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An augmented reality application for robotic cell customization

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ABSTRACT

Integrating the Internet of Things in Industry 4.0 demands the combination of existing practises with new technologies. Augmented Reality (AR) is a cutting-edge technology of the new manufacturing era. The fourth industrial revolution challenges and AR technology advances, promise to improve productiveness, working quality, user experience and allow better use of resources. AR combined with mass customization could fulfil rising market demands and customer functional requirements. This work presents the development of an AR application to integrate customers in the designing process with product customization. The application is to be validated and used in the industry of Robotic Cell Manufacturing.

1. Introduction

In the current era of Mass Customization, it is abundantly obvious that manufacturers around the globe want access in developing or already bloomed markets. One way for manufacturers to get that access is through the market specific regional product requirements. One can easily conclude that there exists a need to integrate manufacturers and customers for the purpose of better designed, better manufactured, closer to specific needs and smarter products 0. The connection between customer and manufacturer empowers the Frugal Production and Innovation concept 0. At the same time, manufacturers aim for progress which will bring them closer to realizing the concept of Industry 4.0. Thus, there is desire for revolutionary production methods and an "out of the box" approach to the processes of designing and manufacturing 0. Augmented Reality (AR) as well as the rise of technologies pertaining to communications and information sharing can be an enabling factor in using smart devices and holographic applications. With such applications and information technologies customers can become part of the manufacturing process and allow manufacturers to get valuable insights in possible new market needs. With such motivation in mind, this work is conducted with the aim to develop a framework through which manufacturers and customers will be integrated on the process of designing and developing a product. The framework is realized through an AR application and will scope to function like a Product Service System (PSS). Customers will be able to create from scratch, or through pre-sets, a preferred product configuration and then visualize their creation in real time. The manufacturer will be able to receive the customers' information and their preferred configuration and then move to manufacturing as well as creating new pre-set configurations depending on the similar requirements set by the clientele. The proposed framework will be implemented in the industry of robotic cell manufacturing.

The rest of the paper is structured as follows. Section 2 presents the State of the Art. In Section 3 the Proposed Framework is presented and in Section 4 the Implementation. Next, Section 5 presents the Experiments conducted. Finally, in Section 6 the Conclusions and Outlook are presented followed by the References.

2. State of the art

2.1. Augmented reality and its applications in manufacturing

Augmented Reality is the technology that enables the view of the real world while embedding it with a layer of virtual objects, made to seamlessly coexist in the real world and real time (Krevelen and Poelman, 2010). AR applications most times consist of three main components, a Rendering component, an Interaction component and a Tracking component (Grubert et al., 2017). The three types of displays used in AR technology include Head Mounted Displays (HMD), Handheld Displays and Spatial Displays (Carmigniani et al., 2011). Input devices and methods like gloves (Reitmayr and Schmalstieg, 2003), gaze

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(Lee et al., 2010) and gesture mechanics (Feldman et al., 2005), are required to enable the user's interaction with the 3D content, thus comprising a 3D Interface (Grubert et al., 2017). Tracking technologies vary (Yi-bo et al., 2008) and are essential to following the user's or the device's movements and rotations in a three-dimensional space (Grubert et al., 2017). Although AR applications have been implemented in other fields, the specific use of AR technology to support industrial processes, such as product design and manufacturing is called Industrial Augmented Reality (IAR) (Georgel, 2011).

