authAR - Automatic Authoring of Picking and Layout Optimization Instructions

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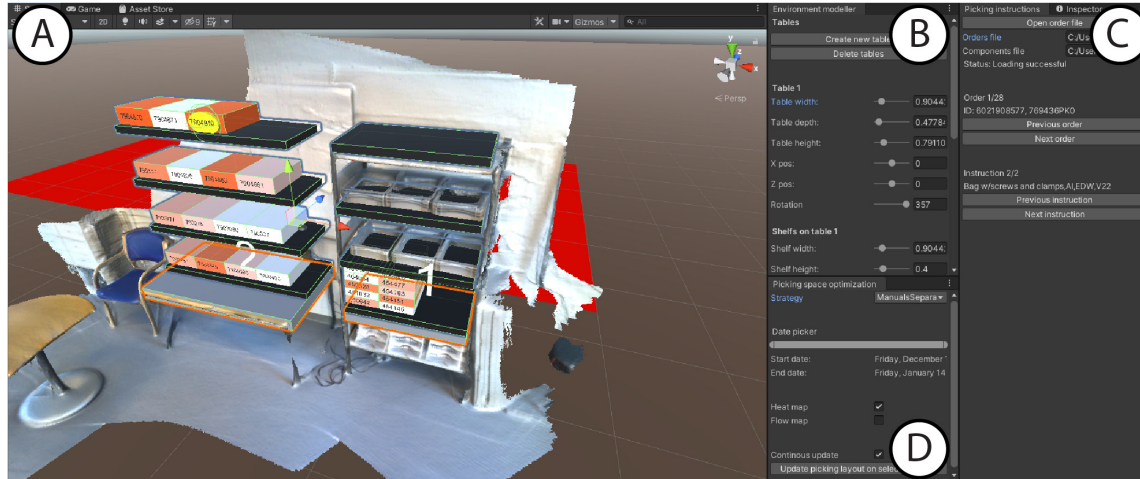
Fig. 1. Screenshot of authAR's editor plugin in Unity3D. A) Scene view of 3D reconstruction of workspace. Virtual racks and boxes are automatically generated on the selected table plane and shelf plane. The yellow circle on one of the boxes is a 3D picking instruction. B) Environment modeler window. C) Picking instructions window. D) Picking space optimization window.

Authoring of AR instructions is typically a time-consuming manual process that requires a user to use a desktop GUI interface or AR device for placing and animating 3D content. This is problematic because manual authoring does not scale to the myriad of product variations of many manufacturing companies. However, automatic authoring is possible, since companies already store data about their products in the form of a bill of materials and bill of processes. In our paper, we present *authAR*, a novel desktop GUI based tool that combines bill of materials with geometric data of a factory workspace to automatically author AR picking instructions on racks and boxes. In addition, authAR uses this data to propose spatial layouts of racks and boxes according to a customizable optimization algorithm. We conducted a preliminary expert review with four manufacturing workers. Our study showed that authAR has many potentials and was applicable to a real use case at the manufacturing company, Velux. The study contributes new knowledge to the field of AR authoring by including the views of domain experts and using real production data. Suggestions for improvements and new features as well as plans for a more thorough study are presented as future work.

CCS Concepts: • **Human-centered computing** → **User interface toolkits**; *Heat maps*.

Additional Key Words and Phrases: authoring tool, picking instructions, manufacturing, workspace optimization, augmented reality

Fig. 2. Special Flashing Factory (SFF). (Left) Rack with boxes containing items for special flashings: screwbags and brackets. (Middle) Rack with letterboxes containing assembly manuals for different flashing product variations. (Right) Overview of workspace for picking of flashing items.

1 INTRODUCTION

In this paper we present "authAR", a desktop GUI based authoring tool that 1) automatically authors AR picking instructions and 2) optimizes the 3D picking space, i.e., proposes optimal placement of racks and boxes in a factory workspace and generates AR instructions on how to obtain this. authAR addresses the research question "To what degree can the authoring of AR instructions be automated based on a geometric scene understanding and order data from the production industry?" This is important in factories with a low-volume, high-variety production where manual authoring of AR instructions is not scalable due to the sheer number of product variations.

authAR is designed for the manufacturing industry and so is demonstrated on a window flashing production line at Velux. It is aimed at the three user groups shown in Figure 3: 1) authors of AR picking and optimization instructions, i.e., typically persons in management roles, 2) users of AR instructions, i.e., factory workers, and 3) programmers at the manufacturing companies responsible for extending authAR with new optimization strategies.

