Technical Maturity for Industrial Deployment of Robot Demonstrators

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***Abstract*— Any technical development done in the context of agile manufacturing has limited benefit if it's not industrially utilized. This requires maturing the developed technologies to a point that they are robust enough to provide a productivity boost, while at the same time adhering to the relevant industrial standards. In this paper we present the various stages in which different robot demonstrators were able to achieve the required technical maturity for industrial deployment. We present the context about the importance of developing technologies that facilitate agile manufacturing followed by the gap between the state of the art and the state of the practice, due to which many promising technologies do not end up being deployed in the industry as they were not subjected to maturity actions required for the transition. We present the journey of four industrial demonstrators that bridged this gap. Furthermore, we provide the assessment methods to ascertain the iterative developmental steps, and present a generic approach to improve the technological readiness.**

I. Introduction

Globally, a lot of research is in progress to assist the manufacturing industry in achieving agility for their production processes. This is particularly the case in Europe, where manufacturing is the backbone of the economy employing nearly 30 million people [1]. The importance of the manufacturing sector can not be under estimated. Apart from providing direct employment, it also creates a complex ecosystem that provides opportunities for creation of up to two service industry jobs for each direct job in manufacturing. Moreover, in the European Union, manufactured goods represent 83% of EU exports [2] providing a trade surplus of €233 billion in 2018. This trade surplus plays a key role in creating growth and providing opportunities to the region's inhabitants. If this trade surplus is compromised, the social and societal ramifications for Europe would be immense.

Manufacturing, however, the world over, is undergoing a rapid transformation. Technology is shaping and changing the way humans manufacture at a more rapid pace than ever before. The role of industrial robots along with the use of other technologies related to information and communication technologies (ICT) in increasing the efficiency of production processes is well understood. Moreover, utilisation of emerging technologies such as collaborative & reconfigurable robots [3] [4], Augmented & Virtual Reality (AR/VR) [5], virtual commissioning [6] and computer vision methods [7] in bringing increased productivity at large manufacturing companies is also generally well established. However, 80% of manufacturing companies in Europe are Small and Medium sized Enterprises (SMEs), which do not necessarily have the skills or capacity to take up emerging, and sometimes semi-reliable technologies into their daily operation. In order to increase the productivity, quality and efficiency and thus to stay competitive, the SMEs in manufacturing sector need to embrace smart robotics along with the aforementioned supporting emerging technologies [2]. It is noteworthy that the SMEs have a significant impact on Europe's employment capacity, they are also the ones that require a more targeted and an easy to deploy support system. Europe in the future, will not only be competing against low-income economies but also, increasingly, against highly automated ones. Therefore, it is imperative that highly automated solutions are not only developed rather they are matured and moulded into a form that is readily accessible and acceptable to SMEs.

Robotics as an application area is very wide and heterogeneous by nature. In order to bring structure to the technological developments, speed up the technology transfer from the laboratories to the industry, and to create a sense of community, the European Union Research Commission established the regional Digital Innovation Hubs (DIHs). The DIHs offer R&D services concentrating on advanced robotics for agile production, human-robot collaboration, reconfigurable robotic modules, Industrial Internet of Things and cyber-security solutions for manufacturing and support of business ecosystems. However, a simple transfer of technology from universities and research centers, in itself is not enough. The technologies developed in the laboratories need to be cultivated to reach a maturity level that the companies can actually deploy them in their own products and more importantly it improves the production process in terms of quality of work for humans, production efficiency, and diversity. Furthermore, these developments must adhere to requirements imposed by regulators and still be feasible from a business perspective. In other words, the applied solution must be robust, profitable and inline with the safety regulations (see Table I).

From a market perspective, the companies in Europe in particular, and worldwide in general, are moving towards smaller lot sizes and highly personalised products. Fulfilling this need requires that the production processes are incorporating aforementioned technologies in even faster phases. There is, thus, pressure on research centers to bring maturity to existing state of the art solutions involving for example, advanced robotics, and in particular, collaborative

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TABLE I: The main standards related to safe robotic systems.

