Augmented Reality as an Innovative and Efficient Technology to Increase Quality in Manufacturing Processes

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Abstract Manufacturing processes are divided into stages whose purpose is to achieve the desired object: the initial phase of these stages is the design of the product, continuing with the cutting of the fabric and the assembly of the pieces. Thus, in the design stage, the prototypes of the product are made, which are distributed to the manufacturing microcompanies so that their assemblers first visualize them according to their instant perception and, later, they keep them in their memory. This process is carried out according to the memories of what people perceived, which can lead to assembly errors and which, in turn, will be translated into losses of time and economic resources. This is where the use of augmented reality makes sense, because to make manufacturing processes more efficient it is important to use digital technologies with tools that simulate the physical structures of products, that is, to allow users to use their cognitive ergonomics in the production process. In this research, a system based on augmented reality is developed that shows a different way of building patterns and, of course, allows multiple benefits in manufacturing processes. The system was focused on the garment industry because of the complexity and variety of garment patterns. The results indicate that augmented reality is an efficient and extremely important technology for the manufacturing area and, consequently, allows the optimization of delivery times, costs, and material waste.

Keywords Augmented reality · Manufacturing · Clothing industry · New technologies

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1 Introduction

The manufacturing areas are key elements in the manufacture of products of any kind (Moghaddam et al. 2018). Each of these areas is of elementary importance, both individually and jointly, for the creation of a product, but they also require new methods to help optimize their processes (Grubor and Milovanov 2017; Guo et al. 2018). For their part, industry leaders have recognized the need and importance of developing approaches to improve competitive advantage in the development of new products. However, the process of product innovation is complex and involves the effective management of different actions (Awazu 2006; Ning et al. 2020). Fortunately, the cost of technologies is falling exponentially over time, which leads to a drop in the costs of their implementation and, consequently, it is intended that more innovative technologies are available to SMEs (Abulrub et al. 2012). In this way, avant-garde actions and methods are currently emerging that help to complement the production processes, such is the case of additive manufacturing or also called 3D printing (Bowman et al., 2005), which is revolutionizing manufacturing with small-scale 3D printing and, later, will serve to create large-scale parts (Roschli et al. 2019). Furthermore, immersive 3D visualization (Mazikowski and Lebiedź 2014; Lebiedź et al. 2010) is becoming the innovative tool for new product development (NPD) in several sectors, including manufacturing. This latest technology can be integrated into NPD processes, or facilitate the understanding of complex information, as well as used in simulation, planning and training. These technologies have the potential to provide a distinct advantage for companies to continue or become leaders in their field.

Other inventions that include intelligent technologies of various types, and that come together as important pieces in the production process, are computer-based models, manufacturing systems and sensor technologies, virtual/augmented reality, the Internet of things and technological trends; all correspond to global patterns, which individually and jointly reveal a range of multiple sector applications (Turovets et al. 2019). These tools must be contextualized, especially in research that directs them toward points of support and thus build intelligent and avant-garde factories, according to the technological era in which we live today (Zhong et al. 2019; Strozzi et al. 2017; Hozdić 2015). Of course, these tools must be able to improve and facilitate both manufacturing processes and derived products and be useful to people (Rao 2011). Therefore, manufacturing areas are key elements in the manufacture of products of any kind and require new methods to help optimize those processes (Šatanová et al. 2015; Afteni and Frumuşanu 2017).

The production phase begins with the design of a new product, which will serve as a prototype and must meet certain parameters related to measurements, materials, and specifications (Shao et al. 2018; Katrijn 2012). The pattern of a product is made geometrically following the indications of the model created by the designer, who is a fully trained person in this profession. Once the new product has been designed, the base model is translated into assembly terms by the manufacturing area staff, who give it their own construction interpretation, especially in the elementary details of the garment; this interpretation can sometimes be wrong or different from the base model proposal. It is clear that if this interpretation is totally correct then a quality product will be obtained. Otherwise, a product with defects could be obtained and, as a consequence, it could not be sold or its value and/or quality could be diminished. These drawbacks show the need to introduce cutting-edge technological tools that help optimize manufacturing processes through the visualization of patterns, which must be coupled or adapted to each person who interacts with the base model. On this type of technologies adjacent to factories, the research trend is focusing on advancing processes through a digital world, which is present in everyday life and is essential for any type of activity (Mekni and Lemieux 2014; Alkhamisi and Monowar 2013).

Companies are currently applying innovative technologies to reduce production costs, introduce product and service innovations, promote their patents, facilitate growth, and raise barriers to entry (Nie et al. 2018; Bravo et al. 2015). Among these innovative technologies is augmented reality (AR), which can help and catapult a company to the extent of gaining a competitive advantage in a market segment (Bulearca and Tamarjan 2010; Baratali et al. 2016).

Despite its enormous potential to streamline business innovation processes, AR adoption is not without risks in traditional areas such as human resources and expected performance levels (Martinetti et al. 2019). On the other hand, the risks of using this new technology can be mediated through careful planning and management, i.e., successful adoption of a technology can push companies even ahead of their competitors (Ong et al. 2008; Nee and Ong 2013; Bloching et al. 2015). A tool that lately converges toward these requirements in the production processes is the AR, which contains, in turn, several technological tools with different purposes for the construction of objects (Bottani and Vignali 2019). The elements that integrate the AR, such as videos, 3D images and animations, open a new world of opportunities from the perspective of the supply chain (Rejeb 2019; Koul 2019; Cirulis and Ginters 2013). In other words, this technology not only makes it possible to increase the efficiency and flexibility of manufacturing and distribution processes, but also modifies, with a special emphasis on the consumer, the relationship between the different steps of the supply chain (Merlino and Sproģe 2017; Condino et al. 2018).