Many studies have compared paper-based order lists to AR picking systems, i.e., technology for warehouses and factories that uses virtual cues on racks, shelves, or boxes to indicate pick locations [2, 3, 5, 11–14]. These studies show that AR picking instructions can be helpful in reducing picking errors because they replace in-head knowledge with in-world knowledge. In comparison, we do not conduct a comparative study of instruction formats. The novel contribution of authAR is the optimization of the 3D picking space according to a chosen strategy, automatically generated AR optimization instructions on how to rearrange racks and boxes, and the ability of programmers to extend the tool by scripting new optimization strategies based on various goals, e.g., ergonomics, worker safety, efficiency, robot collaboration.

Furthermore, we had four domain experts from Velux review the functionality of authAR. This preliminary study contributes new knowledge to the field of AR picking systems by presenting domain experts' perceived usefulness of AR for supporting picking operations, and it contributes new knowledge to the field of AR authoring by using a real case and production data for going beyond the automatic generation of AR picking instructions.

1.1 Special flashing factory

To understand the benefits of our proposed solution, we must first introduce the problem in the context of a use case in the manufacturing industry. At the manufacturer, Velux, flashing is an important component of a window, because it serves as insulation. Velux produces high-variety, low-volume orders of flashing catered to customer demands at a specific facility, henceforth denoted "Special Flashing Factory (SFF)". A factory worker at SFF is responsible for picking and packing the right items for a flashing order, i.e., he must pick the correct items from different boxes placed on racks and pack them in a cardboard box according to the order specification. Due to the high variety of orders on a daily basis, this worker is faced with a large selection of similar looking items and must pick using in-head knowledge of which items belong to an order. Figure 2 shows some of the racks that the worker must pick from (left and middle picture). Figure 2 (left) shows euro boxes with screw bags and brackets, while Figure 2 (middle) shows letter boxes with manuals. Figure 2 (right) gives an overview of the workspace where picking and packing takes place. A quantitative analysis of errors conducted by the authors shows that the picking process in this workspace is particularly error prone, since a large fraction of errors in SFF (approx 40 pct.) stems from the worker picking the wrong items or forgetting to pick some items.

As previously stated, existing research has shown that AR picking instructions can be helpful in reducing picking errors in SFF and similar factory settings [3, 11]. However, manual authoring of such instructions in a high-variety, low-volume environment like SFF is too cumbersome and time consuming, and therefore authoring must be automatic. Hence, we present authAR for automatic, scalable authoring of AR picking instructions in a factory workspace with the aim of reducing picking errors and eliminating authoring time. Additionally, the managers responsible for planning the layout of the factory space at SFF currently have no way of assessing whether machines, racks, and boxes are placed optimally. For example, they already have data on the most frequently picked items, but no way of coupling this data to the physical world. authAR solves this problem by visualizing heat maps and flow maps on the boxes and proposing optimal picking space layouts.

2 SYSTEM DESIGN OF AUTHAR

The system design of authAR is described in terms of its thee user groups: authors, factory workers, and programmers, illustrated in Figure 3. Note that authAR currently supports two out of three user groups: authors and programmers. Hence, while the desktop GUI tool supports the creation of picking and optimization instructions in 3D, the AR-HMD application for visualising these instructions in a factory workspace is currently in development.

Fig. 3. The different user groups of authAR: (left) author of AR instructions, (middle) factory worker, i.e., user of AR instructions, (right) programmer of optimization strategies.