Standard	Name	Summary
ISO 12100 [8]	Safety of machinery General principles for design Risk assessment and risk reduction	Designing safe machines
ISO 10218-1/2 [9] [10]	Robots and robotic devices Safety requirements for industrial robots	Designing human safe robotic systems. Supplementing ISO 12100.
ISO 13849 [11]	Safety of machinery Safety-related parts of control systems	Safety approved sensors
IEC 61508 [12] [13]	Functional safety of electrical/electronic/programmable electronic safety-related systems	Safety approved sensors
ISO/TS 15066:2016 [14]	Robots and robotic devices Collaborative robots	Collaborative robotics and their safety requirements. Supplementing ISO 10218-1

work scenarios. Bringing these solutions are key to bringing flexibility in manufacturing processes, which in turn, enable small batch size production.

Achieving technical maturity goes hand in hand with the safety regulations, and, in most cases, the safety regulations serve as a benchmark for achieved technical maturity. Robots and their associated hardware can be dangerous to operate and collaborate with. Therefore, international standards organizations such as International Organization for Standardization (ISO) and International Electrotechnical Commission (IEC) are forming unified comprehensive standards that can effectively regulate the utilization of robotics in industrial environments. However, these standards are (and need to) constantly evolve with new technologies and practises. The main standards related to robotic systems introduced in this paper are summarized in Table I.

It is no uncommon that the safety regulations lag in keeping pace with the developments. For example, in [15] the defined safety regulations were found to be too conservative and inflexible to reap full benefit from the developments. In worst case scenarios, any production reconfiguration will require a full risk assessment to be in line with the Machine Directive [16]. Consequently, for a vast number of use cases, the risk assessment based on the current regulations will require full separation of humans and robots by fences and/or safety devices. This is a very laborious activity, thus, there is a need to move towards more adaptive safety standards that allow collaboration and ensure safety at the same time [17]. The developments done on lab-scale demonstrators to make them industrially viable are a key tool for further enhancing the existing safety standards.

In essence, the industry is going through a period, where to stay competitive, they require a rapid transition of the state of the art lab demonstrators into industrially deployable solutions. As common sense and ordinary, achievement of maturity seems, in reality, the researchers haste towards more novel solutions and technical maturity is left as an afterthought, which at a good time of need would be achieved by someone else beside the developer. Therefore, in a lot of cases, it takes long time for a developed technology to traverse the route from the university labs to shop floors.

Under the European Union Digital Innovation Hubs (DIH) programme [18], a consortium of leading European research institutes came together in a project called TRINITY [19] and brought various state of the art technological solutions that address the needs of the industry especially the SMEs. These demonstrators were in various stages of development. Each of them charted a unique path to become more industrially relevant. The insights gained are beneficial for the industry at large. They are the main contributions of this paper.

The demonstrator development for achieving industrial maturity followed a module-centric approach. Modular robotic systems are considered as a main enabler for production system re-configurability [20]. Following are a few representative examples of such systems. Gaspar et al. [15] developed a re-configurable robot work cell to support the adaptation to the continuous changes in production. The concept was relying on passive re-configurable hardware components to achieve affordable and autonomous reconfiguration. Hietanen et al. [16] proposed a modular approach for creating a depth sensor based safety monitoring system, where the user interface can be realised with projector based GUI module or AR-based module. Tirmizi et al. [21] proposed a framework to make the programming of cobots faster, user-friendly and flexible for assembly tasks. Their solution combined a force-sensitive cobot in a vendor-independent fashion, with a versatile gripper, computer vision that can handle reflective pieces, and speech recognition to free up the hands of the operator. Gkounelos et al. in [20] propose a framework where mechanisms at the process level and the resource level enable dynamic work re-organization. All of these technologies followed a module-centric approach towards dissemination of their work as it facilitates industrial uptake.