AR goes beyond the use of tricks in games, entertainment and the use of technology, and it is precisely in this context that the benefits of AR in manufacturing production should be highlighted (Etonam et al. 2019). In these production processes, where technologies are not used in a taxing way for users to do new things, AR allows for increased creativity and simultaneously persuades workers to perform their daily activities with other alternatives that provide them with better experiences when performing their activities (Siriborvornratanakul 2018). In this context, it is time to use these new technologies to provide benefits different from what people are used to. The AR has facilitated the creation of new building techniques and even, depending on the type of manufacture to be built, systems based entirely on the AR have been codified and applied in different ways and in multiple contexts.

The AR presents the product design, but not only as a sample of what an object could be or how it would be visualized at a given time; it visualizes it as a useful way to represent both objects and their constructions more deeply, and thus to understand its implications in other areas, for example, the maintenance of a building. To exemplify this case, Khalek et al. (2019) investigated the design of a building, where decisions made at the beginning of that phase had a significant impact, measured by different means of visualization, which allowed inexperienced people to identify, through the implementation of an AR-based system, maintenance problems in a design model.

Nowadays, there are tutorials that allow to complete the construction processes, even some of them are not limited to the use of 2D images and are based on more innovative technologies such as a software that helps to build frames of wooden structures, which uses a software based on AR with a full-scale visualization and audio. In the USA, this technology allows builders to follow extremely specific and exact measurements and thus facilitates the adaptation of frames in wooden houses (Cuperschmid et al. 2016). Without a doubt the success of the AR, applied to this case, is due to the fact that the frames are of a standard type.

Another company that manufactures high-precision instruments and tooling equipment for machining parts in industrial companies is the German company Emuge-Franken (see https://www.emuge-franken-group.com/de/en/). This industry has implemented virtual technical manuals for the tasks related to the creation of tools in thread cutting and milling technology, which constitute a basis for their business. This company has also adopted the animated models of the AR-based HF20 threaded spindle assembly. The experience of this company has shown that the use of the latter product is necessary for companies in the Russian market, as they deal with metal processing by drilling and generating threads (Gren et al. 2018). Thus, the use of these new technologies has been considered, as the key tools for companies to improve their competitiveness and develop their relations with the nodes of the upstream and downstream supply chain. Consequently, the applications of these technologies for supply chain management have become a fruitful area of research mainly due to their clear and strong management implications.

In this way, the AR has been assessed for inclusion in future manufacturing processes. The main purpose of this is to allow workers to perform multiple tasks, which will allow the change from mass production to customized production. There is definitely much to be done to fulfill these promises in an industrial scenario or scale. However, in terms of the development of AR-based tutorials for assembling objects, we can see a greater performance in the tasks with the highest degree of difficulty (Uva et al. 2018). This background is the basis for the implementation of future intelligent factories, which are waiting for the best techniques to facilitate manufacturing processes (Rabah et al. 2018). Therefore, this research is built by envisioning the creation of these new manufacturing companies totally focused on improving the quality of their processes and not only on design forms, that is, these new companies will move from the discernment of the abstract to superimpose it as AR (Segovia et al. 2015).

This research focuses on the area of the clothing industry where the design must have an adaptation that leads to the quality of the garment, which will be achieved by following exactly the geometric characteristics of a prototype, created before starting with the manufacture of the garment and function as a guide for the transformation of raw material into clothing. The workshops are the spaces where the garments are manufactured, that is, where a physical sample is prepared and whose design be memorized by the "constructors". They must memorize even the hidden, but necessary, details so that the garment is visualized and functions as in the original model. A disadvantage in this process is that in many cases the ergonometric or operating details are complex and, consequently, will be difficult to memorize or specify so that, not having the garment that serves as a pattern in sight, the assembly can be done in a wrong way. With this, the manufacturing industry loses material resources, time in assembly and, of course, work done. In addition, when corrections are made to errors in manufacturing, delivery times are delayed and, consequently, the allocation and obtaining of profits, which ultimately result in a significant deficit for the company.

As mentioned above, the AR has been adopted in various ways in factories of some specific sectors, for example, through tutorials that allow the repair of machinery and where inventories are required that require optimization of space (Henderson and Feiner 2007). The AR also works with instructions for building tools or other types of objects; however, this proposal focuses on complementing the manufacturing processes, helping from assembly to quality control. All this with the purpose of obtaining better-elaborated products that led to optimize the cost-benefit equation of a manufacturing company (Sabarinathan et al. 2018). In other words, and as will be detailed in later sections, this research is intended to help ensure that the manufacture of garments is done in such a way that anyone who has this technology, usually with a mobile device, is involved in the production chain in a more efficient and reliable way. This with a view to providing the optimization of manufacturing times and, consequently, obtaining greater profits.

1.1 Objective

Create an AR-based system with previously designed resources that support workers during the assembly process in clothing. Implementing a system of this nature in a factory where garments are made aims to improve and speed up the manufacturing process with the support of technological tools that help optimize delivery times, resources used, and quality of garments. Analyzing the performance of a system with these characteristics will serve to generate recommendations.

