General methodology for the generation and dissemination of manufacturing knowledge: a case study with the Double Diamond AM Knowledge Approach

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Abstract.

The ever-increasing consolidation of industry 4.0 technologies and the imminent advent of the industry 5.0 paradigms makes it essential to use new methodologies for the generation and the transfer of knowledge in the manufacturing sector.

Considering the state of the art regarding pedagogy and Additive Manufacturing (AM) and starting from the need to create a unique tool to make the most of the potential of additive technology, a case-study based on the method called "Double Diamond AM Knowledge Approach" (D²AMKA) is introduced with a deep discussion of the results obtained in the European project CAPT'N'SEE, managed by EIT manufacturing, which saw the collaboration of the Polytechnic of Turin, of the École Nationale Supérieure d'Arts et Métiers of Paris and of Add -Up. In extending the D²AMKA, arose the need to create an information system to carry out the Product Lifecycle Management (PLM) for an AM process taking into account the differences with traditional processes. In order to satisfy this need will be shown how to apply to the case a previously created model to manage the information of a production process with a lean perspective.

To summarize this paper presents a general methodology to (i) capture knowledge needs in a specific manufacturing area and about a specific manufacturing sector, (ii) develop an e-learning path in that manufacturing sector with the collaboration of partners of that manufacturing area, and (iii) organize a journey in the name of training, dissemination, sharing and brainstorming.

Keywords: Additive Manufacturing, Knowledge, Luxury Industry, Industry 5.0.

1 Introduction

"Given AM's recent introduction to volume production contexts, most engineers and manufacturing workers were not exposed to, or trained with, the principles or execution of AM during their formal education. It is likewise challenging and time consuming for universities to construct new degree programs and commensurate curriculum in AM." [1] Since their invention, Additive Manufacturing (AM) technologies are quickly spreading in many manufacturing sectors; however, in most cases a purely technical approach in integrating such technologies may not be sufficient to exploit the full potential. For this reason, sharing knowledge appears to be the unique way to change the perception of additive technologies and help companies in understanding all its potential. Because the AM technologies introduce a completely different approach to design, manufacturing and control of the finished product, the paper develops a methodology to improve the diffusion of AM awareness within the different phases of product and process development.

The case study presented focuses on the luxury sector because it suffers from a lack of multidisciplinary knowledge and it requires two types of specific knowledge: standard design methodologies and the revolution for process designers provided by additive sub-processes. In addition, the fear of investment and business model change is common in the sector, probably due to the inability to have an overview of the AM process and its benefits. Moreover, the intellectual property question, regarding the repeatability of such products and the digital content aspect, represent a real cognitive barrier for companies to guarantee their investment. Finally, many luxury brands are worried about the potential loss of capabilities and the consumers' retention that could be not attracted to this technology facing the old and traditional one.

In this paper, after the introduction, you will find the state-of-the-art section regarding the sharing knowledge methodologies. The third chapter introduces the design framework proposed to share knowledge as an implementation of a previous research work, while the fourth chapter reports a case study to validate the theoretical framework proposed in the luxury sector context.

2 State of the art

This section summarizes the existing methods and tools used today by companies to speed up the process of sharing knowledge and its use in innovative processes in order to design disruptive products and services.

2.1 Knowledge sharing process

Because of the evolution of the various industrial sectors, there has also been an evolution of products and production processes. All this has led to an increase in the knowledge required to work and the need to pass this knowledge on to employees. The main approaches used nowadays to share knowledge through a company organizational structure are trainings, work and innovation labs, seminars, conferences and

workshops (fig.1). From these approaches different learning methodologies for innovation were born such as agile methodologies, creativity, coaching and U theory (fig.1) [2], [3], [4], [5].

