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Product Traceability in Ceramic Industry 4.0: A Design Approach and Cloud-based MES Prototype

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Abstract. We propose a customer-focused approach to design product traceability for Industry 4.0. Our design-science research includes a review of traceability technologies and participative enterprise modeling in the ceramic industry. We find benefits in combining Business Process Modeling Notation and Goal-oriented Requirements Language representations to (1) promote reflection by experts with different backgrounds, (2) reach consensus with a solution that addresses the goals of multiple stakeholders, and (3) ensure that customers' needs are a priority in traceability design. The resulting model combines technologies in different stages of the product lifecycle and is implemented in a cloud-based MES (Manufacturing Execution System) prototype. Depending on each stage and strategic intention, the identification code can be

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embedded in the product, transport, or package. Our contribution can assist managers in the creation of cloud-based MES to support traceability integration at (1) technological, (2) vertical, and (3) horizontal levels that are required in the fourth industrial revolution.

Keywords: Traceability · Ceramic Industry · BPM · GRL · Manufacturing Execution System · Industry 4.0

1 Introduction

The fourth industrial revolution (or Industry 4.0) is changing the landscape of manufacturing at a global scale. Production flexibility and decentralization, resource efficiency, and the emergence of new information systems have the "potential to turn around the industrial practice comprehensively" [1].

Manufacturing execution systems (MES) is one type of plant information systems that handles industry operations, process supervision and control [2, 3]. To take advantage of Industry 4.0 models and technologies, modern cloud-based MES have to deal with product traceability in distributed manufacturing, for example "where workflows of multiple factories are coordinated centrally to provide plant managers with real-time tracking, visibility, and control across several plants". Cloud-based MES have been proposed to address this challenge, integrating different information from suppliers in the supply chain, order tracking, real-time data, materials tracking and complete product information [4].

Product traceability is defined by ISO 8402 as "the ability to retrace the history, the use or location of an article or an activity, or similar articles or activities, by means of recorded identification" [5]. Current concerns of industrial managers include preventing errors in the supply chain (e.g. incorrect product selection, or misidentification of customers' requirements); managing risks of product use (e.g. identification of components, origins of materials, and counterfeit products); obtaining efficiency in inspections; and improved control of quality, inventory, manufacturing, and logistics [6]. The importance of traceability is also present in the popular quality management standard ISO 9001:2015 [7], which highlights this requirement in Sections 8.5.2 (identification and traceability) and 8.6 (people responsibilities). Additionally, [6] mentions the need to consider the goals of stakeholders that are internal and external to the firm and distinct phases of product lifecycle. Namely, product development, production, use, and disposal. Still, according to [8], it is necessary to consider different traceability technologies in industry "because of changes in material properties and various operations in process stages. Therefore, suitable traceability methods need to be identified for different process sections". Also, [9] suggests that it is necessary to integrate various mechanisms for traceability, because each one has its strengths and weaknesses. Despite all this, in some sectors of the economy, product traceability is still in initial stages of development, for example, the millenarian production of ceramics that is addressed in our study.

In this paper, we focus on the table and ornamental ware ceramic sub-group characterized by concurrent production of many different products. For example, a tableware product line can include different models (e.g. cup, jar, and dish) with multiple decorations. Product diversity, aggressive environmental conditions (e.g. kiln firing temperatures above 1000ºC; dusty production environments that make reading and sensing difficult), and the multiple operations in the production line make product traceability a major challenge in ceramics. The company participating in our research is implementing a cloud-based MES for distributed manufacturing, which requires extensive traceability requirements for the entire lifecycle of the ceramic product.

We posit that designing traceability systems can be addressed by enterprise modeling, "*an activity where an integrated and commonly shared model describing different aspects* of *an enterprise is created*" [10]. It can be carried out with the participation of the system stakeholders to improve the quality of the proposed solution, obtain consensus, and commitment from the users [10, 11]. The need to include traceability in the agenda of ceramic production and the need to identify potential technologies and implementation methods motivated us to formulate three research objectives:

1. Model ceramic product traceability systems involving multiple stakeholders;
2. Identify traceability technologies that can be used in table and ornamental ceramic production;
3. Create a cloud-based MES prototype that implements the traceability model for distributed manufacturing in ceramic industry.

The remainder of this paper is organized as follows. Section 2 introduces our design-science research approach, that involved a ceramic producer and a national technological center for ceramic and glass industries. Next, we explore studies addressing traceability technologies and application cases in distinct sectors of the economy. Section 4 details our traceability model. In Section 5, we present a cloud-based MES prototype for the ceramic sector. Afterward, Section 6 discusses results and we conclude in Section 7, stating study limitations and opportunities for future work.