Manufacturing has always been a contributing factor to a country's financial growth and as such an important factor to its general development and progress (Chryssolouris, 2006). The constant and ever-changing challenges that the manufacturing sector faces provide a beneficial ground for AR technologies to advance as an answer and solution provider (Nee and Ong, 2013). Many AR related papers have been published as well as many applications have already been developed (Bottani and Vignali, 2019) and more are expected to come forth. According to recent researches the number of users making and sharing AR content regularly is expected to grow direct AR revenues beyond one billion dollars by 2020 (Binaifer et al., 2019). The main manufacturing fields that AR has been applied include Product Design, Assembly, Maintenance, Process Design / Simulation and Training (Mourtzis et al., 2015). Other fields include Remote Assistance, Safety, Ergonomics, Layout Planning and Robotics, just to name a few (Bottani and Vignali, 2019, Masood and Egger, 2019). In the field of product design numerous applications have been designed. Ng, Ong, and Nee (2010) (Ng et al., 2010), developed an AR system to support the participation of customers in the design process. Arbeláez-Estrada and Osorio-Gómez (2013) proposed an application that enables customers to evaluate products and send feedback to designers. Mourtzis et al. (2017) implemented a combination of two mobile applications, one of which utilized AR technology, for the inclusion of customers in the design process via customization and then the decision-making pertaining to manufacturing planning. Kousi et al. (2019) presented an AR application for Assembly / Disassembly that enables human-robot communication to increase assembly line flexibility. Mourtzis et al. (2018) developed a maintenance service tool that uses AR technology for maintenance, enabling malfunction detection and definition of required maintenance tasks. It is noticeable that most AR applications in industrial environments are focused on providing instructions for assembly processes. Solutions that are adaptable to the user experience and the reduction of costs using AR remote assistance are indicators for the innovation potential of augmented reality in the industry (de Souza Cardoso et al., 2020).

2.2. Robotics and layout planning

At the same time, robotic systems have become integral and vital parts of the manufacturing industry due to their versatility when executing manufacturing tasks in environments of constantly increasing demands. Robotic cells consist of industrial robots capable of performing numerous operations needed to complete tasks (Suemitsu et al., 2016). Tasks allocated to robotic systems are usually ones the human workforce of the production line is unable to perform or that are programmable and don't require cognitive skills with decision making. The need for increased flexibility and production rates requires the collaboration of humans with robotic systems. As such, the layout planning of manufacturing systems is vital to ensure the near optimal positioning of resources and their safety (Berg et al., 2019). Taking into account the additional needs for configurability and cost reduction the decision-making pertaining to layout designing constitutes a tough challenge (Herra et al., 2018).

To address this challenge numerous approaches have been proposed utilizing mostly simulation and optimization methodologies. Suemitsu et al. (2016) proposed a multi-objective optimization technique assisting the layout design for multi-robot cellular manufacturing systems using a genetic algorithm. Laemmle and Gust (2019) developed a tool for the automated layout import of visual components into a desktop simulation environment aiming to reduce the time for model generation and to enable further layout analysis. An approach implementing augmented reality and HMD devices was proposed by Herra et al. (2018). An AR extension was developed to enable the real time simulation and analysis of pre-drafted factory layout configurations.

2.3. Mass customization and customer feedback gathering techniques

In the era of Industry 4.0, the importance of flexibility as a manufacturing attribute (Chryssolouris, 2006) is increasing exponentially since manufacturers are moving towards the production of customizable products and services. Mass Customization is the paradigm that enables the flexible design of varying products based on customer preferences with as much cost efficiency as possible (Hu, 2013). The utilization of methods such as modularity and product family architecture is key for mass customization to suffice market demands, since the paradigm is realized through the assembly-reassembly and reconfiguration of preexisting product parts (modules) (Hu, 2013). Open product architectures are based on open platforms that enable parts with different attributes to combine as one product. Mass customized products consist of common and customized modules. The Original Equipment Manufacturer (OEM) creates the product's main structure on top of which the modules are integrated. They, also, publish the standards or requirements that other components, created either by smaller companies or customers, need fulfill (Koren et al., 2013). Moreover, the process of co-creation and the inclusion of customers in designing, proven to add value to the end products (Hochdörffer et al., 2018), can empower Mass Customization. To implement co-designing, the utilization of open product architectures (Koren et al., 2013), on-demand manufacturing systems (Hu, 2013) along with Cyber-Physical Systems (CPS) (Mourtzis, 2019) is critical. On the other hand, feedback is also crucial for manufacturers and companies to better adapt their products and services to the specific requirements of each market (Mourtzis et al., 2018). Through customer input, market insights can be acquired as well as customer functional requirements. For that reason, companies follow a painstaking process when gathering information on their products or services. They motivate customers to comment on their acquisitions so as to utilize the input when designing or re-designing products. The amount of data, the many opinions and the rise in the use of mobile devices have led to applications to ease the gathering and management of feedback. That way, the design of better products and services is enabled while the notion of frugal production is empowered (Mourtzis et al., 2016; Mourtzis et al., 2018).