We can find examples in literature where industrial research groups have endeavored in the previous years to bring their novel solutions to industry by giving due importance to achievement of robustness and reliability, as per relevant standards, in their developments. In [22], the authors present the implementation of a robotic system for advanced human robot collaboration assembly and discuss all the technological approaches that have been implemented for facilitating the interaction and support of human operators in an industrial setting. In [23] the authors present the impact of eighteen major applications of Robotics for Industry 4.0. In [24] the achievement of robustness for industrial usage of augmented reality with robots is presented. [25] presents a model for maturity activities related to industry 4.0. [26]and [27] did the same for the defence equipment manufacturing sector and the electronic products industry respectively. [28] provides guidelines for agile technologies employment in the industry.

While there are many other multiple excellent solutions as well, in addition to the above mentioned, that took the technology from inception to conception to eventual industrial adoption, the issue remains that by and large, academic developments or industry-academia collaborations stagnate after the first successful implementation of the use case. Achieving technical maturity until industrial uptake should be the norm rather than an exception. To speed up the technology transfer from the academia to the industry, more assessment and standard-centric development is needed. To bridge this gap, this paper presents an approach for achieving technical maturity that expedites the technology transfer process. The rest of the paper is arranged as follows. Section II presents the technical maturity achievements of the presented demonstrators. Section III results section summarizes the impact of the developments. The paper ends with Sec, IV that presents the conclusions.

II. Approach

The approach in this work aims to analyse the maturity actions taken on a set of use case demonstrators made in a modular fashion [29]. These demonstrators are from the field of collaborative robotics and were identified as being the most promising to advance agile production.

A performance characterization of the (sub)systems is done on quantitative grounds, to identify the weakest points and potentially critical Key Performance Indicators (KPI). Using the results of this evaluation analysis, guidelines towards the improvement of the systems were provided that lead to a cross-fertilization process towards integrated solutions ready for industrial uptake.

The assessment method has three parts. The first part is the initial demonstration and/or module description. The second part of the assessment is the general performance criteria evaluation, which is recommended to be performed with an external partner. The parts 1 and 2 are illustrated in Fig. 1. The third part deals with the provision of detailed assessment of standards, their exploitation and identified barriers, including aspects related to cybersecurity. This analysis also assesses the possibilities with respect to up-coming standards related to presented technologies. This paper focuses on the first and second part of the assessment.

In the following subsections the individual journey of each of the four selected demonstrators[1] towards technical maturity is described. These demonstrators are analyzed with a four step approach. The first step deals with the capturing of the industry needs. Followed by the maturity steps taken to address them. The third step presents specific actions taken towards industrial acceptance and the last step presents