2 Method

Design-science has its foundations in the work of [12] and seeks to produce innovations, and create and evaluate artifacts aiming to solve specific organizational problems [13]. In our research we adopt the broad definition of Information System (IS) artifact suggested by [14] that integrates "information artifact", "technology artifact" and "social artifact". According to the authors, "technology artifacts (such as hardware and software), information artifacts (such as a message) and social artifacts (such as a charitable act) are different kinds of artifacts that together interact in order to form the IS artifact" [14].

Our research follows the phases proposed by [15] namely, (1) problem identification and motivation, (2) definition of the objectives for a solution, (3) design and development, (4) demonstration, (5) evaluation, and (6) communication.

The motivation to study traceability in table and ornamental ware emerged in a technological center with the mission to support ceramic industry development in Portugal. This country is one of the top exporters of these products: the first in the

European Union and the second worldwide [16]. Consequently, public and private organizations are joining efforts to evolve the ceramic IS support and achieve competitive advantages towards Industry 4.0. First, we conducted a review of relevant literature, presented in Section 3. Based on the identified cases and technologies and in contacts with ceramic experts, we constructed a holistic model for traceability in table and ornamental ware production that implements a manufacturing execution system and, to external stakeholders, provides real time information (e.g. results from quality tests during production of ceramic products). Design and development (step 3, according to [15]) was inspired by participative approaches to modeling in Information System Development (ISD) [10, 11].

The preliminary results of our research (regarding objectives 1 and 2) were presented and discussed at the ISD 2017 conference that was held in Larnaca, Cyprus. In this revised and extended version of the paper we present the recently developed cloud-based MES prototype that implements our product traceability model. This software is being deployed in a Portuguese ceramic company, that provided positive feedback. We concluded our design research with a joint assessment of the results by researchers and practitioners, documenting and publishing the findings.

3 Literature Review

In Section 3.1 we describe the concept of traceability design and the opportunities to advance in this area. Section 3.2 summarizes the most relevant technologies for product identification and traceability in industry. In Section 3.3., we discuss the implementation of these technologies in different sectors of the economy.

3.1 Traceability Design

Product traceability can have a strategic purpose, going beyond the mere identification of where products are [17]. There are also design principles to build traceability systems that suggest considering multiple actors and elements of the supply chain [18]. Other researchers have proposed different solution for traceability design. For example, [19] proposes a mathematical model for product recall. Other authors, for example [20] addressed graphical solutions to model traceability in manufacturing using graphs. According to these authors, a "gozinto graph represents a graphical listing of raw materials, parts, intermediates and subassemblies, which a process transforms into an end product, through a sequence of operations" [20]. The study presented by [21] adapts the axiomatic design method combining both modeling techniques: graphical and mathematical. The authors start by the identification of traceability functional requirements and graphically map them to the physical processes. Their proposal extends traceability design to different areas of the supply chain.

These studies give important contributions for traceability design in industrial contexts. However, mathematical models have limited use in the initial stages of traceability design, involving multiple experts in the process. The graphical approach suggested by [20] provides detailed information of the operations and the elements involved. Yet, existing models do not address strategic aspects of traceability, namely, (1) the contrasting perspective of multiple stakeholders, (2) the list of possible technologies and the priorities of their implementation, and (3) the participative approach to modeling. There are opportunities to test different modeling techniques to design product traceability in industries.

3.2 Technologies for Traceability

There are multiple technologies available to implement traceability in industrial processes. Examples of popular identification technologies include barcode, Quick Response (QR) code, and Radio Frequency Identification (RFID). Their main purpose is to identify a specific product or group of products (e.g. production lot), but many other technologies can be used individually or even combined for traceability.

Linear barcodes, namely the Universal Product Code (UPC) and European Article Number (EAN) variants, are amongst the most used identification technologies, for example, in the food sector [22]. Barcodes encode product data such as part number, serial numbers, supplier numbers, and more. Barcode scanners allow accurate reading and enable companies to track product information in multiple phases of the supply chain, reducing human errors that are common in manual data entry. Barcodes are a popular way of identification affixed in most products available in supermarkets, but they also suffer from limitations of applicability in industry due to the nature of the materials typically used. For example, in the wood industry the "barcode traceability system is simple and low cost, however, it is difficult to be massively applied in wood trade and traceability, because of the nature of wood" [23].