Conclusively, there are many applications on product Design and Customization along with approaches for Layout planning. Nevertheless, not many AR applications combine the customization of monomer products with their layout configuration that creates a polymer (Bottani and Vignali, 2019) (i.e. Robotic Cells). At the same time, other similar contributions, as indicated in (Herra et al., 2018), are aimed towards field experts without being user friendly. Platforms that can function like interactive product catalogs while also being a widely available tool for customization and layout configuration are scarce. It is this gap that motivates the proposed framework presented in this paper.

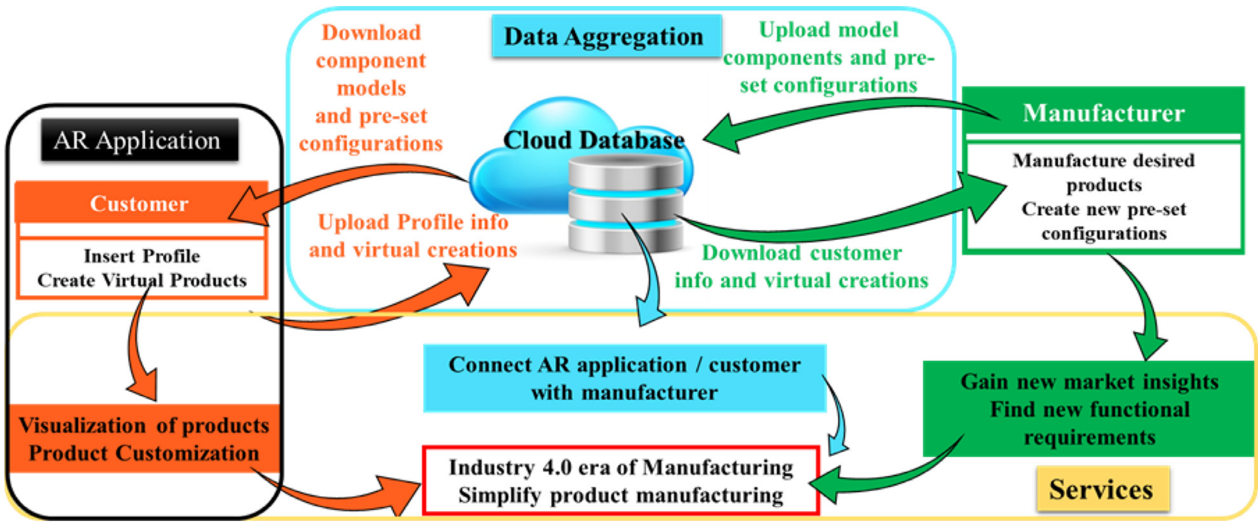

Fig. 1. Proposed Framework Layering.

3. Proposed framework

3.1. Framework requirement analysis

The proposed framework must fulfil a series of specific requirements to achieve maximum functionality. These requirements will lay the foundation on which the framework will be constructed upon and at the same time provide a standard with which to evaluate it. Notes such as these can be used to pinpoint areas of the adopted architecture needing refinement or unveil unexplored opportunities for its future development. The five noted requirements of the framework are the 3D CAD files of the objects to be visualized, an HMD AR ready device, a suitable infrastructure to support the communication between the manufacturer and the customer, a fast and reliable connection to the Internet, and a Cloud database to store the exchanged data. The proposed framework can be used by both experts and non-experts. It will connect customers with manufacturers, a system which will enable the former to create the desired product configuration step by step and the latter to gain valuable insights of the market demands.