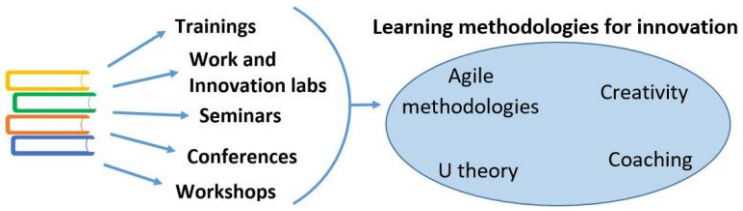

Fig. 1. Knowledge sharing approaches

Seminars, conferences and Trainings. These three similar approaches of sharing knowledge are the most common ways adopted from companies to train their employees.

Seminars and conferences are generally considered the same; however, the only things in common between the two are that they both use audio-visual tools and that they involve people with the same educational background. In fact, seminars, often included in a conference of several days, have a shorter duration and can be classified as lectures to impart knowledge to the attendants that eventually receive a certificate of participation. The aim of the conference, on the other hand, is to allow the sharing of opinions and knowledge related to a given topic.

The other approach is represented by trainings, which always have the aim of training employees, but with a different form and duration compared to seminars and conferences. In fact, generally the trainings can last even months and are aimed at smaller groups of staff who need to acquire specific skills to be integrated into the activities daily carried out.

Workshops. This sharing knowledge approach could be considered a mix of conferences and seminars because it has a less rigid structure than a conference but at the same time, is more formal than a seminar. In addition, workshops tend to aggregate multidisciplinary attendants with the aim of teaching new skills or increase their awareness about not well-known topics.

Work and innovation labs. This approach of sharing knowledge it is a more recent way of training the staff of a company through the exchange of skills. In literature there are different taxonomies to identify work labs, but they could be summarized into three main typologies [4]: (I) Innovation Hub: sharing knowledge through distance learning networks, (II) innovation intermediary: innovative material shared in open access way, (III) Ecosystem attendants: local narrow networks and Fablabs.

Usually work labs are funded by public subsidies and in a small percentage even by private subsidies with the main objectives of educate, increase R&D skills, create social links and help entrepreneurs [4], [6], [7].

3 The Extended Framework D²AMKA including the nuggets and journeys design

This section aims to recall the Double Diamond AM Knowledge Approach [8] as an evolution of the double diamond methodology [9][10] to help apprentices gain knowledge about the Additive Manufacturing process step by step.

3.1 The Double Diamond Methodology and the D²AMKA

The double diamond methodology, officially invented by the British Design Council in 2005 [10] , is a design thinking approach that consists in two phases represented by two diamonds each of which presents one phase of divergence and one of convergence (fig.2). The first diamond represents the problem defining process that is reached through two phases: the divergent one that aims to explore the problems from different perspectives and the convergent phase where the real problem is selected. The second diamond instead is the solution one, where the divergence is represented by the exploration and development of different solutions, prototypes and tests while the convergence is represented by the delivery of the final product.

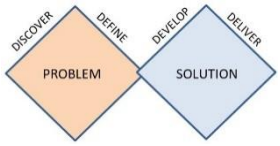

Fig. 2. The double diamond methodology

Getting inspired from the double diamond methodology we created the D²AMKA (fig. 3), in extended form Double Diamond AM Knowledge Approach [8], which helps learners to become aware of AM encouraging its diffusion. The D²AMKA consists of two different learning timeframes corresponding to the two diamonds: the first one is an online collection of nuggets to address learning needs in the long term through a divergent thinking provided by videos and experts testimonies and a convergent thinking obtained from feedback quizzes. The second diamond instead focuses on few major topics treated in the nuggets with the divergence given by experts' presentations and the convergence by workshops experiences.