QR codes are two-dimensional codes that provide high speed reading [24]. Its graphical image stores information vertically and horizontally, thus providing a higher data density when compared to linear barcodes. One of the possible uses of QR codes is to protect consumers and retailers from counterfeit products and they can contain Uniform Resource Locators (URLs), texts, and geo co-ordinates, among other possibilities. Examples of QR code use include advertising campaigns, linking to company websites and contest sign-up pages. More recently, QR codes are being tested in the metalworking industry to identify metal parts [25]. According to the authors, QR codes can be engraved in the products overcoming the problems of detaching that are common in labels.

RFID is another popular identification solution, having its foundations in the work of the physicist Léon Theremin during the last century. It was developed and used by the military to identify and differentiate friendly and foe aircrafts. Since then, it has been used also in commercial airplanes, as well as in many other industry sectors. Nowadays, RFID's are used in laptops, mobiles, building access systems, passports, car keys, and ID cards. An RFID tag can store more information when compared to linear barcodes, for example, adding the production date or the expire date to the product identification code [26]. Another advantage is that it does not require line-of-sight scanning because it uses radio waves to communicate with the reader. The RFID tags are classified as active (using battery to emit radio waves, readable from larger distances) and passive (generating the required power from the scanner's interrogating radio waves) as per the need in the business.

The list of traceability technologies is vast and includes many other options, some of them associated with the emerging topic of Industry 4.0, a priority for Europe and for the entire globe [27]. Wireless solutions, communication technologies such as 4G/5G, mobile devices including smartphones/PDAs/Tablets, Near Field Communications (NFC), Indoor/Outdoor GPS and Cloud platforms are now available to tackle the challenges of traceability in modern supply chains [28]. In fact, Industry 4.0 design principles of interconnection, decentralized decisions, and information transparency [29] require real-time identification of products and their production stages. The priority to reduce lot sizes, individualize production [30], and ensure individualized trace data, call for a combination of technologies and new competencies for the industry [31].

Popular as they are, there are common limitations to traceability tags such as RFID, barcodes, and QR codes, for example, in highly adverse environments such as the case of high temperature processes. Exposures to temperatures of around 1000ºC require solutions that do not require direct contact with the product. Possibilities include computer vision to count/identify specific products. However, in spite of the potential of this technology in quality inspection of defects [32], these types of systems have not yet been tested in the table and ornamental ware ceramic sector, where there are significant challenges posed by the hundreds or even thousands of possible product formats.

3.3 Application Cases: Solutions and Opportunities

Multinational companies are investing in traceability solutions. For example, Hitachi provides solutions targeting the beef and the steel industries [33]. Examples of internal and external traceability solutions in construction, food, and manufacturing are described by [6], accounting for backward and forward traceability. The former providing information about product history and production details (e.g. responsibilities), with the latter describing what will happen to the product in the supply chain [6].

Traceability in the wood industry can use a combination of techniques such as punching, painting, barcodes, QR Codes, micro-wave sensors, DNA-fingerprinting, and RFID [23]. On one hand, the sector is evolving from traditional punching and barcodes to digital systems that involve QR Codes and genetic technologies. On the other hand, some authors identify that "few countries in the forest sector and generally the wood industry are using IT methods of wood traceability" [23], and it would be interesting to develop a standard traceability method to assist this traditional sector of the economy.

The food industry is one of the most critical for human safety and, consequently, for traceability requirements: procedures and systems for the identification of outsourced production; product identification; producer data; and destination of all supplied products. The importance of tracking technologies using carriers tags (e.g. RFID and barcode) in food manufacturing is explained in [34]. However, the authors also state that “data carriers alone do not establish traceability. The use of RFID facilitates chain information management because it eases the automated data capture process, but it does not establish traceability itself. Traceability requires association of identifiers with locations and processes, and following such identifiers through the chain from their emergence until their obliteration” [34].

The healthcare sector is making important investments in mobile technologies and the use of QR codes, for example, for medicine prescriptions [35]. Moreover, barcodes are commonly used in pharmaceutical products. The initiatives for mobile health using remote monitoring are creating opportunities for the use of healthcare applications with mobile devices.

Benefits of product traceability in the cases described are extensive, including the possibility of obtaining complete information for the customer, trace suppliers’ production and logistics, identify quality issues, enhance product visibility, inventory control, certification, counterfeit goods protection, or ethical and legal responsibilities [6, 25, 36]. But in spite of the many existing applications, applications in ceramic industry are scarce. In fact, a Google Scholar search with the keyword combination “product traceability” AND “ceramic manufacturing” returns a single result about current trends in ceramic. Extending the scope of our search criteria (e.g. “traceability” AND “ceramic” AND “RFID”) we found a master thesis directly related to sanitaryware traceability [37]. Sivers and Sjögren [37] compared different technologies and suggested the use of (product engraved) Datamatrix 2D codes, consisting of black and white modules, usually arranged in a square pattern, which are similar to QR codes but more usual in industrial settings. However, the author focused on internal traceability techniques, not addressing the design method and external stakeholders’ involvement in the system design, such as end customers’ goals.

