Lecture Notes in Mechanical Engineering

José Machado · Filomena Soares ·
Justyna Trojanowska · Erika Ottaviano ·
Petr Valášek · Mallikarjuna Reddy D. ·
Eduardo André Perondi ·
Yevheniia Basova *Editors*

Innovations in Mechanical Engineering II

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Preface

This volume of Lecture Notes in Mechanical Engineering gathers selected papers presented at the Second International Scientific Conference (ICIE'2022), held in Guimarães, Portugal, on 28–30 June 2022. The conference was organized by the School of Engineering of University of Minho, throughout MEtRICs and Algoritmi Research Centres.

The aim of the conference was to present the latest engineering achievements and innovations and to provide a chance for exchanging views and opinions concerning the creation of added value for the industry and for the society. The main conference topics include (but are not limited to):

- Innovation
- Industrial Engineering
- Mechanical Engineering
- Mechatronics Engineering
- Systems and Applications
- Societal Challenges
- Industrial Property

The organizers received 139 contributions from 16 countries around the world.

After a thorough peer-review process, the committee accepted 81 papers written by 335 authors from 15 countries for the conference proceedings (acceptance rate of 58%), which were organized in three volumes of the Springer Lecture Notes in Mechanical Engineering.

This volume, with the title "Innovations in Mechanical Engineering II", is specifically spanning from advanced materials and composites, optimization of manufacturing and production processes and converging issues and technologies in additive manufacturing and Industry 4.0. It covers applications in the transport and automotive, and medical and education sector, among others. Last but not least, it analyses important issues proposing a good balance of theoretical and practical aspects. This book consists of 30 chapters, prepared by 146 authors from ten countries.

Extended versions of selected best papers from the conference will be published in the following journals: Sensors, Applied Sciences, Machines, Management and Production Engineering Review, International Journal of Mechatronics and Applied Mechanics, SN Applied Sciences, Dirección y Organización, and Smart Science, Business Systems Research and International Journal of E-Services and Mobile Applications.

A special thank to the members of the International Scientific Committee for their hard work during the review process.

We acknowledge all that contributed to the staging of ICIE’2022: authors, committees and sponsors. Their involvement and hard work were crucial to the success of ICIE’2022.

June 2022

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Contents

Development of Guidelines for the Design of Functionally Integrated Molds for a Novel Vacuum Assisted Resin Infusion Process

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Abstract. In the present study, a newly developed vacuum assisted resin infusion process (FuVak) is described in which the conventional, disposable multilayer vacuum setup is replaced by reusable silicone vacuum hoods with integrated flow channels. In order to ensure high-quality impregnation of the fiberglass textile structure in a short time, while avoiding the use of disposable layers like flow aids, a suitable design of the flow channel geometry and their positioning on the vacuum hood must be determined. To study the effect of the channel cross-section, an experimental setup with varying geometries in laboratory-scale was designed, constructed, and tested. Optical detection of the flow front during the Infusion process and later examining of porosity distribution on the cured part were performed. The relationship between channel cross-section, flow speed and final part quality (porosity distribution) were determined and discussed. Based on this, an industry-scale, 2 m long part with higher complexity was fabricated with the novel process, validating the process ability to control of the flow front and quality of the composite.

Keywords: Fiber reinforced plastic · Vacuum assisted resin infusion · Functional integration

1 Introduction and State of the Art

The vacuum assisted resin infusion (VARI) is an established process for the production of fiber-reinforced plastic (FRP) components with small and medium batch sizes. This is a manufacturing process in which dry reinforcement textile layers (e.g. Glass fibers, carbon fibers) are placed into a mold and subsequently impregnated with a reactive resin system, resulting in a final structural part after curing [1].

Traditional VARI uses a multi-layer vacuum setup, in which all layers are single-use and must be discarded after the production of a single part (see Fig. 1). Additionally to the high level of waste material, the layers must be manually placed at the start of every cycle of production of a single part, taking substantial time and demanding specialized labor. Furthermore, this manual step is a source of variability in the part quality [2]. For this reason, there is a need for a faster and more reproducible manufacturing process.

