by our platform, interactive instruction manuals and OPC UA-enabled projects can be applied across different smart factories. Also, holobuilder itself is a general platform not bound to any particular context. It can be used in any smart factory with any appropriate mobile device.
- ✓ **Modularity** Our platform supports modular systems in smart factories, as it simplifies the process of adding, changing and monitoring individual components of machines.

As becomes evident from the above, holobuilder has the potential of being successfully applied in Industry 4.0 settings—particularly smart factories. Therefore, we have taken the evaluation of our platform one step further and implemented two case studies that are presented in the following section.

5 Case Studies

To demonstrate the feasibility and effectiveness of holobuilder, we have used it in two case studies that are typical scenarios in Industry 4.0 contexts. First, Kristina Tenhaft—in the

context of her Master's thesis—has implemented an interactive instruction manual for a thermostat by using only the holobuilder platform. Second, we have created a project for monitoring a machine used in an assembly line for gears based on OPC UA.

5.1 Interactive Instruction Material

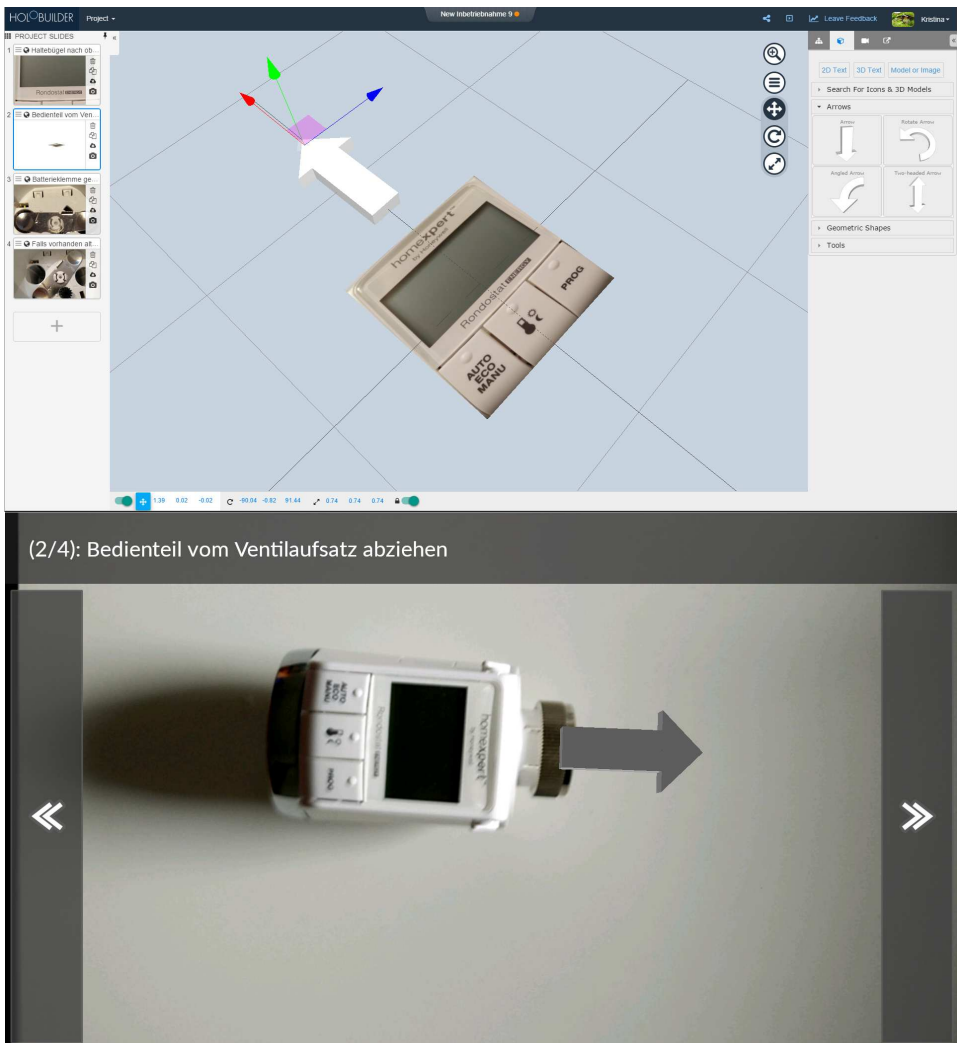


Fig. 4: Interactive instruction manual as created in holobuilder (top) and the corresponding AR scene as viewed through the camera of a smartphone (bottom).

In the context of her Master's thesis, Kristina Tenhaft has created an interactive instruction manual for the thermostat *HR-25* by *Honeywell*¹⁹. The overall goal is to completely replace the paper manual provided by Honeywell with the interactive instruction manual implemented with holobuilder and to investigate the difference between the two, as perceived by real users (i.e., the core research question is “Can the paper manual be replaced by the AR manual?”). The scenarios covered by the interactive manual include setting date and time, changing batteries, adjusting the temperature, defining heating intervals and opening/closing the vent of the thermostat, among others.