3.2. Framework layering analysis

The proposed framework consists of three Layers depicting what the scope of each component is, as presented in Fig. 1. The first layer is the AR app through which the product customization is conducted by the customers. By navigating the application's User Interface (UI) the users insert their Profile and Visualize the desired product in an AR environment, providing at the same time their product Functional Requirements. The second layer includes the Services provided by the use of the AR application. The system enables the Visualization and Customization of products as well as the communication between customer and manufacturer. Through that communication, the customers' Functional Requirements become known to the manufacturer and can then be fulfilled. The third layer contains the Data Aggregation module of the framework. The equipment manufacturer uploads modular component models and component layout configurations to the Cloud database which are then downloaded by the customers for visualization via the AR application. On the other hand, customers upload their desired virtual creation along with their comments which are downloaded by the manufacturer to move to manufacturing.

3.3. Framework architecture analysis

Diving deeper than the layering analysis it is imperative to explain how the system functions. The designed architecture is presented in Fig. 2, where the four modules comprising the framework are reflected, namely the user front-end, the AR application, the manufacturer back-end and the Cloud database. Users install the AR application in their HMD device, register to create their account and then login, proceeding to the application's UI. Through the AR application, users' profile information can be updated and most importantly the product customization can take place. Users have the option to begin customizing products with pre-set layout configurations or step by step creating their own layout. The application enables the real time interaction with downloaded 3D models and the visualization of the product components. Once the desired configuration is reached, a form is created, containing the customers' profile information and the final product configuration, which is sent back to the manufacturer.

Manufacturers use the Cloud database to download the customers' information and virtual creations. Then, the customer functional requirements are reviewed to determine if there are enough similar ones to justify the creation of new pre-set models and layouts. After this process is completed, manufacturers can move towards manufacturing the customers' desired products as well as upload the pre-sets and component models in the database.

The Cloud database is used as a mediator between the manufacturer and the users. It is used to store the files containing the product models and the user information. It enables the communication of these files between parties and allows manufacturers to easily manage their clientele and orders.

With the proposed architecture the manufacturers and the customers can both be integrated on the product design phase. Due to the user-friendly application, the design process can be realized by experts and non-experts alike, meaning that non-designers can get their requirements across in an organized and easily manageable fashion. At the same time the framework can function as a platform for customer feedback input and manufacturer provided services, since it enables easy communication between manufacturer and customer.

4. Implementation

In this section the tools used to develop the proposed application will be described. In terms of software, the component and