[1]https://trinityrobotics.eu/catalogue

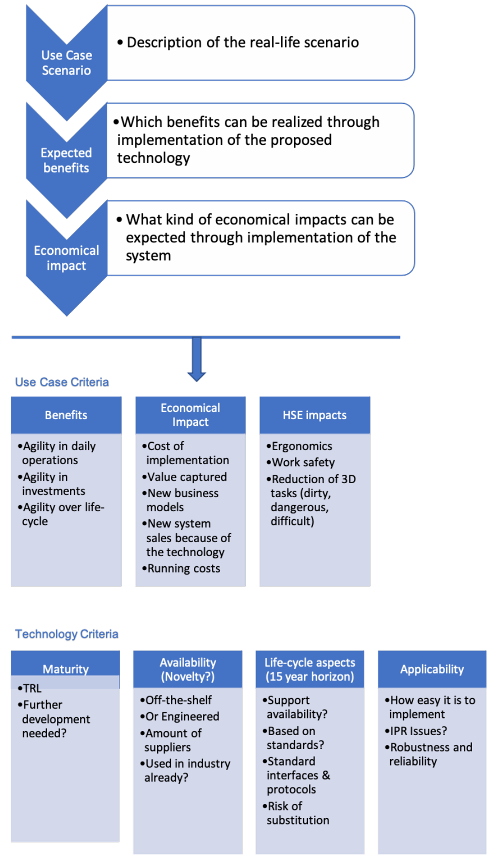


Fig. 1: Principles of the assessment method's parts 1 and 2

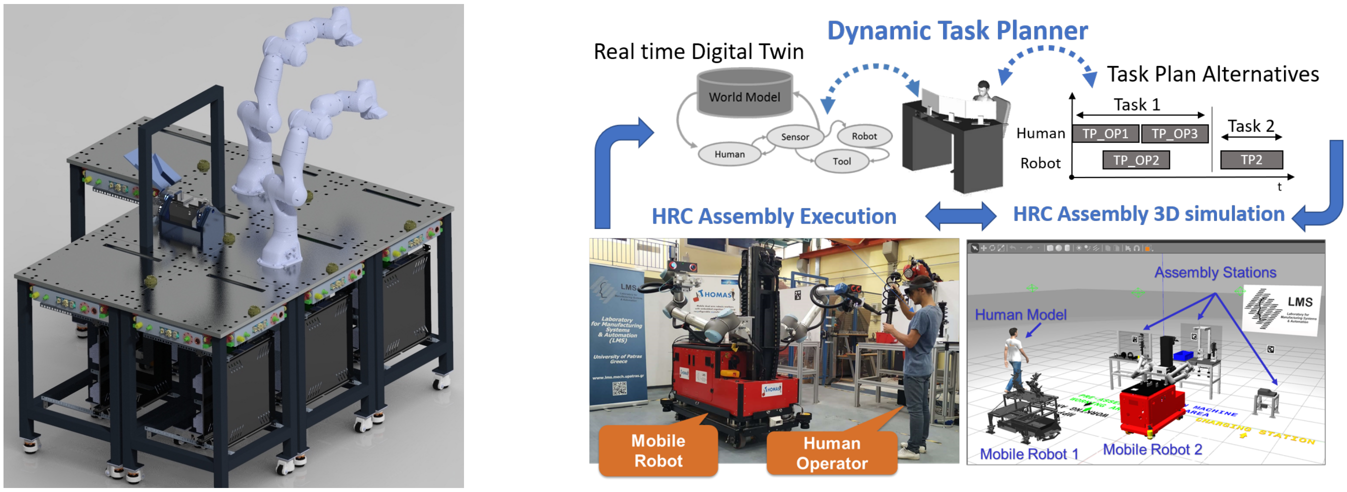
the interest these actions generated in industry for potential uptake. From these four steps, a generic approach precipitates that is presented in Sec. III.

A. Robot work cell reconfiguration

The application of robotics in large-scale production processes is well understood and robotics is widely used by all types of manufacturing companies, small and large. However, an economically viable application of robots for small scale or even one-of-a-kind production is still problematic. We developed a reconfigurable robot workcell (see Fig. 2a) to enable fast changeovers and partially automatic switching of production from one product to another [15].

1) Needs and requirements: While the first results were promising and the results were successfully applied for automated assembly of different types of products that come in a variety of different models (automotive light housings, linear actuators for smart furniture, robot grippers, runway signalling lights, and mounting of PCBs), it became clear that it is difficult, especially for SMEs to handle a complex system like a reconfigurable robot workcell without providing essential subsystems for automated setup of workcells.

2) Steps taken towards maturity: In the initial system [15] many steps were performed manually. Therefore, steps were taken to increase the level of automation for a new production setup. For example, an automated procedure for setting up reconfigurable fixturing systems was developed [33].



(a) (b)

Fig. 2: (a) A reconfigurable robot workcell built from standard modules connected with plug-and-produce connectors [15]. (b) Dynamic task planning and work reorganization framework [30]–[32].

Moreover, new, user-friendly approaches for programming by demonstration of complex robot operations were provided [34]. This facilitates individuals with limited exposure to robots. The automated systems for setup and programming resulted in increased possibility of Industrial take-up by SMEs.