When using the manual with their smartphone or tablet PC, the user first has to select the scenario they want to accomplish. Subsequently, they have to ensure that the thermostat is in the field of view of the camera of their mobile device. For the interactive instruction manual, a 2D marker has been used in terms of a photo of the thermostat surface (cf. Sec. 3 and Fig. 4). Based on this marker, holobuilder recognizes the real thermostat and presents the user with the necessary steps to accomplish their task, which is illustrated by, e.g., virtual arrows (Fig. 4) and other 3D objects. Besides holobuilder's rooms, the manual also makes use of text and checklist slides. In particular, a text slide is used to include a video explanation of how to install the thermostat on a radiator²⁰. This is possible since text slides in holobuilder also allow the embedding of arbitrary HTML content. Moreover, checklist slides are used to, e.g., ensure all necessary components have been unpacked and are ready to use.

According to Ms. Tenhaft the implementation of an “average scenario”—i.e., a scenario like changing batteries, which contains several steps and markers—requires about 20 minutes to create for a user who has been previously familiarized with holobuilder. Moreover, she appreciated the possibility of cloning slides. She described this functionality as “highly convenient” since interactive instruction manuals contain a considerable amount of redundant steps that are omitted in paper manuals²¹. Furthermore, Ms. Tenhaft noted that most of the time effort while using holobuilder has to be accounted to creating custom animations (which are “compose[d] from the basic ‘rotate’, ‘scale’ and ‘position’ animations” [Sp15]) due to occasional technical flaws.

5.2 OPC UA

To demonstrate holobuilder's capability of leveraging machine-to-machine communication via OPC UA, we as well implemented a corresponding case study.

The hardware set-up was a machine that used multiple sensors to measure, move, grab and release gears on an assembly line. The contained sensors detected the type of the material and counted the number of gears that passed the assembly line. Moreover, the machine

¹⁹ <http://www.homexpertbyhoneywell.com/en-DE/Products/rondostat/Pages/HR-25.aspx> (accessed 2015/04/27).

²⁰ This step has been included in terms of a video since it would otherwise require a more complex AR set-up with a variety of different markers or a true virtual reality (VR) scenario. Yet, the latter two have no significant added value compared to the video.

²¹ For instance, changing batteries could be a prerequisite for a different scenario.



Fig. 5: Case study showcasing real-time information communicated via OPC UA in an AR scenario.

detected and punched out the inner cylinder of the gear if one was present and collected this data as well.

The connection established via an OPC UA server provided all data measured by the sensors to the mobile device displaying the OPC UA-enabled holobuilder project. This included the current temperature of the punch press in case the press was currently working and whether it operated correctly (Fig. 5). The assembly line sensors measured the type of the gear, the material it was made of, whether it had an inlet and the current count of all gears running through the assembly line. Modifying the machine state through the holobuilder project was possible as well. In this case study, we added a virtual button to reset the gear counter of the machine. Hence, we were able to demonstrate the changing of machine properties through our mobile device via OPC UA.

The AR scenario displayed by the holobuilder player (Fig. 5) showed all relevant information on top of the corresponding physical counterpart (i.e., the machine in the real world as viewed through the camera). In this way the information was visible where it was most relevant and the relation between the displayed information and the functionality of the machine became most clear. Additional information could be shown in a separate UI accessible through info buttons “floating” above the machine (Fig. 5). Finally, a virtual version of the punch press was overlaid on top of the real pump and colored in red or green to indicate whether it was currently in use or not (Fig. 5).

6 Discussion & Conclusions

Currently, we are witnesses of the fourth industrial revolution, which has been coined *Industry 4.0* by the German federal government [HPO15, Hi15]. This revolution is driven by various technologies that enable communication between humans, machines and products to form smart factories [HPO15]. One important concept of Industry 4.0 are cyber-physical

systems [HPO15], an example of which are *augmented reality* applications that provide a fusion of the real and the virtual world (which is a property of CPS according to [Ka14]). Yet, to date there are only individual, industry-specific solutions for such AR applications. At the same time it is rather difficult for end-users without specific training to easily create corresponding AR content. Hence, we have introduced *holobuilder*—a novel web platform intended for end-user design of AR content. *holobuilder* allows for the creation of interactive instruction manuals in Industry 4.0 settings. Additionally, its projects can be enhanced by adding OPC UA capabilities for direct communication between devices displaying AR content and the monitored machines. We have shown that our platform enables Industry 4.0 according to the six design principles specified by [HPO15]. Moreover, its effectiveness and feasibility has been demonstrated based on two real-world case studies involving a thermostat and a machine handling gears in an assembly line.

Yet, our approach still has several shortcomings. First, not all included features are fully mature yet. For instance, as has been stated in one of the case studies, creating custom animations for 3D objects takes a considerable amount of time, which can be attributed to non-optimal intuitiveness and occasional technical flaws. Second, as *holobuilder* has only recently left the alpha testing state, some crucial functionalities are not yet existent. In particular, our platform still lacks an undo function as well as functionality to copy/paste 3D objects across rooms. Third, the sets of predefined 3D objects and animations are still rather limited, which we intend to tackle by growing our database and letting users contribute to the publicly available models/animations. In this way it would be possible to provide a “clip art gallery for 3D content” alongside *holobuilder*. Finally, the *holobuilder* UI can not be considered optimal yet, as end-user design of 3D content is not a trivial task and has to be communicated to average users in a simple and understandable fashion. Therefore, we are performing ongoing qualitative user studies. Yet, a quantitative evaluation—also in relation to similar approaches—still has to be carried out. Tackling the above shortcomings is our main focus for future work. Particularly, we are confident to be able to report on quantitative findings concerning the effectiveness and efficiency of *holobuilder* in the near future.

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