2 Methodology

The XP methodology, also called Extreme Programming, is an agile framework where the proximity of the client to the development team is important for the correct design of a small project. The fundamental principles of this framework are based on a quick feedback, its simplicity, the acceptance of incremental changes, and high-quality software. The main stages that were considered for the development of this application were: planning, design, coding, testing, and release, which will be described below.

2.1 Planning

In the garment industry, garment production is done in stages. Each of these stages is a process that at first sight might seem easy and autonomous, however, each of these stages has its own degree of difficulty and, simultaneously, each is different. On the other hand, there are different levels of difficulty in the assembly, where it is essential to take into account several aspects such as the union of pieces that are different, the details that are hidden and the combination of different colors, just to mention some of them. One of the main problems that the manufacturing process faces is, precisely, when the assembly is not done properly. That is to say, when the assembly of the pieces is not done according to what is established by the prototype of the garment. This problem leads to large production errors that, consequently, generate considerable losses in time, money, and effort.

The phases involved in the manufacturing process of a garment can be listed chronologically. The diagram of activities in Fig. 1 shows the process involved in making a garment: the process involves everything from designing the garment and cutting the fabric in the factory, through the assembly process and up to the return of the new garments for their corresponding packaging.

In this context, the phase of this entire process that takes on the greatest importance, and from which this research work emerged, was the assembly stage, which is described by the following actions:

- When the packages of cut fabric arrive at the maquiladora, the person who delivers them is responsible for teaching and giving instructions about the garment called "sample" or "pattern" to the assemblers who, in turn, observe it and keep in their memory as many details as possible to later proceed with the assembly process.
- The elaboration of the parts that make up a garment is carried out in series, that is, there is a team of people who perform a specific process such as the assembly of necks, sleeves, backs, and front. After these tasks, the garments are transferred to the people who proceed to finish the garment; this process considers from the placement of buttons, eyelets, closures and/or clasps to the final stage, which is when the remaining threads are removed. The finished garments are transferred to the ironing area, followed by packaging.
- The quality control is carried out in the packaging, because it is precisely at this stage where the garments are arranged to be packaged. That is, at this stage people review the finished garments in detail and, if necessary, they notice some defect in the assembly. This stage is of the utmost importance in quality control, since the presence of the slightest error, usually, will be presented in several garments. The latter is due to the fact that all garments are produced in series and, therefore, the slightest error will also be reproduced in chain.

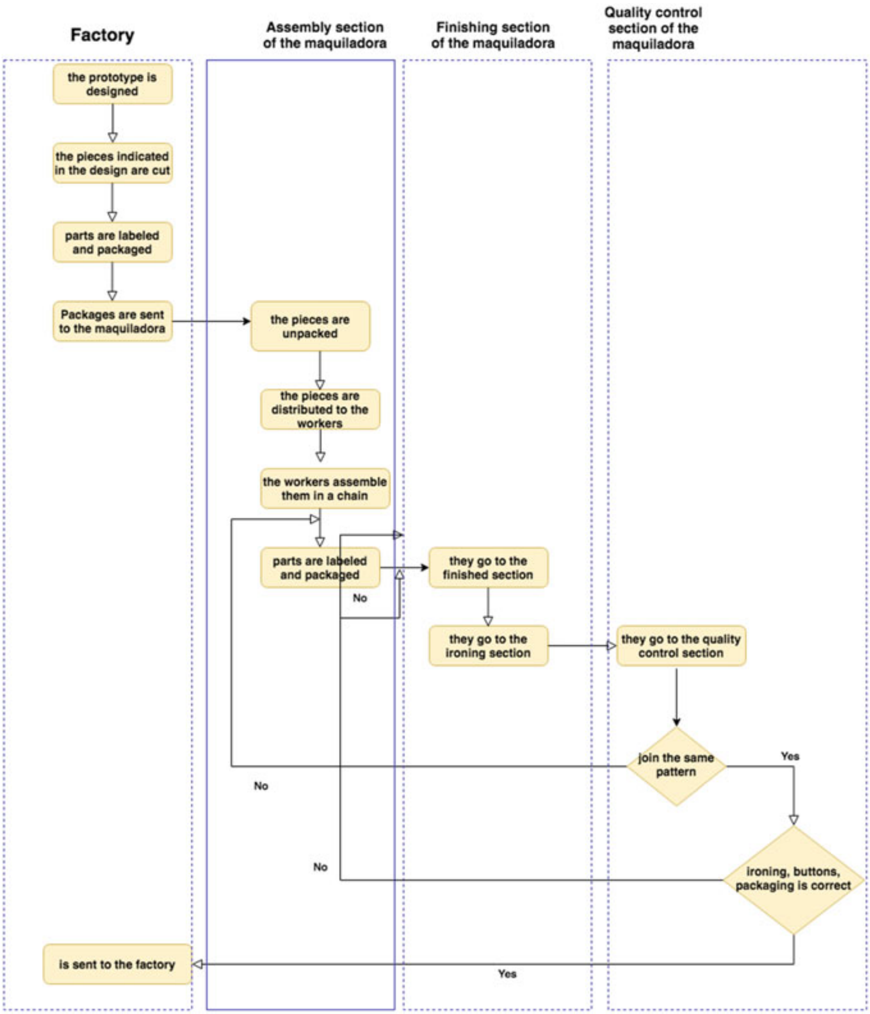

Fig. 1 Process of making a garment. *Source* Author's own elaboration

- A drawback, and perhaps the most important, is that the quality of the garment is reviewed, generally, at the stage of packaging or, what is worse, has happened, that when the garments are delivered to the factory, the personnel of the area who receives the clothes realizes the mistakes. At this stage, the error in the garments is corrected, the correction of the assembly being essential, before the garments are accepted by the warehouse or the parent factory.
- In the assembly industry, there are processes where people have to face real challenges related to the different parts of the product; sometimes there are complex components that have been shaped in the patterns of the garment and rarely consulted by the workers. The workers responsible for processing these complex