3) Improvements towards industrial acceptance: Reconfigurable robotic systems can be applied to a greater variety of production processes than standard workcells. However, they are typically more expensive and slower compared to dedicated automation solutions. To address the cost problem, a concept of passive reconfiguration was developed [15], which enables automatic reconfiguration without equipping each subsystem with its own actuator. In this way a flexible yet affordable solution was provided. The problem of longer cycle times compared to dedicated solutions cannot be solved as dedicated solution can often be more optimized. To ensure that a reconfigurable alternative remains economically viable, it needs to provide a sufficient amount of flexibility so that new production tasks can be quickly set. If a flexible, reconfigurable robot workcell is considered in the context of a variety of tasks that it can support, such a solution is more profitable than several dedicated solutions.

In accordance with the Machinery directive 2006/42/EC, the manufacturer of a combination of machines is obliged to carry out a risk assessment in the course of a conformity assessment procedure. For the reconfigurable robot workcell, the assessment was carried out in accordance with EN ISO 12100 Safety of Machinery – General Principles for Design, Risk Assessment and Risk Mitigation. Based on this analysis, we prepared several safety concepts to bring the workcell into compliance with legal requirements.

4) Interest shown by industry: Two separate strategies are currently followed to bring reconfigurable work cells and their elements to real industrial applications. Firstly, a start-up company Flex Hex[2] has been established to commercialize the developed passive fixtures. Furthermore, the digital innovation hub at Jožef Stefan Institute, Slovenia (JSI) offers several components of the reconfigurable workcell as stand alone modules. They have already been used in several industrial applications.

B. *Dynamic task planning and work reorganization framework*

This use case introduces a decision-making framework which generates and evaluates alternatives for task allocation and rough motion planning of human and robot operations, using information and data extracted from simulations. The evaluation of the generated alternatives is based on multi-criteria decision-making, integrating 3D graphical representation, simulation, and embedded motion planning. The dynamic task planning & work re-organization framework can be applied in production lines that use either mobile or stationary robots alongside humans. It presents a holistic approach of task (re-)scheduling, in dynamic assembly lines, utilizing AI, heuristics and a simulation environment for evaluating alternatives that results in optimal utilization of human and machine resources

1) Needs and requirement capturing: The industrial need for this framework came from assembly line applications. Flexible manufacturing requires an array of diverse resources like humans, robots and other automation agents. Each of them comes with their own set of strengths and weaknesses. Intelligent allocation of tasks in such manufacturing scenarios provides a surge in productivity, optimal resource utilization and improvement in human operator ergonomics. An absence of such intelligence can result in long idle times and production bottlenecks. Manufacturing plants are well aware that dynamic production environments require careful consideration of the execution sequence of the assembly

[2]http://flexhex-robot.com

actions. Human-Robot Collaboration makes addressing of these need even more critical. Workplace design and task allocation therefore is a key barrier in cycle time reduction.

2) Steps taken towards maturity: In the initial implementation of this human robot collaborative task planning framework, the decision making for cycle time optimization was based on precalculated task duration [31]. To generate more realistic results, the decision-making engine was integrated into a 3D simulation tool by SIEMENS, roughly generating robots' motions plans and human postures for each alternative assembly task plan execution [30]. This allowed the evaluation of the different task alternatives based on near-realistic cycle time calculations that considered ergonomic criteria for the human operators as well. The next step towards maturity was the end to end ROS based integration of the task planning algorithm with the factory's Digital Twin that includes the spatial constraints of the layout and feedback from the real robot controllers on the actual task duration and the optimal motion plans [32]. Safety aspects were also captured through the Digital Twin. In parallel with the technical maturing, the decision-making framework has been upgraded to support the modelling and task planning for human robot collaborative execution of multiple manufacturing processes. All these endeavors complied with ISO 12100 [8], 10218-1 and 2 [9], [10].