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The goal of the research presented here is to improve on the current standard VARI processes by developing not only a reusable silicon vacuum hood, but also integrating flow channels in its internal surface, so that the flow of the resin is optimized for the best product quality and minimal infusion time. To achieve this the geometry of these flow channels, both the cross-section and their arrangement on the surface, must be evaluated and tested. Furthermore, the initial results are validated in a mold for a large and complex part. In this context, the newly developed VARI process described here represents an important technological step.

The basic idea of the FuVak-process is based on the use of functionally integrated, reusable silicone vacuum hoods (see Fig. 1) [3]. Compared to the conventional VARI-process, it enables a reduction of expendables (peel ply, flow aid, vacuum bagging film, resin entrance lines, vacuum channels, sealing tape, etc.), which in turn means a significant saving of resources, reduced cycle times, greater reproducibility, and less person-hours required from the workers. In the conventional VARI process, a separate, multilayer vacuum buildup must be laid for each component. In the FuVak-process, only one silicone vacuum hood has to be produced, which can then be used to produce at least 500 parts of the same geometry.

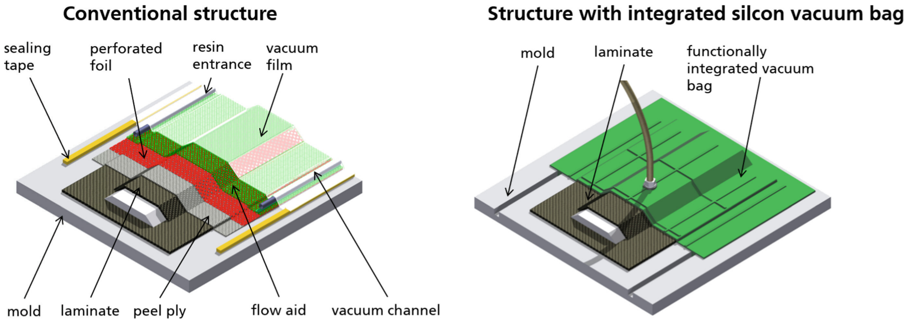

Fig. 1. Multi-layer vacuum build-up in the conventional-VARI-process (left) and simplified vacuum build-up in the FuVak-process (right) [3]

The integration of fluid-dynamically optimized flow channels in the silicone vacuum hood allows fast and reproducible resin impregnation of the textile reinforcement structure. This eliminates the time-consuming, material-intensive and not entirely error-free application of expendables to build up the resin-/vacuum system.

Numerical methods validated according to the current state of science and technology exist and their applicability to conventional VARI methods has been proven [4–6]. Nevertheless, there is recent research that has found that the physics of resin flow may be different for some applications and a conventional approach may not apply to all resin filling operations [7–9]. Due to the novel approach of the FuVak process to integrate flow channels into the silicon vacuum hood, it is necessary to verify to what extent a classical modeling approach is valid for this application. It may be necessary to develop a modified calculation approach that describes the resin spreading in the flow channels as well as the impregnation of the reinforcement textile with sufficient accuracy. These steps are outside the scope of this work but are being currently developed by the authors.

2 Experimental Determination of the Optimum Flow Channel Geometry

2.1 Experimental Setup and Parameters

To investigate how the infusion channel cross-section affects the flow front and the impregnation quality, a silicone vacuum hood with varying resin infusion channels was designed (See Fig. 2 and Table 1). By means of a large volume linear inlet sprue (channel cross section "1"), the low viscosity resin is infiltrated through the multilayer structure of fiberglass weaved fabric, which is kept under vacuum by the outer evacuation ring and outlet linear channel (channel cross section "2"). The flow front can be observed through the partially transparent silicone of the silicone vacuum bag.

Five layers of bidirectional (BD) fiberglass 260 g/m^2 fabric with known permeability were used in the experimental setup. The unsaturated polyester resin was infused through a 12 mm diameter infusion nozzle attached to the silicone vacuum bag at atmospheric pressure. The vacuum was drawn on the other side and at the right channel down to a pressure of 0.15 bar. The test parameters as well as textile and resin properties are shown in Table 2.