3.2 Nuggets design and objectives

This paragraph aims to explain all the actions undertaken to create the final nuggets. First, we decided the general topics related to AM that could be interesting for the potential learners and industrialists conceived as the target of the approach. The topics were selected thanks to the expertise of the project consortium members and academic partners who shared their knowledge on the AM process and on the luxury sector during some meetings held to define the contents to be shared. Secondly, we defined

the learning path framework on which to fit each nugget. In particular, each learning path consists of a minimum of five different nuggets: (I) the connect nugget used as introduction or preface of the learning path that explains how it interacts with the other learning paths. No duration recommended for this kind nugget (II) the info nugget requires the participation of an expert who speaks about a specific topic strictly related to the whole learning path. Recommended duration from 5 to 15 minutes (III) the question nugget that follows each info nugget with a set of questions to help the development of a convergent thinking in each learner and to give a feedback on their enrollment in the knowledge process. Recommended duration from 2 to 5 minutes (IV) the task nugget, which involves the knowledge sharing of another expert belonging to a firm that has already had a practical experience in the info nugget topic treated. Maximum recommended duration of 45 minutes (V) the set up nugget that summarizes all the topics faced in the learning path to enhance the durability of the delivered knowledge but also increase the visibility of the project. No duration was recommended for these kind of nugget.

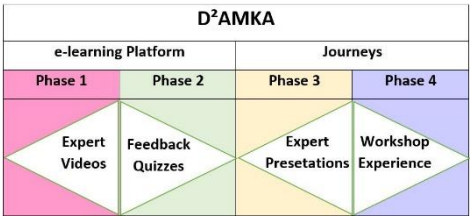

Fig. 3. The double diamond additive manufacturing knowledge approach

As third step, we started a call for experts by e-mail and by phone for the contacts in the research group network, 166, and by LinkedIn for the contacts outside the network, 187. These contacts were selected taking into account the correlation of their profession with the topics of the project, therefore the luxury sector, the AM sector, and in a small percentage the manufacturing industry in general. The final step was related to the definition of some Key Performance Indicators (KPIs) needed to assess the quality of the material created. In particular the KPIs selected are: (I) training and mentoring activities – 3 of institutions and 8 of courses, (II) 8 digital nuggets created related to creativity, innovation, design, part finishing, part control and Manufacturing Execution System technologies for AM in the luxury industry.

3.3 Journeys design and objectives

The training program has been divided into two “journey” programs, which integrate the same topics developed on the training platform by the nuggets. The first step taken was the careful definition of the time tables to be followed taking into account the nuggets produced, with the addition of some process demonstration, a fablab tour, an all-day workshop dedicated to creativity and brainstorming activities to easily involve participants. Subsequently we have selected the candidates based on their potential interest in the fields related to the project topics: luxury sector, AM and manufactur-

ing in general. The following step was the call for participants sent to all the potential people interested by means of a registration form. With the same strategy applied in the call for experts for the nuggets, we used LinkedIn and the research group network as main source to target the right audience, delivering a high quality and tailored training. As done for the nuggets we created some KPIs to assess the quality of the journey: (I) 20 Participants in education and training, (II) Training and mentoring activities – 3 of institutions and 8 of courses, (III) 2 Educational Journeys related to creativity, AM and MES technologies applied to luxury industry with attendants active interaction.

4 Case study: spreading AM in the luxury industry

By carrying out research on the services available today online, there is an obvious lack of AM courses focused on the luxury industry, notwithstanding the compatibility of the latter with AM in terms of scales of production and of need to be in proximity of the client [12][13][14]. Furthermore, several major issues have been identified among the literature for this sector such as the unseen potential of AM by companies, the fear of the economic investment, [15][16][17] and the lack of awareness about the creative power of AM [14]. In addition there are doubt due to the need of adapted materials to be processed and the intellectual property question related to digital content ownership and repeatability [5][12][18]. Finally, many brands are afraid of the consumer point of view that could be disinterested in such technology because is in contrast with the old and traditional one that made the brand image.