patterns have the responsibility to store them in their short-term memory, but on many occasions they may forget extremely important details.

The most frequent difficulties in assembling a garment can be of various kinds, depending on the design of the garment. Some examples are mentioned below:

- The side seams are not properly aligned.
- The stitches are the wrong size.
- Some flaps are not made in the right way and size.
- Buttons are placed on the wrong side.
- The color combination is wrong.
- The bags are not in the right place.
- The number of buttons is wrong.
- The hems do not correspond to what is required.
- The collars can be simple and made with a foot collar or vice versa.
- The bags are not aligned.
- There is confusion in the colors.
- The embroideries are in the wrong place.
- The brooches are inadequate.
- The width of the fold is different from the base sample.

Of course, the errors involved in the manufacture of the garments generally depend on their design. The main problem during the design stage occurs when an error is made in the process of assembling various pieces (sleeves, collars, back, etc.), which, in turn, was made up of several garments. As mentioned above, this is because the pieces are assembled in series that, in consequence, allows an error made in one piece of the garment to trigger others, which can lead to defects in an entire batch of garments consisting of multiple defective garments. Also, the different types of errors involved in the manufacturing process involve significant monetary losses, but, above all, time losses. Some of the errors involved in the manufacturing process of a garment are described below:

- When a batch of defective garments is unsewn to correct the assembly, they must be undone and redone, which multiplies the initial planned time for making the garments. In addition, new yarn is used and, consequently, the yarn used before the error was detected has already been wasted. This disadvantage multiplies the cost of the material resources used to make these garments.
- In some cases, the assembly of certain garments uses fragile and/or delicate fabric, which can lead to a garment being damaged or spoiled in the error correction stage. This will undoubtedly result in new fabric being used to remake that part.
- If the buttons are placed on the opposite side, then they must be removed and placed on the correct side. At this stage, the most complicated part is when the buttonholes have the same error because the procedure becomes considerably more complicated and the loss of resources, both material and time, increases.
- The stage where the finished garments are checked is during quality control. However, if the people responsible for this stage do not notice any errors, then the garments will be packed and then sent to the warehouse of the parent factory. If

an error is subsequently detected in some garments or in a batch of garments, they are returned to the factory for correction, which will undoubtedly generate more costs and inconveniences. This stage is very important, because if the defective garments are not detected before they are presented to a store manager then the loss of that customer can be incurred or, worse, the confidence of the people who buy the garments can be lost due to an error in the quality control of the manufacturing.

These errors, and many others, cause delivery times to be considerably extended, resulting in delayed payments and production losses, and consequently reduced profits. All of the above results in the following question what technological factors influence the improvement of a manufacturing process in a factory that uses AR? To answer this question, the following null hypothesis is posed:

H_0: *The AR is an efficient technological tool capable of helping and improving a manufacturing process that is implemented by a factory that makes garments.*

2.2 Design

For this phase, which impacts the entire manufacturing process, the solution proposed by this research work is the creation or implementation of an AR-based system. This system is intended to serve as a guide and training for the assemblers, but in a complementary manner; the system will be provided to the affiliated maquiladoras, along with the manufacturing materials, so that it is shared among all the members that make up the entire production team. In addition, this system has the advantage that each member of the assembly team can consult it, using only their mobile device, each time they require it. All this is carried out to visualize the virtual model superimposed on the piece of fabric that is want to be built; this virtual model, previously established, includes detailed instructions in audio, image, or video format.

At this stage, the AR is very useful, because it is an emerging technology that is defined as a digital shot or computer-generated information, either with images, audio, video, or tactile sensations and that is generated by overlapping in real time; that is to say, the AR is the mixture between the real world and synthetic (Kipper and Rampolla 2013). In this context, the AR is extremely suitable for the area of maintenance in the industry, being easily implemented in processes that can improve the view of users in different scenarios and that also include visual animations, sounds, written, or static instructions (Novakova 2018).

The production line of this new technology is on the rise. This is due to the fact that at present it has found various applications, among which the following stand out: military use, medicine, design, engineering, robotics, manufacturing applications, maintenance and repair, teaching and learning, entertainment, psychological treatments, among (Azuma 2015). For its part, virtual manufacturing is defined as an integrated synthetic environment that is exercised to improve all levels of decision and control. Furthermore, its classification can be focused on design, production and control (Novak-Marcincin et al. 2013). Based on this type of definition, digital elements are used that combine physical and virtual reality, and where design tools can be used in a wide and varied way, for the construction of the virtual manufacturing system. Under this scheme, the AR presents excellent construction tools, although its design should be simple and easy to understand to avoid the user feeling confused instead of being helped. In this way, and considering these principles for the realization of the proposed AR system, the diagram of activities is presented in Fig. 2.