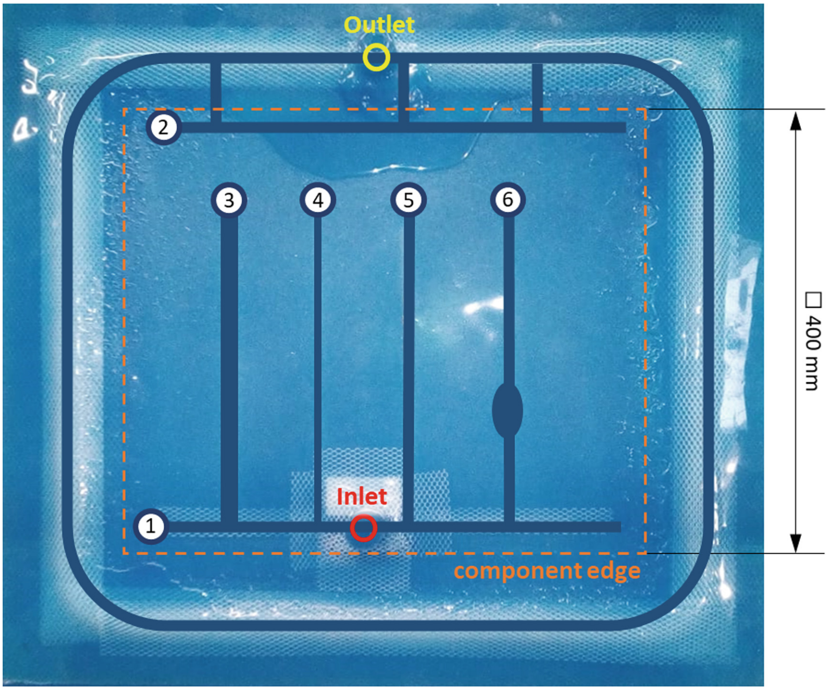

Fig. 2. Schematic representation of the experimental setup, functionally integrated silicone vacuum hood with varying flow channels

Table 1. Channel geometries on silicone vacuum hood with varying flow channels

Number	Width [mm]	Height [mm]	Notes
1	6.0	4.5	Inlet sprue channel
2	6.0	1.5	Outlet vacuum channel
3	9.0	1.5	Infusion channel
4	4.0	1.5	Infusion channel
5	6.0	3.0	Infusion channel
6	6.0	1.5	Infusion channel with node

Table 2. Experimental parameters for VARI permeation test

Infusion pressure p_{inf}	15.3 kPa
Ambient pressure p_{atm}	101.3 kPa
Resin viscosity η (at 20 °C)	400 mPa·s
Textile thickness per layer	1 mm
Total Number of textile layers	5
Total textile wight per unit area	1307 g/m^2
Fiber volume content ϕ_0	54%
Permeability K_0	1.695 10^{-11} m^2

2.2 Execution and Evaluation of Experiments

The flow front progress during the VARI process was recorded optically (see Fig. 3) and clearly shows that the infusion velocity of the resin is dependent on the channel cross-section. While the resin flows rapidly in the central infusion channels “4” and “5”, it is considerably slowed down in channels “3” and “6”. As a result of the vacuum in the infusion channel, a strong contraction of the silicone material takes place in the case of a wide and flat channel cross-section, as is the case in the channel “3” which significantly reduces the flow cross-section and increases the flow resistance (see Fig. 4). In comparison, channel “4” is considerably narrower, limiting the bending arc of the silicon material above it. The quickest flow in on the channel “5”, which is the one with the highest cross-section and an intermediate width between the two just discussed, minimizing this constriction of the channel. The infusion channel “6”, with 6 mm widt, shows a quick flow up to the node, and at this point the flow is greatly restricted. The reason being the same channel constriction, as in the channel “6”, but this time localized.

High flow velocities in the channel result in a resin flow front parallel to the flow channel and low flow velocities result in a wedge-shaped spread in the reinforcement textile (see Fig. 5).

When two parallel flow fronts meet, a weld line occurs [6]. The effect is characterized by incomplete impregnation due to air trapped between the resin flow fronts, leading