2.1 The Author Interface

The authoring functionality of authAR is built as an editor plugin for the 3D application development platform, Unity3D, on PC. It consists of three windows with UI controls that extend the standard functionality of Unity3D (see Figure 1).
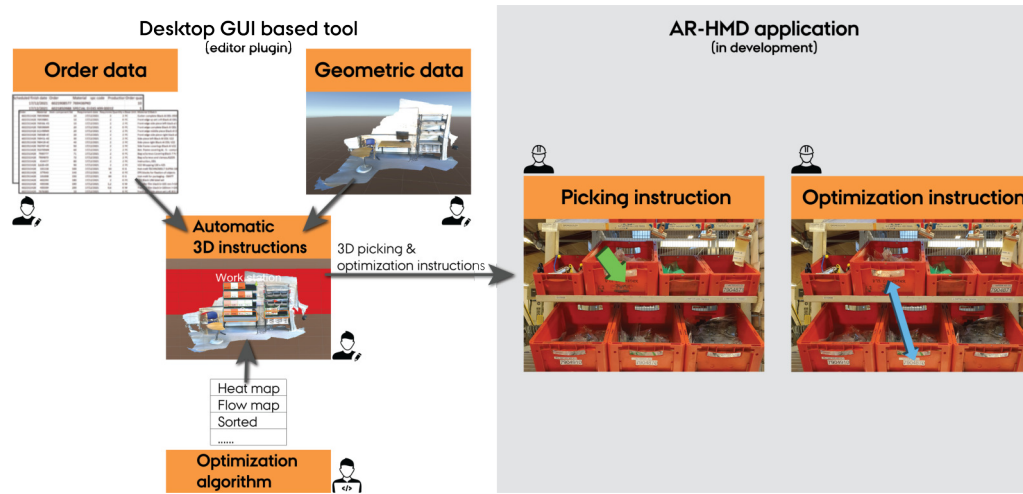
Fig. 4. authAR system diagram. (Left) Diagram of desktop GUI based tool, a Unity3D window editor plugin. Order data, geometric data and optimization algorithm are combined to automatically generate a layout of racks and boxes in a workspace, including AR picking and optimization instructions. (Right) Sketches of AR-HMD application - currently in development - for showing picking and optimization instructions in AR in the workspace.
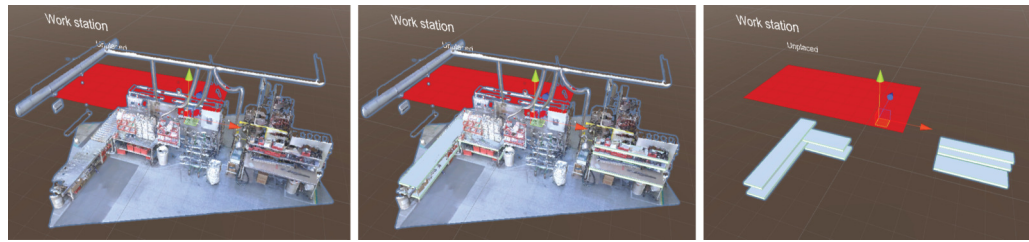

Fig. 5. Reconstructed SFF work space. (Left) Mesh reconstructed workspace in Unity3D. (Middle) Reconstructed workspace with horizontal planes. (Right) Horizontal planes only. The author selects the planes that he wants to use for the optimization step.

With authAR, a user can define horizontal planes in a 3D model of a workspace. These planes are automatically populated with racks containing boxes with items needed for flashing orders. Each box contains an item variant with its unique ID written on the front of the box. The planes are populated according to an optimization strategy chosen by the author, for instance one strategy spatially groups the boxes most frequently picked from. Picking instructions, in the form of a yellow circular highlight, appear on the boxes to pick from for a given order.

The way data flows into the editor plugin is illustrated in the system diagram in Figure 4. An author loads order data in the "Picking instructions" window and automatically ties it to geometric data in the form of CAD model or 3D reconstruction of the factory workspace. Then, an optimization strategy scripted by a programmer and selected by an author uses the order and geometric data to generate a proposal for how to place racks and boxes in the factory workspace.

The three windows of authAR, 1) Environment modeler, 2) Picking optimization, and 3) Picking instructions, are responsible for different functions as can be seen in Figure 1.

In the "Environment modeler" window (Figure 1, b), an author can obtain horizontal planes (or "tables") in a 3D model of a workspace by manually selecting the plane corners or alternatively can create new planes and align them with the 3D model. The position and dimension of planes can be adjusted using sliders and input fields. For the "Environment modeler" to work, it needs geometric data of the factory workspace in the form of either a 3D CAD model or a 3D reconstruction created with depth acquisition technology, such as a commodity LiDAR scanner. Figure 5 shows a 3D reconstruction of the picking space in SFF (left), and how planes are extrapolated from the reconstruction (middle right). These planes are used as input to the optimization strategy. In the "Environment modeler", the author can further specify the dimensions of the racks on the planes using sliders and input fields.

In the "Picking optimization" window (Figure 1, d), the author can decide on a picking space optimization strategy using a dropdown menu and select different visual overlays on the boxes, heat map and flow map, by clicking their checkboxes. Whenever the author changes a parameter value in the "Environment modeler", such as the width of a plane, that affects the placement of racks and therefore the placement of boxes on the racks, the chosen optimization strategy is re-applied and a new layout of racks and boxes is generated taking the parameter changes into account. Changes in parameter values that lead to re-optimization include changes to the selection of planes, dimensions and positions of planes, and the dimensions of racks on each plane. These optimization strategies are already included in authAR: 1) boxes ordered alphabetically, 2) boxes ordered according to heat map, 2) boxes ordered according to flow map, and 3) separating boxes based on item types.