The garment designer, in addition to making his patterns in 2D images with measurements and assembly instructions, must also draw them in 3D images. The latter will favor the visual display of the details to be shown of the garment through a virtual environment; the 3D images should show quite specific details of the model to be reproduced such as measurements, colors, number of components, instructions issued by audio or text, thus fulfilling a primary objective of the companies, which is to manufacture products that meet the needs of their customers (Sun et al. 2016). It is in this stage of the manufacturing process where the use of videos and text messages that explain and show clearly the procedure for the assembly of a garment is used to its fullest. Undoubtedly, using images, audio, and animation means creating a teaching–learning model that transmits in greater detail the assembly process of each piece of the product, specifically in those where the procedure is more complex.

2.3 Coding

The application that managed the digital components was also used to design, build, and implement the manufacturing system, based on AR, combining elements of different formats to achieve a complete digital reality. Currently, there are several AR managers that have similar functions, but differ in their development environments called “IDE”, i.e., have different characteristics that translate into advantages and disadvantages for the AR building user. Some of these managers are: Aurasma, Vuforia, Layar, and ArToolKit with its ARTag variants, ATOMIC Authoring Tool, FRARTooKit, NyARToolKit, and ARDesktop.

For the design and implementation of this AR-based manufacturing system, we used Aumentaty software (see http://www.aumentaty.com/indexEN.php), which is a program entirely designed to create innovative content through AR. This software presents the functionality of handling digital elements in the form of video, 2D or 3D images and points of interest with GPS. An add-on to this software is the Scope app, through which AR is displayed on mobile devices. In addition, there is currently a large collaborative community where interested users are allowed to use their projects or technological developments for free (see http://www.aumentaty.com/community/es/). The Aumentaty software has a content manager called Creator, which is quite accessible to build the projects with AR, which can be shared in the cloud and then downloaded to mobile devices to be used.

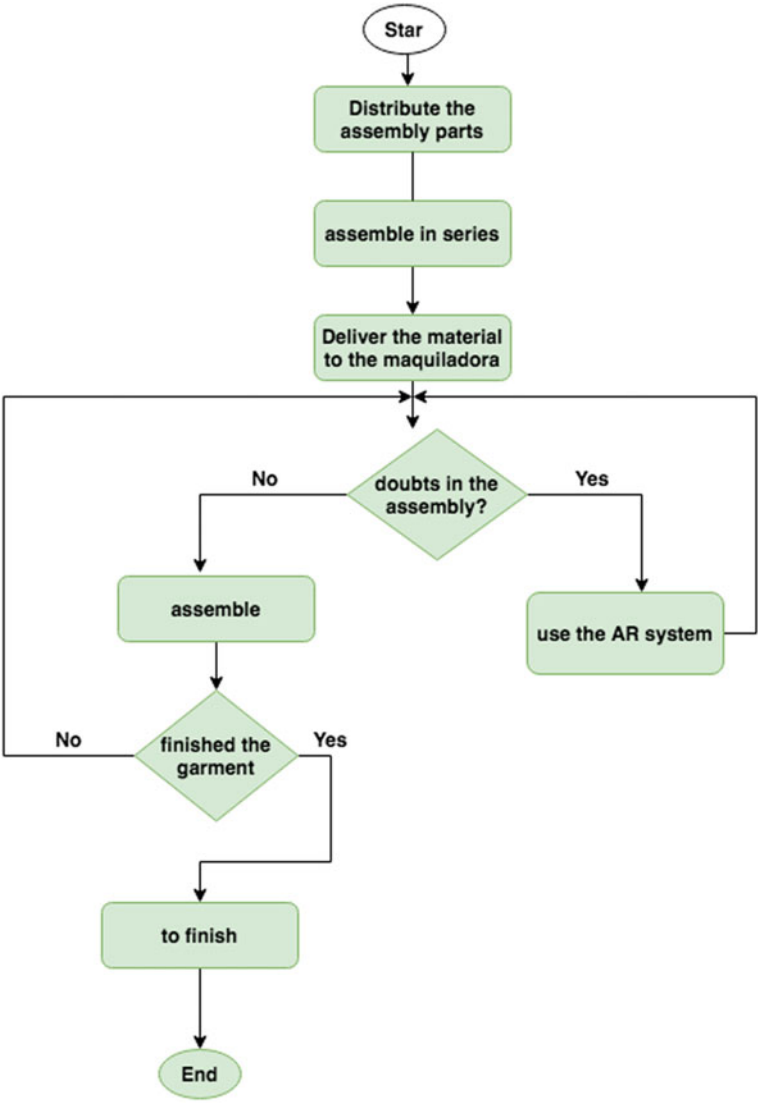

Fig. 2 Manufacturing process of the garments

The AR resources are shown in 3D image and video format, which shows the correct way to do the assembly. These resources allow visualizing step by step the assembly procedure and whose purpose is to provide all the construction instructions to the people responsible for this stage, so that the safety of doing the job in the right way is implicitly adhered to. In this sense, it is recommended that the videos are short, since they are only part of the help that is done through the AR and it is suggested that they have a maximum duration of 2 min. The investment in the time to review

Fig. 3 Sample of a shirt called balloon, using AR

the AR is a resource that is made with the benefit of making many pieces correctly. In order to explain the AR system, we took into consideration the success story of a maquiladora (see Fig. 3), where a specific garment is used, although the system can work with all garments manufactured. For the construction of the manufacturing system, based on AR, the following phases should be considered:

1. The garment is modeled and its general details are added, which will be necessary in the deployment of the AR. These characteristics give the specificity to the garment, and are denoted with the labels of name, color, sizes, and general conditions, as shown below:

Name: Globe-Shirt.
Color: White.
Sizes: 28-42.
Details: Combination of colors, white and cherry.