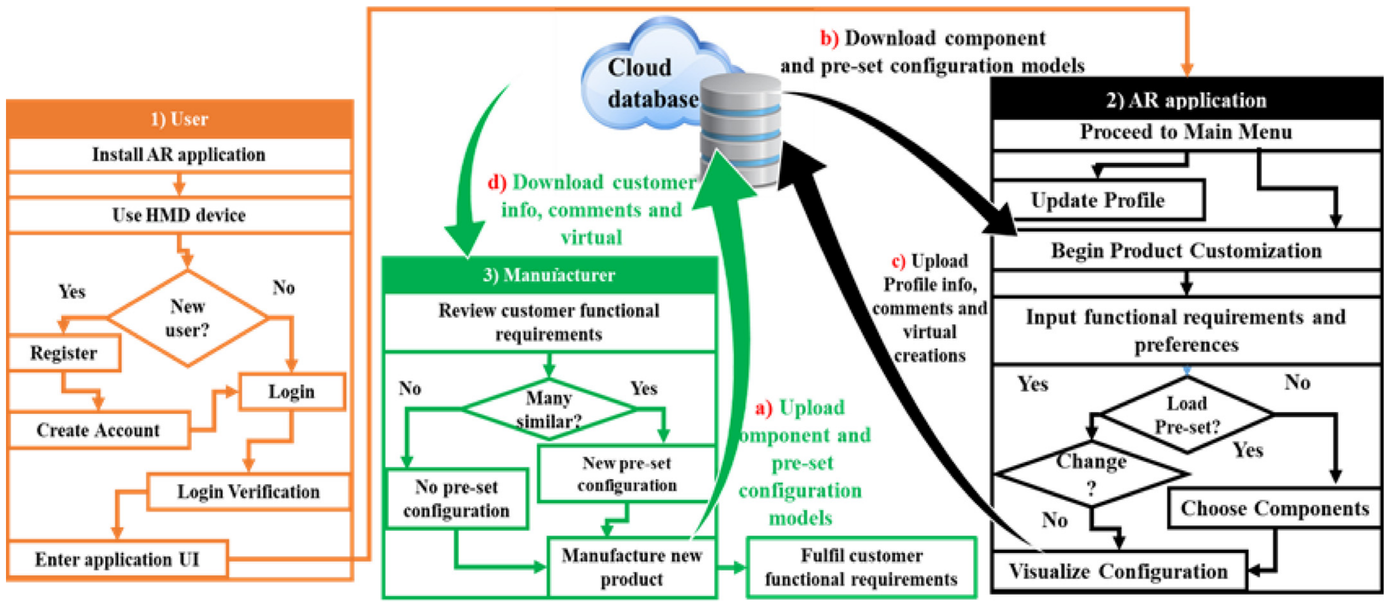

Fig. 2. Proposed Framework Architecture – a, b, c, d, refer to the sequence of data transfers.

product CAD designs are needed for the creation of the AR models after they have been converted to .obj files and a development environment is required for the creation of the application's interface. Towards that end, Unity 3D™ has been used in conjunction with the HoloToolkit library, to support the desired hologram interactions and input methods. Scripts are written in C# programming language using the Microsoft Visual Studio integrated development environment which is directly compatible with Unity 3D™.

In terms of hardware the application was developed for Microsoft HoloLens which is an AR ready HMD. The device was chosen as such because, it offers a better user experience, while at the same time it allows the user to have their hands free, thus enhancing their haptic experience. What is more, due to being light and wireless, in addition to being adjustable to the user's head, HoloLens provides increased mobility. The selected HMD utilizes gaze and gesture input methods to interact with the AR interface which provides valuable flexibility to the user when in a manufacturing/production line environment.

Lastly, an FTP (File Transfer Protocol) server is required, to enable online data exchange and an SQL (Structured Query Language) Cloud database, so that information is stored in a structured way. FTP is chosen since it offers access to directories with sub-directories in the host server which enables manufacturers to keep track of clients, their profile information and orders. On the other hand, an SQL Cloud database is preferred since the stored data follow the relational model. SQL allows for data description, manipulation and permission setting.

5. Experiments

In order to assess the applicability of the developed application and thus the proposed framework, two sets of experiments were conducted. The first experiment was focused on the design of a new robotic cell, while the second was focused on the customization of an existing robotic cell using the AR application.

In that context, today's customers who are interested in acquiring a robotic cell or customers that are willing to renew their existing fleet, for their production line, either navigate the manufacturer's webpage to view the cell's brochure, pictures and specifications or physically visit the manufacturer's exhibition/premises to view the desired products. This process is a painstaking and time consuming one, leading to ambiguity pertaining to some of the cell's specifications. The most common ambiguity met is whether, the desired robotic cell fits the customer's available space and particular needs while at the same time adhering to safety regulations. To that end, the decision-making process adds extra costs, as the customers are required to travel to the manufacturer's exhibition or acquire the wrong product due to miscalculations or misconceptions. The proposed framework addresses these problems by enabling the visualization of the Robotic Cell's components as interactive holograms in real time and simultaneously enabling their customization, while also assisting the manufacturer in filing clients and orders.