The author can load the order data in the "Picking instructions" window (Figure 1, c) and step through 3D picking instructions overlaid on the boxes. The order data is represented as two relational tables (stored and read as .csv files) with orders and items in orders respectively. Table 1 contains all orders with unique order IDs. Table 2 contains all items that each order contains. Each item contains a reference to a unique order ID. It is important to note that the order data can be historical or based on future orders. Currently, authAR reads specific items from the order data that are known to be stored on racks: screwbags, brackets and manuals. Including more items and standardising the data format is left for future work.

2.2   The Factory Worker Interface

It is envisioned that the picking and optimization instructions are visualized to the factory worker on an Augmented Reality (AR) head-mounted display (HMD). Both types of instructions rely on the tracking of boxes using unique markers, such as VuMarks or QR codes. A picking instruction is visualized as an arrow pointing to the box to be picked from (see Figure 4, right). This is similar to previous research on AR picking systems [3, 12, 13]. An optimization instruction shows how to rearrange racks and boxes to optimize the layout. To our knowledge, this is a new type of instruction. Concretely, an optimization instruction is visualized by highlighting two boxes that need to swap positions (see Figure 4, right). If a box must be moved to a new unoccupied position, an animation is shown moving the box from its current to new position. Similarly, if a rack needs to be moved, an animation is shown moving the rack from current to new position.

2.3   The Programmer Interface

authAR optimizes the position of racks and boxes on the racks given an optimization strategy. authAR comes with a series of optimization strategies implemented as shown in Figure 6. However, new strategies can be scripted by a programmer using the language C#. Each strategy is a separate script file that must be placed in a specific Unity project folder. A script file must contain a class implementing the *OptimizationStrategy* interface with one method,
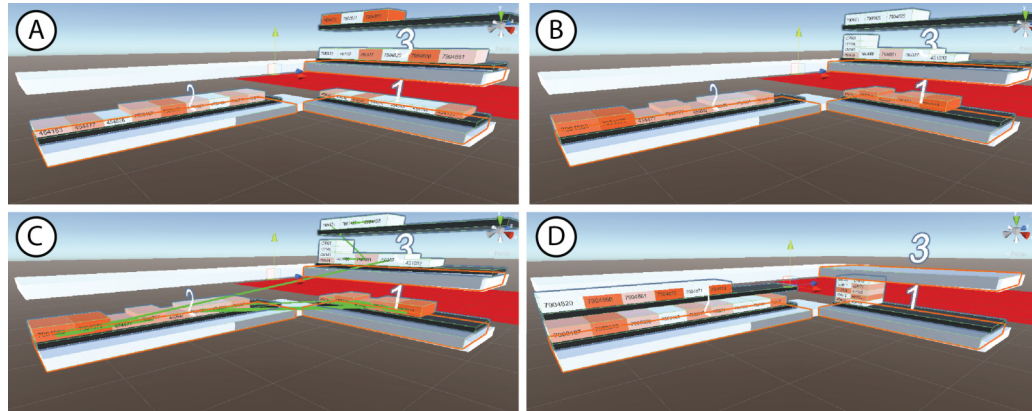
Fig. 6. 4 different optimization strategies on three selected planes from SFF workspace. A) boxes are ordered on racks alphabetically. B) Boxes are ordered on racks according to how often they are picked from as shown in the heat map visualization. C) Boxes are ordered on racks based on flow map data, i.e., how frequently a worker picks from two boxes in sequence (thickness of green line). This optimization also supports stacking the letter boxes with manuals. D) Boxes are separated according to item type. The big boxes containing either screwbags or brackets are sorted alphabetically on one rack, while another rack is used for stacking letter boxes with manuals. All strategies were scripted by implementing the *OptimizationStrategy* interface.

optimizePlacement, which takes as input the horizontal planes defined in the "Environment modeler" and the order data loaded in "Picking Instructions". It is the job of a programmer to implement this method by writing the strategy for placing racks on the planes and boxes on the racks. An SDK is available that exposes the order data and geometric plane data of the factory workspace and allows for common operations on racks and boxes, such as adding a box to a rack, checking if there is room for a box on a rack, and checking if there is room for a rack on a plane etc.