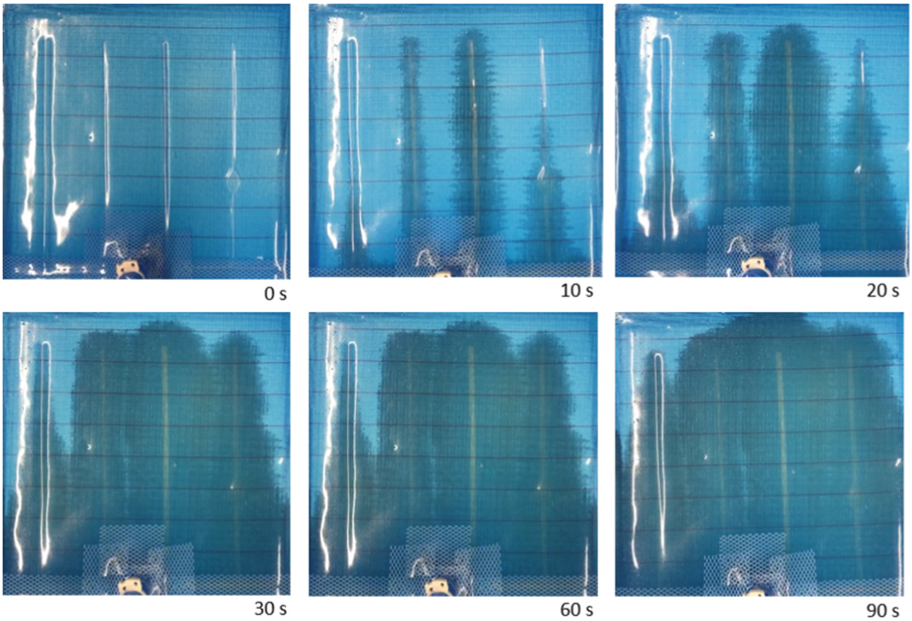

Fig. 3. Flow front curve during the VARI filling process with varying flow channels

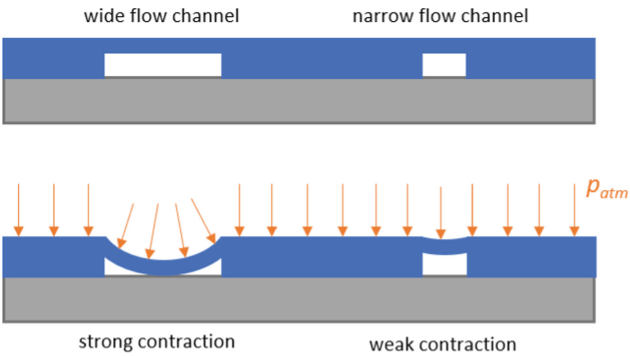

Fig. 4. Contraction of the silicone vacuum hood due to the negative pressure in the flow channel, leading to constriction of the flow cross-section

to defects (micro porosity) in the laminate in the affected areas (see Fig. 6). It can be seen from the test plate that weld lines occur to a much greater extent with flow fronts that meet in parallel than with flow fronts that run in a wedge shape to each other. In addition, a significantly worse impregnation quality of the reinforcement textile in the thickness direction can be observed at high flow rates. This is assumed to be due to a quick flow and spread of the resin on the whole area of the top layer of textile, before the resin can diffuse in the z-direction down to the lower layers. Thus, the quickest possible

Fig. 5. Shapes of the flow front propagation as a function of the flow velocity in the impregnation channels 3 through 6

impregnation leads to low quality parts, and a compromise has to be found between a quick process time and the impregnation quality.

For a high-quality component with high strength, it is essential that no air pockets or micro porosity occur [10]. The best impregnation of the reinforcement textile is observed around the channel cross-section "3", so this geometry was selected for subsequent testing. The constriction of the flow channel slows down the flow velocity of the resin sufficiently, so that it has sufficient time to spread in the Z (thickness) direction. In addition, the flow front course is wedge-shaped, thus avoiding weld lines.