The lack of solutions for our target ceramic sub-group and the possible benefits of combining technologies reinforced our decision to continue the research with participative enterprise modeling, as described in Section 4.

4 Modeling Product Traceability in Table and Ornamental Ceramic Industry

Our participative approach involved experts in ceramics, IT, and electronics. After reviewing potential traceability technologies, we visited a ceramic company and interviewed an expert in the ceramic process from a private research and development institute. The simplified process of table and ornamental ceramic production is presented in Figure 1, using Business Process Modeling and Notation (BPMN).

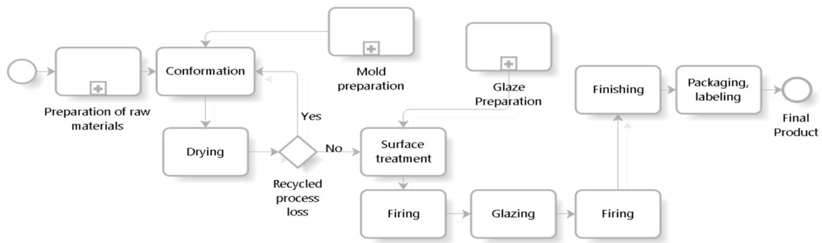

Fig. 1. Ceramic production model (adapted from [38]).

The sequence of activities in the ceramic process and the simultaneous production of multiple product references pose specific challenges for traceability design, as illustrated in Figure 2.

Fig. 2. Ceramic product mix: a complex scenario for traceability design.

Figure 2 shows the several references in the production line. The fragile consistency of the ceramic material in all the production stages and the low cost of each unit limits the use of some traceability options, such as (proportionately expensive) RFID tags. Moreover, this case revealed a highly manual process that is mostly supported by paper records. Process participants may be internal (e.g. customer service, sales, marketing, production) or external to the company (e.g. the customers, partners, and material suppliers), each one demanding an analysis of the most applicable traceability technology. Figure 3 presents a mapping of selected traceability technologies according to the manufacturing process activity.

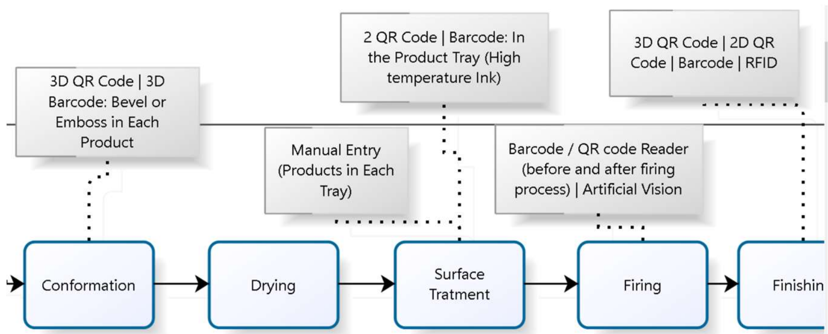

Fig. 3. Business process model for traceability identification (extract for production activities).

We highlight (1) QR codes, barcodes, or 2D Datamatrix embedded in the ceramic product at conformation stage, (2) high temperature ink to make the codes readable during/after firing above 1000ºC (there are multiple intrusive/non-intrusive marking techniques available that are out of the scope of our paper, such as laser marking, dot pen or ink jet), and the possible use of computer vision for automatic product count in areas of difficult access. The automatic reading of trays before and after the firing process will allow real time identification of the product under fire and ready for the finishing activity.

The process model of Figure 3 is useful, but does not explain why the technology was needed or used in each activity. Therefore, we could not establish priorities and clarify the comparative interest of the specific technology. For example, if an activity could use barcode and QR code, which one was the best for that activity and for the overall traceability purpose? So, in a second stage, we created goal models with the jUCMNav Eclipse plug-in [39] to understand the needs of each stakeholder of the traceability system.

Figure 4 presents an extract of the GRL model we developed for the customers.