Robotic Cells can be designed in many different variations, with a variety of component configurations and sizes. As such, to simplify the designing problem, it is assumed that a base robotic cell consists of a Robotic Arm, a compatible gripper and a protective boundary fence. All other cells derive from this base either by adding, removing or changing at least one component of the above categories or by changing the components' layout in space. The base cell can be supplemented by auxiliary components (stocks, buffers, etc.). It is also assumed that the manufacturer has uploaded the component models in the correct format (.obj files) in the Cloud Database and that these components are compatible with each other, meaning robotic arms and grippers are interchangeable. With these assumptions in mind, a robotic cell can be designed and customized by a potential customer, even if they are a non-expert since the application is intuitive and contains an easy to use GUI (Graphical User Interface).

As indicated in Fig. 3, the procedure starts with the customer using a HoloLens device connected to the Internet to download, install and start the Robotic Cell Customization application. The first screen shown prompts the user to proceed by "Air-Tapping", the main gesture input method of the device. The next screen enables registration or login, if an account already exists, using email and password. The account is registered in the SQL database through the FTP, with the creation of a customer folder containing their credentials. Both the database and the FTP are docked on a Cloud database. After logging-in, users gaze at the application's Main Menu with the options: Begin Cell Construction, Profile Settings and Exit. The Profile Settings option leads to the GUI that allows the users to input their profile information, save, and then