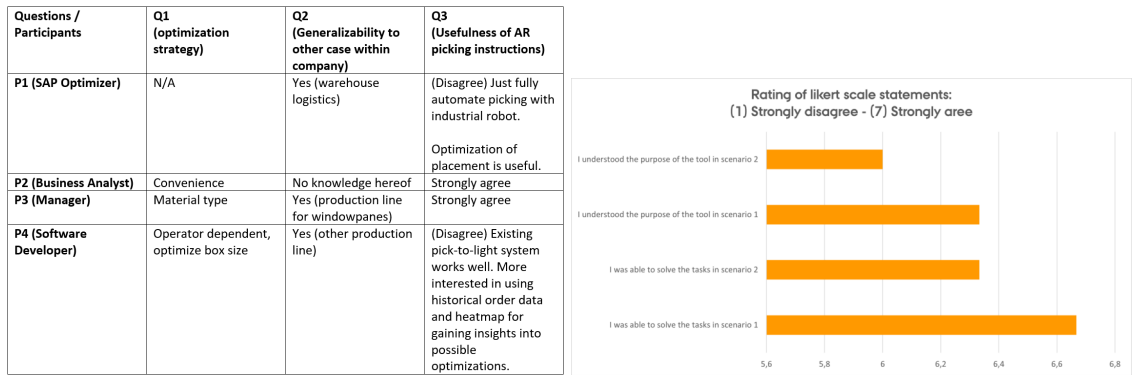| Questions / Participants	Q1 (optimization strategy)	Q2 (Generalizability to other case within company)	Q3 (Usefulness of AR picking instructions)
P1 (SAP Optimizer)	N/A	Yes (warehouse logistics)	(Disagree) Just fully automate picking with industrial robot. Optimization of placement is useful.
P2 (Business Analyst)	Convenience	No knowledge hereof	Strongly agree
P3 (Manager)	Material type	Yes (production line for windowpanes)	Strongly agree
P4 (Software Developer)	Operator dependent, optimize box size	Yes (other production line)	(Disagree) Existing pick-to-light system works well. More interested in using historical order data and heatmap for gaining insights into possible optimizations.

Fig. 7. (left) Summary of preliminary findings from qualitative study with domain experts. (Right) Participants' avg. likert scale ratings, where a 7 is the best (strongly agree).

3 PRELIMINARY FINDINGS FROM QUALITATIVE STUDY WITH MANUFACTURING EMPLOYEES

A qualitative study was conducted with 4 domain experts from Velux, who took on the user-role of author. They were faced with two scenarios in which they had to use authAR on PC to model a workspace in SFF, optimize the placement

of boxes containing flashing items in this workspace, and progress through picking instructions. In the first scenario, participants were asked to model a new workspace, i.e., create and move planes, in an empty room, and then place racks on boxes on these planes according to a chosen optimization strategy. In the second scenario, they were asked to create planes in an existing 3D reconstruction of a workspace, i.e. create and align virtual planes to the planes in the reconstruction, and then place racks and boxes. After each scenario, participants filled out a questionnaire probing them about alternative optimization strategies ("Can you think of other optimization strategies to use?"), other use cases beyond SFF ("Can you think of other cases within Velux where optimizing the placement of boxes and racks may be relevant?"), and the usefulness of AR picking instructions ("Do you believe that AR can lead to a reduction of picking errors on the production lines?").

A summary of the preliminary results is given in Figure 7. The important takeaways are that the participants had many different suggestions for optimization strategies, they understood the purpose of authAR, and could see how the plugin could be generalized to other cases within their company, for instance on other production lines and in warehouse logistics. Interestingly, their opinions were divided on whether AR picking instructions were useful. P1 believed that the picking space layout optimizations of authAR could be a driver for further robotization and automation, thus replacing the worker responsible for picking and packing entirely. P4 had positive experience with traditional pick-to-light systems consisting of an LED light per shelf/box and therefore was sceptical of what AR could contribute to further improve picking. He was more interested in using historical order data to visualize an AR heat map directly on the racks for gaining insights into possible optimizations. Thus, P4 perceived authAR as a potentially useful analysis and planning tool, but he did not consider it a tool for supporting daily picking operations.

4 FUTURE WORK

This work presented the first prototype system authAR and a preliminary study. Both the system and the study will be improved in the near future and is already undergoing development

As for the system, we are currently developing the AR support for the factory worker, enabling him to view picking and optimization instructions directly in his workspace. Similarly, we are also working on visualizing the heat maps and flow maps directly on the racks, which P4 suggested. Thereby, authAR can be used to make an in-situ analysis of a workspace. For this purpose, we are using the Microsoft Hololens 2 and Vuforia VuMarks.