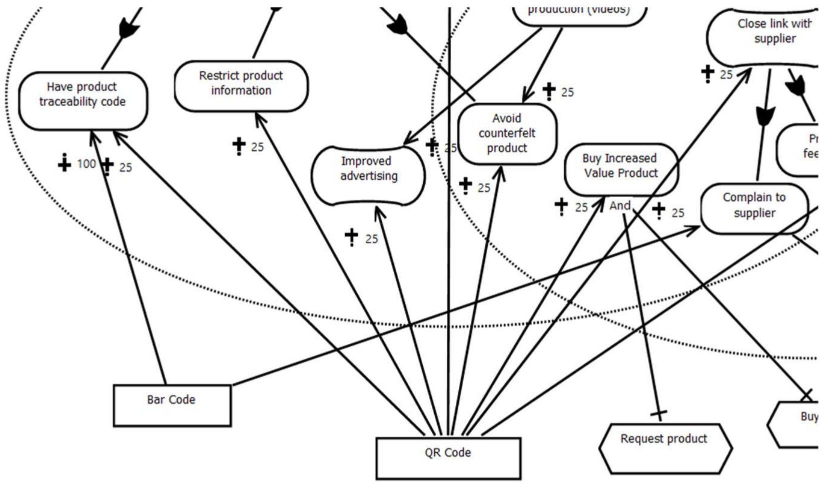

Fig. 4. Goal model for traceability identification (extract for customers: reseller and end user).

Goal models can be useful for communication in the initial modeling process, identifying requirements and the main goals of the system actors. There are recent studies adopting GRL in participative enterprise modeling [40]. Figure 4 includes two main traceability technologies that the design team found more valuable for the customer of table and ornamental ware: barcode and QR code (represented as GRL resources in the bottom-left of Figure 4). The modeling team connected the resources with the goals of the actors and considered barcodes useful for only two goals (two contribution arrows – to "Have a product traceability code" and to support "Complains to supplier"). QR codes could address eight goals and/or soft goals of the customers, which suggests that it was preferable to the actors in this scenario. After completing our models we established the most important traceability technologies for each actor and process activity (represented as tasks in the bottom-right of Figure 4). In our goal model, resources (traceability technologies) are connected with goals, not tasks, but we can identify the link of resources and tasks via contribution arrows. Moreover, in this model we can identify why the technologies are used (e.g. in support of the identified goals of the actors), thus adding information that was not available in the BPMN model.

Figure 5 shows the traceability landscape for table and ornamental ceramic.

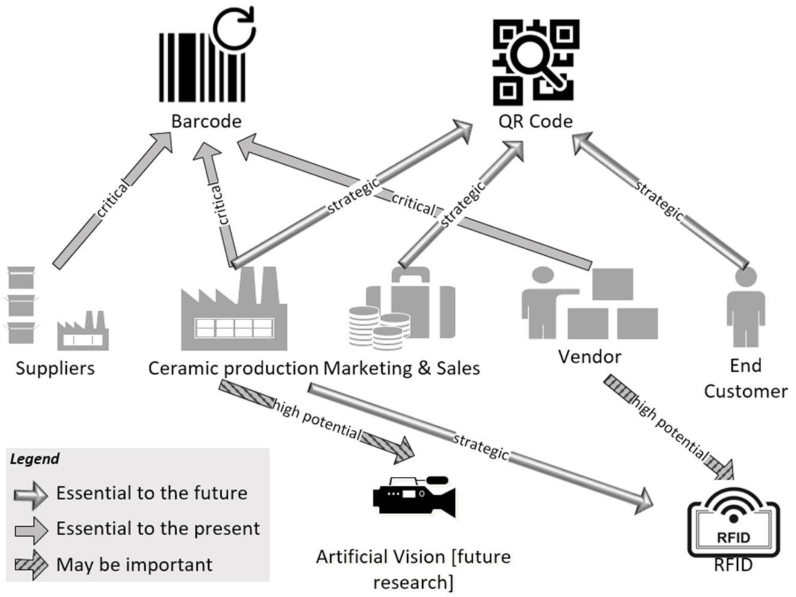

Fig. 5. Product traceability landscape: model for table and ornamental ceramic.

This model suggests that QR codes are strategic for internal processes and to customer use. For example, the end customer (reseller or end user) can access a web page to see a video about the product or the production. However, external partners such as suppliers and vendors/retailers need barcodes for lot checking and sales process (e.g. in supermarket points-of-sale). Due to its higher cost, RFID is an option for high-value products only, for example, with intensive manual finishing or historical value, but it can be used in the future to track transport cars. For this classification of traceability technologies, we got our inspiration in the McFarlan strategic grid [41], detailed in Figure 6, for the ceramic production stage.