3) Improvements towards industrial acceptance: To gain industrial acceptance, two set of activities were performed:

- The performance of the framework was assessed via use cases from the automotive and white goods sectors. These iterations led to performance enhancements based on the needs of end users. It also led to the optimization of the Graphical User Interface for easy interaction with the production engineers.
- The TRINITY project's manufacturing companies network was utilized to create a set of visual materials, including demonstration videos and presentations that communicated the benefits of the framework to the stakeholders and provided them with the added flexibility the framework brings to the production lines.

4) Interest shown by industry: The industrial companies were engaged through a) participation in collaborative projects where the end users expressed their interest in implementing the different versions of developed decision making tool, b) during different showcase events at international workshops & fairs, and c) through individual interaction with local SMEs that exhibited interest in deploying human-robot collaborative operations in their factories.

C. User friendly programming of human-robot collaboration tasks

This demonstrator introduces a framework [21] for programming robotic applications in an intuitive, and user-friendly manner that requires no prior robot programming expertise. The intuitiveness in programming is achieved by using parameterizable robot skills that can be sequenced by using interfaces like a Human-Machine Interface (HMI), speech, and teach by demonstration that allows creation and modification of robotic applications in a cost and time effective manner. The overall framework is supported by a middleware based on skill-based robot programming. This framework targets SMEs and large-scale industries requiring flexible assembly solutions as end-users.

1) Needs and requirement capturing: The problem of robot programming being a very time consuming process is well known. For example a typical robot application takes 3 months to complete [35]. The needs were captured by doing a series of interviews with robot integrators. This was followed by visits to the industrial units where robots are deployed. The series of interviews and visits led to identification of slow and tedious programming as a major bottleneck that drives up the cost for deploying robot solutions. The information gathered was mapped on a value chain to prioritize the improvements that would benefit the manufacturing ecosystem the most by removing the most debilitating technological barriers.

2) Steps taken towards maturity: To realize this user friendly programming framework, a flexible architecture was developed, where the implementation of various robot-skills and the high-level human inputs needed to use or modify them are linked by different nodes and Robot Operating System (ROS) is used for communication between these distributed nodes. The various ROS nodes are:

- A vision node to identify and locate work pieces and tools.
- A speech node to recognize operator commands and give feedback.
- An executor for the process model that activated the various skills as input by the user
- A low-level control system to compute real time motions with an option to invoke skills that are programmed with constrain-based programming approach.

The system was tested to carry out the assembly of an air compressor which involves complex handling and manipulation tasks during the process. A complete application for air compressor assembly can be made by piecing together easily programmable subtasks/skills without any need of complex coding. These skills can be further modified to better adapt the needs. This framework allows conspicuous reduction in programming time without prior need of robot programming experience and it introduces an efficient robot programming method in contrast to the temporally expensive classical robot programming methods. Furthermore, the existing robot applications can be easily adapted to the production needs in case a variation is introduced in a certain assembly process. This addresses a major need to frequently reprogram to deal with product variability and customization.

3) Improvements towards industrial acceptance: A first mock setup as shown in Fig. 3a was created that resembled the actual assembly station of the manufacturer. Approximately 3000 tests were conducted to look for issues that could hinder industrial deployment. The first improvement was to move away from ROS1, as it made the system prone to failure in case a single node/device failed. The framework was migrated to ROS2.

(a) (b)

Fig. 3: (a) Flexible assembly work cell utilizing a user-friendly robot programming framework for quick programming of robots [21]. (b) Collaborative assembly with vision-based safety system [16], [36].

A user study was conducted to identify further issues with new users that had no background in robot programming. This resulted in improvements in the Graphical user interface, developments of new parameters for the robot skills and additional information displays. Throughout this developmental process the ISO/TS 15066:2016 standard compliance was ensured.

4) Interest shown by industry: To increase technology uptake in industry various dissemination activities were carried out, which included, publications, and workshops. New skills were developed to appeal to a broader range of companies, for example, a screwing skill, was added to the robot-skills library. These activities led various companies to assess the framework for potential uptake.