As for future studies, we want to conduct different studies with the authors and users of AR instructions. The ongoing qualitative study with domain experts in the author role will continue. Additionally, we plan to conduct a controlled study with factory workers in the user role comparing AR optimization instructions to other instructional media including 3D instructions on a tablet and paper instructions. The comparison of AR picking instructions to other types of instructions has been covered extensively in previous research, but the optimization instructions are a new type of instruction not covered in empirical studies before.

So far, authAR was designed to work with the order data from SFF. However, we plan to generalize authAR to other use cases as well. The power of an authoring tool, and an HCI toolkit in general, is partly measured by how generalizable it is to different cases [9]. Specifically, we are currently obtaining order data and a 3D reconstruction from another pick-pack line at Velux and working to standardize and apply the data from multiple use cases.

5 RELATED WORK

authAR is a prototype system for authoring AR picking and optimization instructions. Therefore we divide the discussion of related work into a discussion of AR authoring systems and picking systems.

Winer et al. [1] categorizes authoring systems into: 1) linking systems [6], 2) AR previewers [10] , 3) virtual registration [4], 4) hybrid methods, 5) context aware systems, 6) knowledge based systems [7], and 7) 3rd party packages such as Unity3D and Vuforia. They further categorize the interactions with the systems as follows: 1) Desktop GUI based authoring, 2) Mobile AR authoring, 3) HMD authoring, 4) authoring by demonstration, and hybrid authoring. Our system, authAR, belongs to the categories "knowledge based systems" and "3rd party packages" because it incorporates the domain knowledge of the author during the authoring phase, i.e., order lists, thus is it knowledge based, and it is developed as a window editor plugin for Unity3D, thereby making it a 3rd party package. authAR uses desktop GUI based interactions. Research on AR authoring in an industrial context [1, 4, 7] can be described using the above categories. For instance, Gimeno et al. [4] use desktop GUI based authoring and virtual registration to place virtual markers in static images of the industrial environment and then place 3D content on those markers. By placing a printout of the virtual markers in the same location in the physical environment, a user can see the authored 3D content through an AR smartphone application. While this approach requires a lot of manual work by the user, Jo et al. [7] use desktop GUI based authoring and a "knowledge base" consisting of manuals and multi-media to automatically retrieve instructions on aircraft maintenance, thus partly automating the authoring process, similar to how authAR works.

In a nutshell, AR picking systems give step-wise instructions on where to pick an item and, if needed, where to place the item. Additionally, information about the quantity of items may be displayed. These systems are predominantly explored for use in warehouse logistics but can also be beneficial on production lines as evidenced by the SFF case.

Research shows that AR picking systems based on head-mounted displays or projectors are superior to paper-based picking lists and pick-by-light systems in terms of picking times and error rates [2, 3, 5, 11, 13, 14]. Interestingly and in contrast to previous results, Funk et al. [3] found that projector-based AR is superior to paper-based picking instructions, while AR on a head-mounted display is not. According to the researchers, this deviation in results may have been caused by hardware and tracking limitations of their head-mounted device.

Since plenty of empirical research already exists comparing AR and other instructional media for order picking, we build upon this work and focus on adding an additional layer of functionality to the classic AR order picking systems by optimizing the picking space. Thus, authAR is developed as a tool for optimizing picking space layouts and generating AR instructions on how to rearrange racks and boxes to achieve this goal. Similar work on optimizing picking routes exists. For instance Latif et al. [8] recently proposed to use an AR-HMD to 3D scan a warehouse and process the resulting mesh to calculate optimal picking routes. Our work differs in that authAR proposes AR instructions on how to change the current picking space layout and is extendable by 3rd party programmers, who can script new optimization strategies based on various goals including but not limited to finding the shortest picking routes.

6 CONCLUSION

We return to our research question: "To what degree can the authoring of AR instructions be automated based on a geometric scene understanding and order data from the manufacturing industry?" We provided the authAR prototype as an example answer. The focus of authAR was on generating optimal picking space layouts and AR picking and

optimization instructions based on 3D model and order data from a factory workspace. authAR was perceived as useful in a preliminary study with domain experts, but more so the optimization functionality than the promised AR picking instruction functionality. Hence, our study contributes new knowledge to the field of AR authoring by including the views of domain experts and using real production data for going beyond the automatic generation of picking instructions. A study with the users of the AR instructions, i.e., factory workers, is left for future work since the AR-HMD application is still in development.

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