In addition to the problems presented it becomes more and more necessary to manage the AM New Product Development (NPD) phase towards mass customization guarantying a comprehensive product information about intellectual properties and quality, and sharing at the same time knowledge related to Product Lifecycle Management (PLM) with particular attention to the design phase. This is mainly because, when approaching to AM, many companies do not know the differences in NPD between traditional and AM processes. If a company uses to develop new products by means of traditional “linear” processes, it will face many difficulties in applying the same scheme to AM. In fact, in subtractive manufacturing, the standardization of production techniques allows for greater linearity in the NPD process and so the changes made at each step do not challenge the choices made at previous stages, indeed features can be added to a part without calling the concept of the product into question. Conversely, in AM as soon as one of the parameters is modified, all the design choices must be reviewed because there are strong interdependencies between the way a part is produced, the material used to make it and the final properties. All the choices made during the design phases will potentially have an impact on surface quality and material integrity, and hence on the mechanical characteristics of the part. This is why it is important to set up multidisciplinary working group, which meets at regular intervals, when creating a part in additive manufacturing until the optimum is obtained. Experts for the various stages must be brought together from the start of the project, so they can confer and make sure no aspect is forgotten.

4.1 Presentation of the case study

The case study presented in this work has been the foundation of the CAPT'N'SEE project and it gives a solid framework to achieve its objectives of offering an efficient and relevant training offer fostering a more creative, flexible, and smart use of AM in the manufacturing sector in general, and in the luxury sector in particular. The implementation of the project allowed, in turn, testing the methodology presented and enriching it with valuable feedback from a direct application.

CAPT'N'SEE (CAPTure aNd foStEr additive manufacturing knowlEdge for luxury industry) is a training program dedicated to professionals willing to enhance their expertise in the use of Additive Manufacturing technologies. The project has particularly treated the AM early design stages and the Manufacturing Execution Systems that allow the real-time control of processed parts. Starting from the expertise of its consortium members and gathering experienced industrial and academic partners, the project has initiated a dynamic shift in the way to work with AM in the luxury industry, which is in strong growth and where high value-added productions require enhanced creativity and high precision. This activity has received funding from the European Institute of Innovation and Technology (EIT).

The CAPT'N'SEE network associates two renowned academic partners and one skillful industrial: Arts & Metiers Institute of Technology (ENSAM) in France, Politecnico di Torino (Polito) in Italy, and AddUp which is operative mainly in France. AddUp is a joint venture born in 2016 from Michelin and Fives with the aim of develop additive metallic manufacturing solutions for industrials and supports them throughout their projects with services offered for a profitable experience.

The project outcome consisted firstly in the production of two series of nuggets filmed and edited and secondly in the organization of two educational journeys related to creativity, AM and MES technologies applied to luxury industry. The two journeys took place in Paris from 27 to 29 of September, under the supervision of ENSAM, and in Turin from 20 to 23 of October under the supervision of Polito.

4.2 Nuggets produced

As required from the project KPIs, we developed eight learning paths related to AM, according the structure described in 3.2, in order to address most of the needs highlighted in the analysis reported as introduction of this section. We choose to enroll some AM experts of the luxury industry to share their knowledge on these topics and give a practical approach, showing all the potential of AM we wanted to highlight. In terms of content, the different activities have been structured as mix of videos and quizzes allowing the participant to diverge and converge their knowledge according to the first stage of the D²AMKA. This knowledge is then further consolidated thanks to the Setup nugget, a summary sheet of the entire learning path, which narrow the learning experience to few important elements.

The eight learning paths created are: (I) **Multidisciplinary to learn and innovate:** Multidisciplinary working groups, Transform your company into a learning organization**,** Innovate trough collaborative projects; (II) **Stand out through AM:** Use value

at the core of innovation**,** Adding value through AM; (III) **Innovation with AM as an economic asset:** Be able to consider AM as an alternative technology, The real economic benefits of adopting AM in your company; (IV) **Creativity and AM:** Creativity as a systematic process that has its place in the industrial company**,** Experiencing creativity in AM**,** Disseminate AM innovative culture in a globalized enterprise; (V) **Lean management:** AM and Human Resources: the hike in skills**,** Lean management of the AM process; (VI) **AM costing:** Knowing how to estimate the cost of a part**,** Installing an AM machine in an existing factory**,** Cost comparison between AM and traditional production processes; (VII) **Enterprise Information Systems:** Introduction to Computer Integrated Manufacturing (CIM)**,** PLM and AM: key resources towards mass customization**,** Additive Manufacturing Resource Planning (MRP)**,** Additive MES: managing the production to optimize the design; (VIII) **Artificial Intelligence:** Data generated during the lifecycle of an AM product**,** Generate information through an AM data architecture**,** Artificial Intelligence for a smart AM;