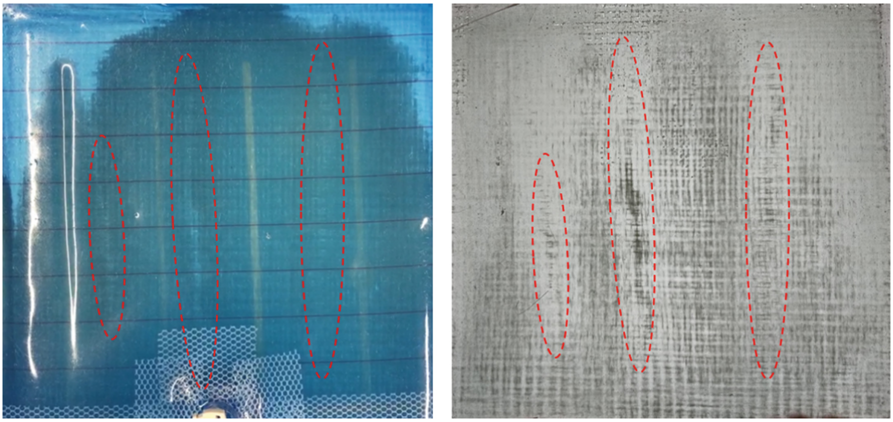

Fig. 6. Filling status after 90 s (left) and backlight image of the impregnated and cured test plate (right) with marked porosity on the weld lines due to trapped air. Darker regions between the weld lies (under the channels) indicate micro porosity due to insufficient impregnation in the z-direction.

2.3 Experimental Validation of Flow Channel Geometry on Complex Application Examples

Further VARI experiments were performed to validate whether the previously obtained findings regarding the good infiltration quality also apply to FRP structures with increased component size and geometric complexity. As an example, an existing mold was chosen with which glass fiber-reinforced plastic (GFRP)-door pillars for rail vehicles have already been produced using the conventional VARI process. A silicone vacuum hood with integrated infusion channels (9 × 1.5 mm) was designed and manufactured for this purpose (see Fig. 7 and Fig. 8). The channel geometries on the silicone vacuum hood are listed in Table 3. In comparison to the previously presented experiments, a so-called morphrunner system, which has a much larger volume for quick infusion times, was also used to realize the inlet sprue channels [11]. A VARI test was performed with the same parameters as before, listed in Table 2. The flow front profile and a demolded component are shown in Fig. 9 and Fig. 10.

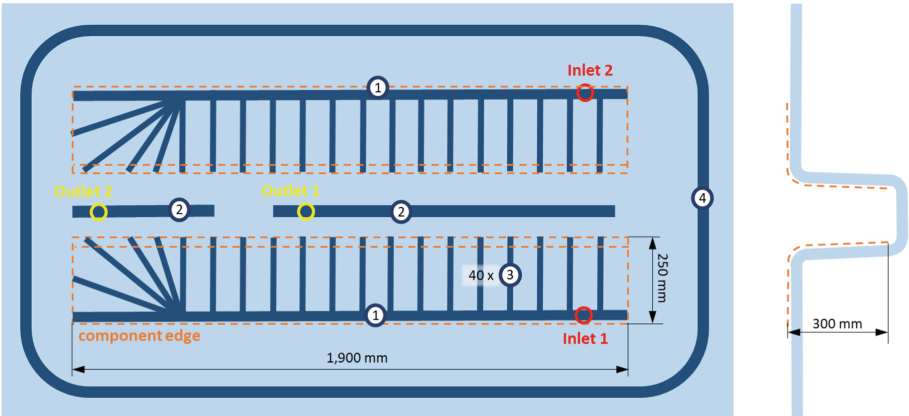

Fig. 7. Schematic representation of the experimental setup, silicone vacuum hood for complex application example

Observation of the flow front progression confirms that the goal of realizing a wedge-shaped resin spreading by the selected flow channel geometry is achieved. This is also reflected in the good quality in the impregnated areas on the component in question.

It can be seen that as the distance of the flow front from the inlet point increases, the flow velocity decreases, which can be explained by the pressure loss in the system. Due to the insufficient pot life of the resin, the test was stopped after 25 min, resulting in a non-impregnated area near the outlet “2”. In order to be able to avoid such process-related component defects in the future, suitable calculation methods for predicting the resin spread in the textile reinforcement structure must be determined for the process design.

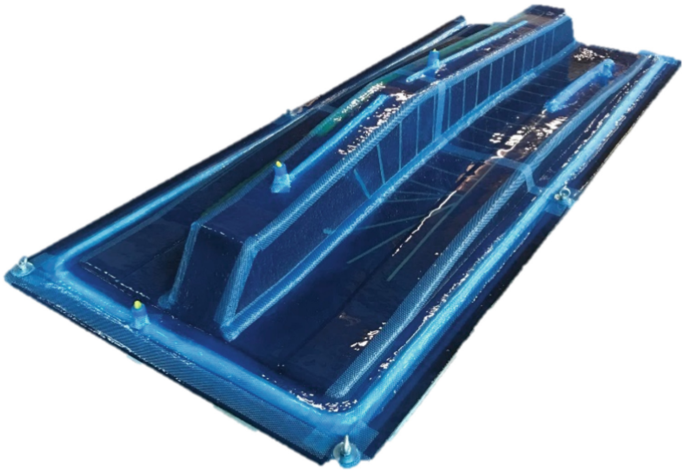

Fig. 8. Silicone vacuum hood for complex application example

Table 3. Channel geometries on silicone vacuum hood for complex application example