D. Collaborative assembly with vision-based safety system

The vision-based safety system for human-robot collaboration consists of a dynamic 3D map of the working environment that is continuously updated by a depth sensor. It is utilized for safety and interaction between resources via a virtual GUI. The robot's working zone is projected to a planar surface providing the user an awareness of the safety zones. The virtual GUI also provides instructions about the assembly sequence.

1) Needs and requirement capturing: The needs and requirements for the use cases and modules in the collaborative assembly work cell were extracted from an industrial use case, as described in [16]. The test product that was used is a diesel engine's upper part, which is currently assembled manually. The task described in the earlier work [16], [36] required the assembly of different parts of the diesel engine in a collaborative shared workspace, where the collaboration levels consist of co-existence, synchronisation and collaboration. The use case follows the standards ISO 12100 [8], 10218-1 and 2 [9], [10], however, the demonstration was conducted with a UR5 robot and the tool point speed was reduced to comply with the standards. The residual risk in this case comes from the sharp edges of the part and the gripper. However, this was assessed to be minimal.

The industrial need is for the utilisation of collaborative robotics in industrial applications. The production batch sizes are getting smaller, which sets requirements for the system adaptability to the product variants. The technical feasibility includes also the robustness of operation. The used system components such as sensors and communication must be reliable during the non-stop production. The greatest technical barrier still is the operational requirements coming from the Machine Directive and robotics safety standards. For example, the used ROS architecture is not a real time system, and time from the safety border violation to the full stop of the robot system is over 250ms, which poses a clear technical problem from a safety perspective.

2) Steps taken towards maturity: The maturity assessment carried out led to the following taken steps:

- *Technical development:* Integration of industrial ROS packages to the system, improvement of used sensors and analytics methods, including cyber-security by design into the next development round
- *User interfaces and user experience:* Utilizing composable technologies such as AR Goggles and projection, developing further the augmented work instructions
- *Design touch points:* Gathering more targeted feedback from industrial partners, further dissemination of associated materials (tutorials, video lectures) and demonstrating the system performance in different events.

3) Improvements towards industrial acceptance: The improvements towards acceptance relate to regulatory and technical improvements. The technical improvements aim to prove that the solution is feasible to be applied to both collaborative robots and heavy industrial robots. The delay times between the sensors and robot control poses a challenge towards utilisation by the industry.

4) Interest shown by industry: The modules have been used by two consortia of companies that received funding from TRINITY. The source code has been shared openly, but it has not been recorded who has actually used the code. In addition, various dissemination activities were carried out to promote the demonstrator and its utilized technologies.

III. Results

This paper analyzed the technical maturity of four collaborative robotics demonstrators via a proposed maturity assessment method (summarized in Table II): 1. Needs and requirement capturing, 2. Steps taken towards maturity, and 3. Improvements towards industrial acceptance. By following this method, industrial maturity is achieved to a point that manufacturing companies can valorize the technologies to gain a higher production efficiency. Individual attention garnered from the industry by each demonstrator has been achieved by either dedicated adoption of the technology, in-person showcasing events or the commercialization by a start-up company. All demonstrators and their pathway to increased maturity followed the required technical standards (see Table I). However, although on surface these different demonstrators followed their own unique trajectory to gain industrial maturity, a careful analysis and maturity assessment showed that generic inferences can also be gained from this work that can be used by other robot technologies to gain similar industrial acceptance.

Table II shows a snapshot of each demonstrator's captured needs (step 1) from the evaluation and the results of the maturity assessment exercise. This exercise conducted for each of the demonstrators by independent reviewers resulted in concrete steps that brought the demonstrators close to industrial utilization (step 2 and 3). Before this, they gathered needs from the industry on whose basis the assessment was conducted. These are presented in column 1 of Table II. Even though other guidelines and assessment methods exist [28], our approach targets agility in manufacturing by current state of the art technologies, such as collaborative robotics, effective user interfaces based on augmented reality and speech, re-configurable robot work cells, among others.