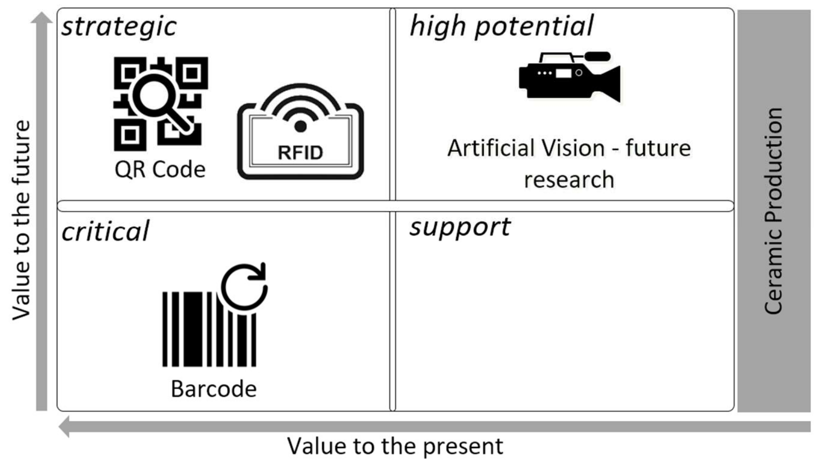

Fig. 6. Product traceability: Technological portfolio - production (adapted from [41]).

The grid presented in Figure 6 is created for each actor of the system – the example is for ceramic production, but it can be extended to the end user, vendors, and other actors. According to [41], strategic solutions (on the top left of Figure 6) are important to the company future; critical solutions (bottom left) are important to the present; and high potential solutions (top right) may be important to the future, but it is uncertain. The design team considered QR codes as strategic to provide increased value to the customer and contextualized information during production stages, RFID as strategic to identify transport cars location in the factory, and computer vision as high potential for product traceability that requires additional field testing. We also found an opportunity to identify product moulds with barcodes to improve traceability of the tools used in the process (e.g. how many products were made by each ceramic mould).

We discussed our approach with a medium sized ceramic company that agreed to participate in a European Union co-funded project to develop and validate the integrated traceability system in a new cloud-based MES. According to the company manager, this model can provide the foundations to build a comprehensive cloud-based MES for table and ornamental ceramic, supported by traceability technologies, and integrating multiple actors of the ceramic production supply chain, particularly useful in distributed manufacturing scenarios that occur in the company. The manager stated that "nowadays, (…) product traceability is needed for different parts of the supply chain (…). The product history is as important as the price tag […and] information must be available at all stages of cradle-to-cradle or cradle-to-grave design".

The next section describes the cloud-based MES prototype that we developed using the proposed model for traceability.

5 Cloud-based MES Prototype for the Ceramic Sector

The cloud-based MES aims to support the entire lifecycle of table and ornamental ceramic production, including requirements of distributed manufacturing and integration with three traceability technologies: barcode, QR code, and RFID (computer vision will be integrated in a future research project). The requirements include the use of mobile information systems [42] to support the company workers via tablets and smartphones. Figure 7 presents screenshots of the cloud-based MES dashboard.

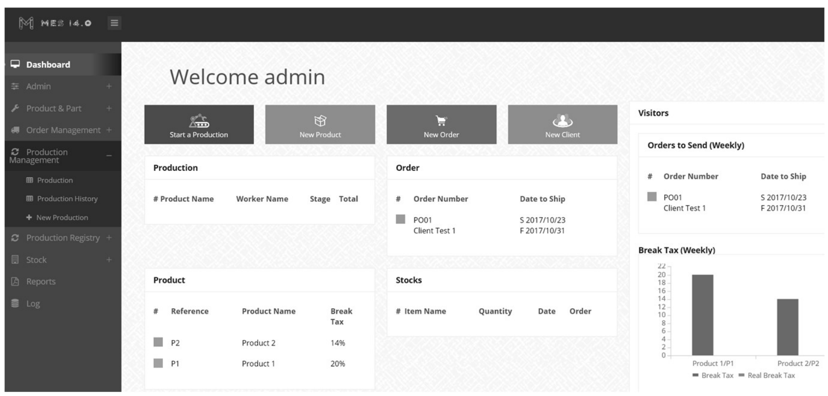

Fig. 7. Cloud-based MES prototype – Dashboard

The cloud-based MES was designed for mobile devices, allowing the production team, production managers, and the external partners to share data about each production order, product characteristics, and responsibilities in the process. Traceability data is critical in the cloud-based MES for (1) automatic data input, (2) data quality check, and (3) output generation (e.g. QR code labels) tailored for each stakeholder in the process. Inputs include data obtained by barcode readers (e.g. suppliers' material) and product logistics in the plant area - provided by the RFID system. The data obtained by sensors is then compared with the data directly inserted via tablets/smartphones in each process phase (e.g. good / bad parts and rework) to show discrepancies to the production manager. Finally, the cloud-based MES also prints the required barcode and QR code labels to use in the different stages of the product lifecycle, for example, the final packaging QR code and the dynamically generated webpage for the product information (accessible via QR code to the end customer). Another area of our prototype is presented in Figure 8 – material traceability reports.