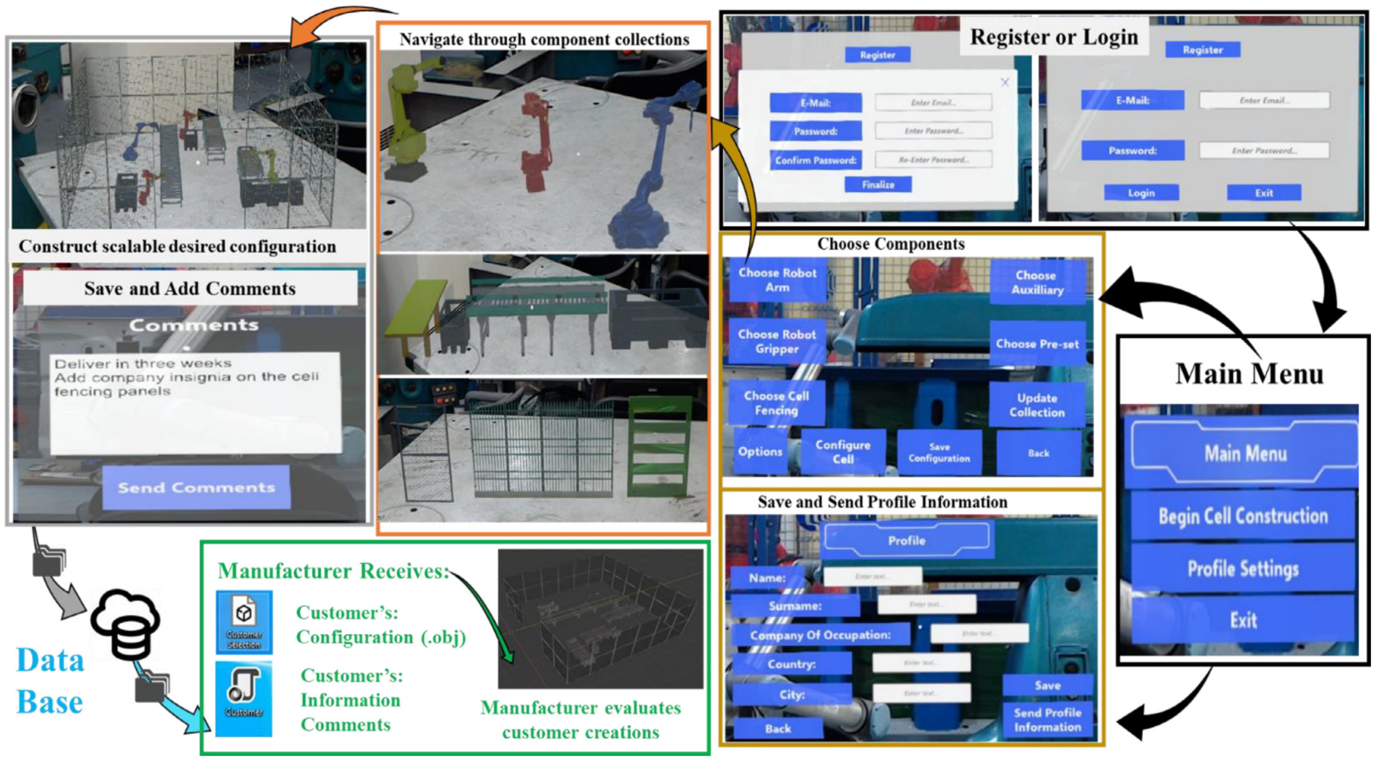

Fig. 3. Testing The Developed System.

send it to the database creating a sub-directory in the customers' folder containing their profile information for future reference.

The main function of the application is enabled by the Begin Cell Construction option. The GUI that follows contains holographic collections of pre-set configurations and cell component models that users can navigate through. Once the components are chosen, the users can interact with them. The holograms can be scaled, duplicated, removed, moved freely, rotated and customized (preferred components, layout configuration etc.) When a desired configuration is reached, they can choose to add comments in the respective field and save it. The configuration model file (.obj) is exported to the customer folder in the database and another sub-directory is created containing the customers' comments while saving process.

On the other end, the manufacturer has access to the server, to ensure access and review the customer models. Meaning each order is evaluated separately and the manufacturer can reach back to respective customers to finalize transactions. Simultaneously, orders are evaluated collectively to gain regional, or otherwise shorted -depending on customer profile information- market insights. Finally, the Model Collections can be updated accordingly, by the manufacturer, with new components or pre-set configurations based on those insights.

The second set of experiments consists of a scenario in which a customer requires a robotic cell for a production line. The scenario demands that the required cell configuration needs to receive products from an input stockpile, transfer them in batches of four to a drilling process station, and then transfer them again to be packaged in bags, by a human workforce, and moved to an output stockpile. The responsible engineer of the customer company uses the application, to construct the desired configuration and then send it to the robotic cell manufacturer. The fully constructed robotic cell, is composed of four robotic arms with their respective grippers, three conveyors, an input stock, an output stock and two buffers. The robots tasked with transferring the unpackaged products are identical and equipped with a dual arm gripper to cover the demand for product batches of four. The drilling process is completed by a drill robot while the robot tasked with moving the packaged products to the output stockpile is equipped with a jaw type bag gripper. Lastly, the fencing is made up from identical panels and the conveyors chosen are of the roller type.

6. Conclusions and outlook

A framework to integrate customers in product designing and the development of an Augmented Reality application were presented in this paper. The framework aims to function as a platform enabling customers to design or customize products to their specific needs, manufacturers to gain market insights and the communication of parties. It can be concluded that the AR application can be an applicable tool towards the digitalization of design processes and the simplification of production, demanded by the Industry 4.0 era of manufacturing. As far as future work is concerned, the framework needs to be validated and evaluated in a multitude of other manufacturing cases to produce more quantifiable results while the platform could be adapted to other industries as well. Work will be focused on the framework's refinement in terms of the application, data aggregation and security.

CRediT authorship contribution statement

D. Mourtzis: Supervision, Conceptualization. **G. Synodinos:** Writing - original draft, Software, Writing - original draft. **J. Angelopoulos:** Methodology, Investigation, Validation, Methodology. **N. Panopoulos:** Writing - review & editing.

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