4.3 Journeys outcome

As said previously we organized two different three-day journeys considering the study of industrial use-cases proposed by the experts in the network. The objectives of these journeys were to disseminate the learning contents and test the training program to support teams that deals with AM in developing strong skills in creativity and process management, with a specific focus on the luxury industry. The timeline encompassing each journey spans around three phases: journey design, journey execution and the post journey analyses. The journey design was already treated, so this section will describe the following two phases for each journey.

The first journey, managed by ENSAM, aimed to reconsidering the product development process from the early design stages in order to satisfy new creativity and multidisciplinary needs required by the AM processes. For this reason, the main activities concerned the enhancement and the promotion of the creativity allowed by AM thanks to the use of collaborative methods and tools. In this journey, we had 48 participants, 43 of which responded to a satisfaction survey we sent after the event declaring that they increased their knowledge of AM during the journey. The main topics in which attendees declared to have learned new things are innovation thanks to AM, creativity enabled by AM, multidisciplinary of AM projects.

The second journey, managed by Polito, was dedicated to the smart monitoring and control of the AM process or, more in detail to Manufacturing Execution Systems and finished part control solutions. Therefore, the main objective was to support attendants in developing strong skills in the management of the AM digital chain. For this reason the journey has been designed starting from the concept of AM Information Systems, continuing with the design and the execution of an additive process, and ending with the quality techniques and sustainability criteria implemented in AM. Moreover, we presented a model to manage the information of a production process with a lean perspective showing an appropriate methodology for specific use-cases [19]. Subsequently there was the execution of a simple open innovation experiment to engage the audience and share the open philosophy. In this second journey, we had

71 participants, with a daily attendance of 41 on the first day, 52 on the second day and 39 participants on the third day. To ensure continuous participation of the attendees, we organized a quiz with prizes to win a backpack offered by the sponsor for each day of the journey.

In order to allow the development of the convergent thinking and the birth of a common wisdom between attendees we scheduled Q&A sessions during the two seminars. This was helpful as well to measure the degree of knowledge of the participants on AM and its possibilities. For instance, we asked if it is possible to print gold or copper, which showed that 50% of the participants were unaware of the possibility to use gold or copper in AM.

Although the number of participants was quite high for both journeys, the maximum registration capacity given by the capacity of the classrooms was not reached. We therefore did not have to apply the selection process, based on the following priority levels: (I) professionals from the luxury sector, (II) professionals from the AM industry, (III) with equally relevant profiles, favored women. However if it had been asked to choose, with equally relevant profiles, we would have preferred women to balance the gender inequality. Moreover, during the advertising of these events, we were very careful to distribute equally to men and women all the material and the invitations. However a bit more of 2/3 of the total registered people were men.

In the end, the vast majority of the registered attendees for this event were professionals, followed by professors, academic researchers and students. An half of them were from the Additive Manufacturing sector, others worked in the luxury sector and the remaining were in other industries such as consultancy, energy and sustainability.

5 Conclusions and future works

By examining the KPIs required for the project assessment, we can state the successful ending of the same with the production of 8 learning paths and 2 journeys related to creativity, innovation, design, part finishing, part control and MES technologies for AM in the luxury industry. Thanks to this path, we have had the opportunity to understand the needs of the players in the luxury sector who want to introduce AM into their processes and above all to test the D²AMKA for the first time. From the responses received from the participants, we can only be satisfied to find an increase in their general knowledge on the subject. However, it will be necessary in the future to question the participants about the investments made in relation to the increase in knowledge and to test the D²AMKA in other contexts to have more confirmation of its effectiveness.

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