2. The construction of a garment is made up of several pieces, which have been designed, cut, and integrated into packages for the construction of several garments. Each package of pieces contains all the necessary elements, for example, a shirt is made up of sleeves, collar, back, and front. It is important that each package matches your size and prototype, as all these elements have different shapes that will be joined together. Figure 4 shows the parts that make up the neck of a shirt called shirt-Balloon.
3. For the development of the system, based on AR, at least the following components must be available:

3D images. The 3D images, which are formed from 2D images and can be photographs or drawings, will serve to model the garments in more detail.

Fig. 4 Assembly parts for the collar of a Balloon Shirt using the AR

Markers. Will function as "triggers" to display the AR. The markers are images that will serve to "trigger" the AR when the camera of the mobile device is focused on them.

Multimedia videos. The videos are films where the most complex processes are interpreted. These films are created separately and trying to be brief. In turn, these short films are intended to resolve a question quickly, which will allow the investment of time to translate into a benefit of improvement for the work.

Audio. The audios are files with instructions in voice format that will be able to guide, in a verbal way, the users during the assembly processes.

Cloud storage. This type of storage serves to make available the digital material used in the system. This can be implicit in existing AR managers and can be freely accessible, since if there are few components up the AR then a plan can be contracted that best suits the needs of the company.

AR management. This application is composed of specific markers, which are only words that make up the name or number of the specific garment to concatenate, in turn, the name with its respective image.

The persons who will use the system will be employees working in the garment manufacturing factories. The manufacturing system, based on AR, is quite didactic, that is, it contains virtual elements that are integrated to the physical reality providing the user an easy and safe interaction. Moreover, it is not necessary for the user to have prior knowledge of this technology, since the movements produced are natural, easy to learn and could even be so simple that it would be like moving a body part or an object (Cordeiro et al. 2015). Therefore, the use of the system will not generate any additional expense for learning, as would a training course. Rather, the only thing that will be required is a series of brief instructions to operate the system, since it was created, to be learned in a totally intuitive way.

2.4 Tests

The maquiladoras will receive the elements for the construction of the garments, including the elements of the AR-based system. The workers responsible for assembly will use the system when necessary, that is, when they do not remember a phase of the process looks like, ignore it completely, or need to be sure of some detail. When the user needs to consult how to make a model, it will be enough to place the mold of a part of a garment on a table, open the application on the mobile device and focus its camera on it mentioned mold. The system will recognize the garment's part will superimpose the associated AR, to instantly solve the doubt about the assembly process. This type of AR was designed to show the basic shapes of a product, such as the combination of colors, measurements, sizes, placement of ornaments that are superimposed, the size of the stitches, and color of the thread. (see Fig. 5).

Fig. 5 AR system displaying the sleeve of a garment

Fig. 6 AR system, showing the assembly process by means of a video

Figure 6 shows the implementation of the system, based on AR, using the digital resource in video format. In this case, the user focuses the camera of the mobile device to the neck of the garment, which serves as a "launcher" of the AR, overlapping the help in the form of a video tutorial that shows, through images and audio, the process of assembling a neck for a shirt. Of course, the complexity of the process will depend on how you want to show the AR.

When making use of a code, which must be the name or number assigned by the factory according to the design of the garment and which will serve as a "trigger" of the AR, what is desired is to show the prototype of a garment, to that users appreciate it and consult whenever they need it (see Fig. 7). In this example, the database has a series of names associated with the garments that are manufactured in the workshop. In this way, when the camera of the mobile device focuses on the name "Shirt-Bona", the AR superimposes the image of the selected shirt showing the complete design.

3 Launch

This system, based on AR, was applied in a microsewing company (located in the State of Tlaxcala, Mexico) where uniforms are made and assembled for various commercial companies. The system was applied for one week and the workers

Fig. 7 AR system for a shirt associated with a marker

involved were asked a survey with 15 questions, which were previously designed to obtain the perspective of these users. In other words, the survey was applied to both workers and company management, where the answers to these questions allowed them to know, in a rough way, the activities and/or procedures that correspond to each worker, for example, if they have knowledge about what AR is, if they have a mobile device, what opinion they have regarding the operation of the AR-based system, if they liked the AR-based system, what benefits they believe an AR-based system will provide them, if the manufacturing time is reduced when they applied the AR in the processes they perform The concentration of survey responses is shown in Table 1.