Fig. 4 shows the path taken towards maturity and industrial acceptance (steps 2 and 3). As the approach is general, it can be reproduced by other technology providers that are seeking industrial utilization. The path and its individual actions were identified as common activities that were conducted by each partner albeit in a version that was a manifestation of their local industrial ecosystem.

Another aspect that needs mentioning is the role of training materials that were created to support industrial acceptance. Any technology is as useful as the industrial base that accepts to use it. Many a promising technologies rest in archived folders because there weren't any easy to understand training materials that help the end-users in reproducing the functionalities of a demonstrator and its modules. It was identified that it is important to provide training services to the SMEs, towards boosting their familiarization to novel robotic technologies. To this direction, an Education and Training platform[3] was developed, that is open to the public, where the interested industrial companies have access to a set of training modules including, demo casing videos, presentations of the applicability and the advantages of the developed use cases as well as tutorials on how to implement, develop and use the technical modules that comprise the demonstrator. Through this platform, awareness was raised and the demonstrator owners attracted the interest of first time and intermediate users, eliminating their possible concerns and barriers to adopt robotics in their factories. Special focus was given on upskilling the companies' personnel in terms of comprehension of the new ICT technology and learning how to interact with it for improving their job quality. The provided training material was carefully designed based on the results of a systematic survey. The partners used this survey for capturing the training needs of their industrial partners. In essence, training materials are important in achieving the goal of industrial deployment. They are an important reusable result of the work presented in this paper and their importance in facilitating industrial uptake can not be ignored.

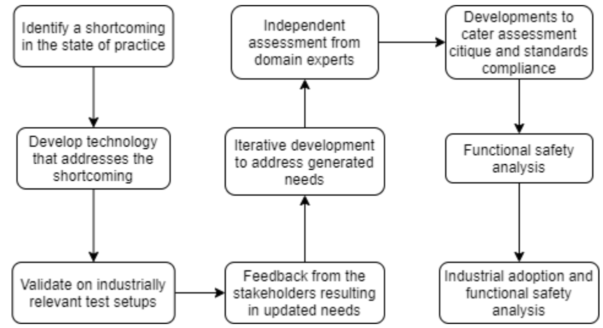


Fig. 4: Path taken towards maturity and industrial acceptance. These steps can be utilized by other technology providers seeking industrial utilization.

IV. Conclusion

In this paper we highlighted the gap in the technology transfer pathway from laboratory to industry, and proposed a maturity assessment method to evaluate the robotics solutions. The proposed maturity assessment method is successfully tested and evaluated with four different robotics cases. The outcome demonstrates that industrial maturity can be achieved by following the proposed assessment method. Uptake and interest of the demonstrators by industry is shown by either dedicated adoption, showcasing through networking events or commercialization by a start-up company. Future work encompasses 17 additional robotics cases in total, as well as the adaptation of the proposed methodology with several SMEs. Expanding this study will further evaluate the methodology and its processes to include the second part of the assessment formalization and deployment. This will enable us to address specific requirements from related standards and technical reports.

[3]`https://trinityrobotics.eu/catalogue`

TABLE II: maturity assessment

Improvements done to the maturity and industrial acceptance of the use cases		
Demonstrator	**Needs captured from evaluation**	**Steps done towards maturity and industrial acceptance**
Robot work cell reconfiguration [15]	Initial investment is significant, reconfiguration requires expertise in robotics	Increased automation of reconfiguring, user-friendly approach to programming, lower initial investment via passive reconfiguration option
Dynamic task planning [30]–[32]	Short support expectation, specific simulation software required	Testing and validation for multiple industrial use cases, alternative simulation software evaluated, integration and testing for normal working conditions
User friendly programming [21]	Initial investment was high, robustness lacking for industrial deployment	Improved robustness, conducted a study to validate benefits, proved the concept with high visibility projects
Collaborative assembly [16], [36]	Multiple suppliers for hardware, cybersecurity related access control, improved robustness	Integration of industrial ROS packages, improvement of used sensors, implementation of cybersecurity by design

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