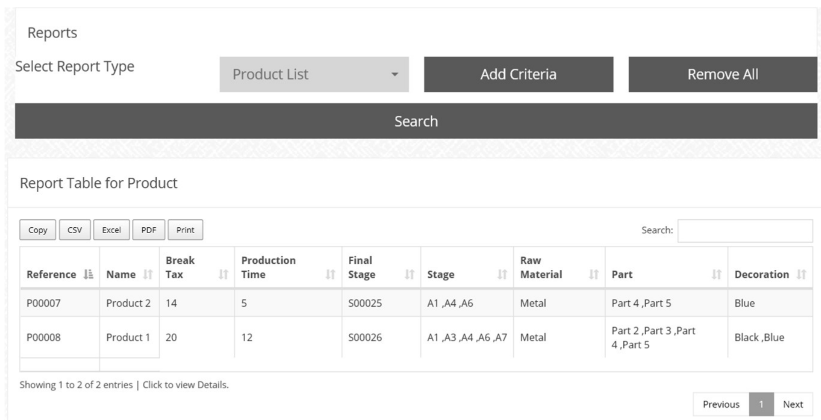

Fig. 8. Cloud-based MES prototype – Material traceability

The solution developed for the ceramic company enables tracing the final products, product parts, and materials. Figure 8 presents an example of production report with multiple criteria, providing a traceability analysis for each product stage, material used, or product part. The traceability components of RFID, barcodes, and QR codes provide inputs to the cloud-based MES (e.g. stock movement) but also a complementary confirmation of data quality. For example, contrasting product stock levels recorded in each department with the information obtained by the RFID readers enables the identification of potential problems in the process flow (e.g. wrong quantity input, defects, rework, delays in specific departments) and more precise identification of the stage of each product in the required production plant/line. Figure 9 present the main modules of the cloud-based MES.

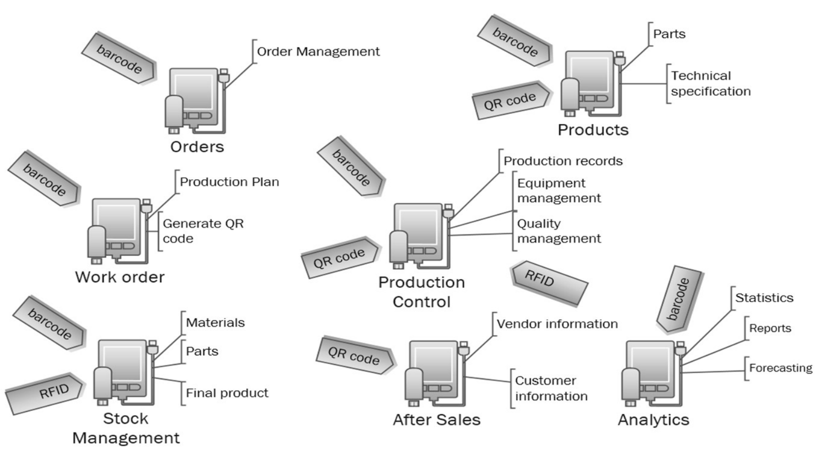

Fig. 9. Cloud-based MES prototype – Modules

The Products module includes all the information required for each product, such as parts, materials, production time (adjusted automatically), and partners information. The Orders module is where the production cycle begins, providing the data for work order generation (for each factory). The Production control module includes a mobile interface and support for automatic data input from the traceability layer (e.g. RFID readers). Our cloud-based MES also includes a Stock management module, the After Sales module, that dynamically generates the web pages for vendors and end customers (via QR code) and the Analytics module. Other modules, under development, were omitted for sake of simplicity, such as ERP integration, maintenance management, and energy management. For each module, in figure 9 we represent the most relevant traceability technology (e.g. QR code for the after sales module).

6 Discussion

In spite of the different options available for product traceability in ceramic production we did not find a single technology that could be used throughout the entire product lifecycle and address the needs of internal and external stakeholders. QR codes are interesting for consumer information, while linear barcodes are low-cost and efficient for tray identification during a production process. RFID can also be used for transport cars identification and for more expensive products, but has several limitations for use during production in aggressive environments such as those we can find in the ceramic industry.