Therefore, the content of Table 1 translates into the following results:

1. On the efficiency of the system, based on AR, users agreed that it is efficient because it allowed them to do their job better. That is to say, when the user has a doubt about some detail then he only has to place the cell phone on the garment to focus the camera and that is when the system shows the 3D image including the specifications and/or instructions for the correct assembly of the garment. In this way, the worker does not waste time asking the people in charge of supervising the garments, which in the worst case are far from the factory or because the employee works in a branch office far from the main workshop or even at home.
2. In terms of accessing AR material, workers commented that the application was stored on their phone and each time they were given new designs then the people responsible for that stage gave them the correct indications, such

Table 1 Concentration of responses through a survey

Procedure	Without AR	With AR	Benefit
Doubts in the assembly	If the employee does the work at home, contact the head of the maquiladora to consult him; In case you do it in the company, wait for the supervisor to answer the question	The employee opens the application, places the camera of the mobile device in the mold or on the sheet where the parts of the garment are shown	Time saving, immediate response, continue process activities
Learn some new process	See the sample and try to memorize the procedure for the worker	Open the application and focus the camera on the name of the piece you want to see and, using the system, appreciate the image or a video through the AR	Train workers step by step and repeat the process as many times as necessary so that they learn it better.
Use of the cell phone	They consulted him just to check their social networks	They consult it to open and consult the AR system, when required	They consult it as a working tool to improve quality in the production process
Use of the cell phone	They consulted him just to check their social networks	They consult it to open and consult the AR system, when required	They consult it as a working tool to improve quality in the production process
Ease of the system	He was not aware of the existence of applications, based on AR, to improve his work	They find it innovative, didactic and easy to apply in their work activities	He was not aware of the existence of these applications for use in his work area

as the name of the new design, to download. Workers found this AR stage quite interesting and innovative because they said that if they had to store all that information in their device memory (photographs and videos) they would easily get confused with the garment models and consequently their search would be longer and more time-consuming. The latter, in the short term, would become complicated and tedious. On the other hand, with the AR system, they would associate the model of a garment in real time.

3. Regarding the functioning of the AR, as a support tool to improve the quality in the correct way of sewing, the results showed in the first instance that, through the AR it is possible to modify in time and form the seams in case their error. So much so, that this system with AR is involved from the precise moment that the assembly of a garment is initiated, that is to say, it serves to consult and to verify the form of assembly, previous to initiating it. In addition, when a damaged piece or garment is detected, the system allows not to damage the others, which results in a correct assembly and to continue with the generation of high-quality garments.

4. With respect to the materials used by the AR, the videos allowed the worker to be shown the correct assembly process for a piece of garment, which included folds, seam adjustments, stitch size, thread color, etc. This phase of the system gave them an excellent understanding of what the garment designer required; workers mentioned that they went to the system whenever they needed to and found the images extremely attractive and easy to appreciate.
5. On the resource of the videos, the workers noticed the advantage of visualizing them through the AR. This consensus was due to the fact that these workers mentioned that if they had to search for a design on their mobile devices, without making use of AR, then they would have to locate them in the gallery of their mobile device where they have their personal videos and photographs, which would generate a search conflict and imply a more extensive search and, consequently, loss of time.
6. Regarding the complexity in the use of the system, the workers agreed that it does not have major difficulties; on the contrary, they found the system quite didactic with a fast and attractive handling.
7. Regarding system compatibility, just to mention that currently almost all workers have an Android smartphone, which meant that none of them had any problem downloading or using the application. It should be noted that the system, based on the AR, also works with iOS.
8. With regard to motivation, it is important to emphasize that the workers were encouraged, happy and excited about the application. They were so enthusiastic that they felt self-sufficient with respect to the assembly of the garments. Although the vast majority of workers interviewed received some training in tailoring, it is always important that their doubts are clarified, so this system makes sense from the very moment of its design because it solved their doubts the moment they were raised and, even more, they were resolved correctly.
9. On the cost, the workers interviewed stressed that they had no conflict with this, as the tool is free and open access. This is undoubtedly an aspect to highlight because it is convenient for both the owners of the maquiladoras and the employees.
10. The time investment to use the application is not expensive, since it only takes a maximum of 3 min if it is a detailed process (video) and one minute if it is a process with AR in image format. Of course, this will depend on the speed at which the data is transmitted.
11. On the learning side, AR is a new, innovative and efficient technology for teaching and training users. The workers interviewed because the vast majority agreed that they learned new learning processes and that supported this result, of course, they did not know about them.

For all the above reasons, there is evidence not to reject the null hypothesis H0: The AR is a technological tool capable of improving the manufacturing process in a garment factory. Likewise, and in order to answer the question ¿What factors affect the improvement of a manufacturing system in a factory using augmented reality?

- Easy and quick consultations: The worker, when using the AR, consults his doubts, related to the manufacturing process, in time and form.
- Time: when the employee makes use of the AR-based system, he does not have to ask the supervisor about the doubt he has, which avoids the loss of time in moving to the maquiladora or the waiting time to be attended.
- Optimization of material resources: When the errors are minimal or nil, then the waste of material is also considerably reduced.
- Motivation: When a worker feels confident to do things or have a support element at hand, he makes the manufacturing process that corresponds to him with more enthusiasm and security, which will result in a greater, but above all, a better productivity.
- Digital resources: The images show how the garment or its parts are displayed, giving the user a comparison of what they are doing versus what they should not do. With respect to the videos, they show all the phases of a process, obtaining abstract details that provide a visual, auditory, and kinesthetic learning to the users.

4 Conclusions

This work shows that AR is an innovative and efficient technology that is applied to various areas of the industry such as manufacturing, the clothing industry, maintenance, quality control, sales and design, just to mention some. In a small family business, a virtual information system, based on AR, was implemented in one of its manufacturing processes and where the main objective was to analyze the results of its implementation. This analysis led to obtaining highly significant deductions such as, the AR-based system allowed material losses to be reduced considerably, even these margins became null in a certain production process (such as in fabric cutting used for clothing).

This result was obtained, mainly, because the AR was used to dispel, in real time, any doubts that the workers had regarding their production process. In other words, the AR-based system had a positive impact in order to considerably reduce some errors derived during the entire production process, such as, for example, that no damaged materials were wasted, which were detected by the process involved in the correction of the assembly. For its part, the time spent for a consultation using the AR-based system was relatively low, which positively impacted the entire production process. This reduction of queries, through the AR-based system, resulted in a minimum loss for response time compared to making the query directly with the person in charge of the assembly process. All these results allowed to positively increase the quality of the products derived from a production process and, at the same time, considerably reduce the time of the production line; This premise is supported to recommend the use of this technological tool in other manufacturing companies, since it is expected that a considerable increase in their production will then obtain an increase in their monetary profit.

Likewise, the AR allows the response to a query about a procedure to be almost instantaneous, since by placing a mobile device with the AR-based system on the piece of fabric, then the correct design and the ideal way will be obtained to elaborate. This action is very quick to consult (of course, the speed of the response depends on the transmission of the data), which contrasts if said consultation was made through a wide gallery of photos. This last way of carrying out a consultation, without a doubt, would represent a higher investment of time and, even, a more tedious process for the personnel involved, this without forgetting the confusion that the employee could have, when searching in their gallery photos, the model associated with the article of clothing. Therefore, the AR allows to show the assembly sequence that is essential for the construction of the pieces of clothing in a visual, animated, and auditory way. The implementation of a system, with the characteristics shown in this work, in a manufacturing process is understandable for anyone, even if they have little experience in cutting and making clothing, since AR resources show identically the correct way on how to create each piece of clothing.

AR goes beyond being a tool for solving queries, because today it is also considered as a novel and efficient means for learning and training. In the present work, these results were verified when employees viewed the videos with the intention of learning their processes and repeated the videos, as many times as necessary, in order to train in the construction of a garment. On the other hand, the monetary resources for the implementation of a system of this nature are few, since if it is taken into account that only the videos must be reproduced to show the 3D images and that currently a large part of the workers have a smart phone, then the only cost would fall on the transmission of data, which is already an essential service for a company and even for a person who uses new technologies.

It is important to mention that AR also has areas of opportunity, since the development of systems based on this new technology require specialized personnel in computer processes, who are responsible for designing the images, recording the videos, combining everything in the system, generate the APPs and upload it to the computer cloud and, in addition, carry out the process of distribution of the computer material. The companies that wish to implement, at any stage of their production process, these new technologies, without a doubt, would obtain multiple benefits when hiring this type of specialized personnel, among them the following can be mentioned: the quality of the products would be increased, It would achieve a decrease in production times and, consequently, a substantial increase in profits would be achieved. The challenges of new technologies are many, however, there are other scenarios that are not so easy to detect, such as, for example, there are people involved in a production process who find it difficult to understand and manage mobile devices. In addition, it must be taken into account that some of these people, or at least in the company where the AR system was implemented, are elderly. These people, for obvious reasons, do not have extensive knowledge about the handling of mobile devices and, moreover, they present great barriers to learning new technologies. However, the ease and simplicity of the system, presented in this work, allowed these elderly people to quickly learn to use and manage it.

Another benefit of the AR-based system was reflected in delivery times and, consequently, in payment times and increased production. For its part, this type of system can be implemented in any manufacturing process, since if it is adapted correctly then it will be of great help and even essential in a short time. In this type of technology, mobile devices are in frequent use, so the implementation costs do not require a considerable investment of human resources, much less infrastructure. In addition, mobile devices are of daily use for people, so these tools, in conjunction with new technologies, must be adapted to manufacturing processes, in order to obtain a useful benefit from their use. Thus, and by making use of a system based on AR, it is expected that quality control based on this new technology will achieve better performance and, consequently, processes will be more efficient and dynamic (these results are obtained, during the time it was analyzed, in the company object of this work). This type of systems, based on new technologies, will impact all those companies that decide to use them and whose objective is not only to improve their productivity, since these innovative and efficient processes will allow them to be at the forefront of the technological context, because this digital trends of sorts are already taking place in multiple companies around the world.

An avant-garde and innovative company, without a doubt, will facilitate the creation of other new technologies, since by supporting and promoting this type of new processes, it will motivate many companies to implement and adopt them; which would facilitate the way to the automation of various processes in the manufacturing industry. Another important aspect about the implementation of an AR-based manufacturing system is that this new technology provides workers with several benefits, among which they stand out: the feeling of feeling motivated, encouraged and confident that they are doing their job well, consequently, makes them feel part of an efficient and quality production, the latter, without a doubt, would strengthen the organizational culture of the company. All these aspects of well-being, in turn, lead to production efficiency, which translates into minimizing the loss of staff idle time, optimizing the assembly process, improving the quality of work and, of course, profiting monetary, which is one of the main objectives of all companies. Lastly, AR-based technologies are creating new ways of seeing the world, including their interaction, which is of great benefit to manufacturing companies and in the near future, this interaction may be used to make AR closer to physical reality.

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