To deal with the problem of selecting a suitable mix of traceability technologies for the particular industry in our study, we found benefits in using multiple representations of the production system with participative enterprise modeling. First, the contrast of different models – BPMN and GRL – improved the reflection about traceability challenges amongst experts of different domains. BPMN clarifies the sequence, interactions, and elements of the supply chain, while GRL explores the "why" of the system actors, their requirements, beliefs, goals, and resources. Second, it helped in the construction of a consensual perspective for the next steps that includes sourcing the traceability system aligned with the company strategy. On one hand, RFID has several advantages for storing data and reading at a distance, but it was not compatible with high temperatures, and it is proportionately expensive when compared to the low average price of ceramic products. Also, it is not practical to provide extra features to the end consumer. On the other hand, QR codes provided advantages for multiple goals of stakeholders (e.g. consumer) and to develop online web services (thanks to the ability to encode full URLs), but we can't simply eliminate linear barcodes because retailers need them (e.g. in point-of-sales in supermarkets).

The use of multiple modeling techniques helped us move the focus from technology to the requirements for our cloud-based MES platform. When the team started this project, the goal was to identify candidate technologies for product traceability. Then we shifted our attention to the goals of the different stakeholders included in BPMN and GRL models. We agree with [43] in that the operational backbone of the organizational IS must be complemented with digital services targeting different stakeholders. Traceability in the context of Industry 4.0 requires supply chain integration increasing the need to use multiple models, accessible to different experts and ensuring a strategic focus [41].

Cloud, wireless, and mobile can provide "the glue" for traceability information in cloud-based MES for distributed manufacturing. The information traced in the product line can be available to customers or to specific partners/suppliers to plan deliverables of raw material and final product components according to the plan. The use of smartphones in the production line also opens possibilities for future research, taking advantage of QR/ barcodes in products, and trays. For example, for quality control, embedded QR codes can simplify product recall (e.g. the same product model can have problems in a single production lot while the others conform to specifications).

According to the company managers, the cloud-based MES prototype was able to integrate traceability requirements from multiple stakeholders, rather than staying restricted to those of internal operations. This benefit is particularly relevant for small and medium sized companies that struggle with (1) the lack of human resources for production control tasks, (2) the need to share information between multiple elements of the supply chain, and (3) the flexibility needed for constant changes in the production plan and real-time information requested by their partners and end-customers.

7 Conclusions

We presented an approach to model product traceability that integrates multiple technologies and stakeholders' viewpoints. The ceramic industry provided the setting that includes adverse environmental conditions for traceability technologies. An overall model for product traceability landscape is proposed, inspired by the classification of [41] and a prototype for cloud-based MES implementing the model was created. Our results suggest that a multi-model approach has the potential to contribute to team learning and creativity in complex scenarios that involve distributed manufacturing and require the participation of multiple stakeholders in ISD. We confirmed previous studies pointing to the benefits of enterprise modeling for achieving consensus in ISD [10] and found new opportunities to use traceability technologies and promoted debate amongst team participants using the models. Our approach extends the work of [4] by (1) proposing an approach to model traceability requirements and (2) implement a sectorial cloud-based MES prototype.

As for limitations, first, the technologies and application cases identified in our literature review are restricted to those found in the consulted literature databases. Second, we restricted the modeling artifacts to BPMN and GRL models, because the design team was already familiar with BPMN tools and recent research suggested benefits of GRL for participative enterprise modeling [40]; other modeling methods and languages can be used. Third, in spite of our participative approach to enterprise modeling, traceability in ceramic production is highly complex and the environmental conditions (e.g. temperature and dust) present challenges to system implementation that require additional research. Nevertheless, our project identified opportunities to use mobile devices and automatic tracking in traditional product lines, including product, transport, and package identification codes. Fourth, although we already found a company that validated our initial model with a cloud-based MES prototype, the system is still under development and we do not have experimental evidence of the benefits for efficiency and effectiveness in the production. These are opportunities to address in upcoming phases of our research that may be extended to other sectors of the economy.

Currently, we are implementing the cloud-based MES in the company and testing the distributed manufacturing of products combining ceramic and cork - a specific model of lamp that is produced in parallel by two distinct companies, one responsible for the cork parts and the other for the ceramic parts, assembly, and packaging. The main contribution of the present project is a graphical approach to design traceability integrating multiple stakeholders' viewpoints in cloud-based MES with requirements of distributed manufacturing. Moreover, our design-science research evaluates existing artifacts (BPMN and GRL) concluding for their positive synergy in the development of product traceability. For managers, we identify traceability technologies and suggest digital innovations in the context of table and ornamental ceramic.

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