Number	Width [mm]	Height [mm]	Notes
1	10.0	8.0	Inlet Sprue channel with *morphrunner* in the first 600 mm
2	10.0	8.0	Outlet Vacuum channels, reinforced with fabric
3	1.5	1.5	40 x Flow channel
4	10.0	6.0	Vacuum channel for positioning and fixation, reinforced with fabric

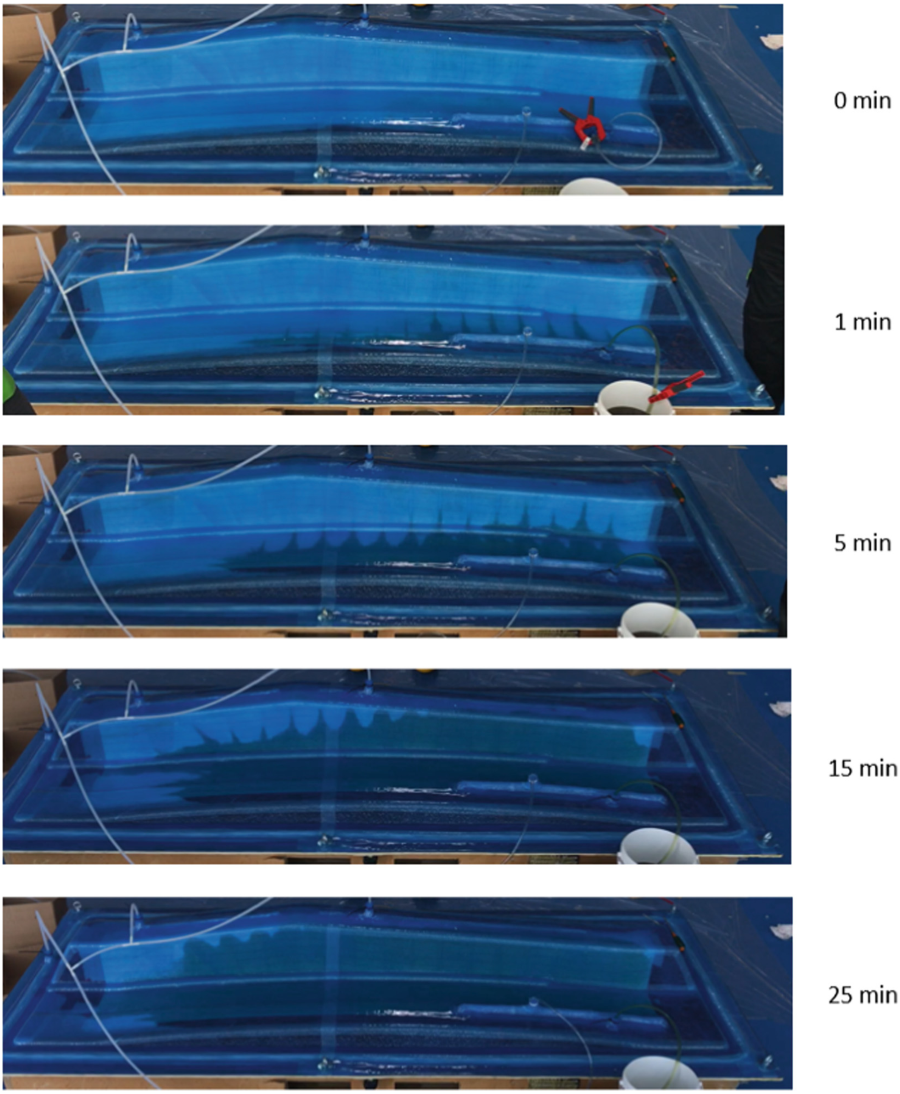

Fig. 9. Flow front curve during VARI filling process with complex application example

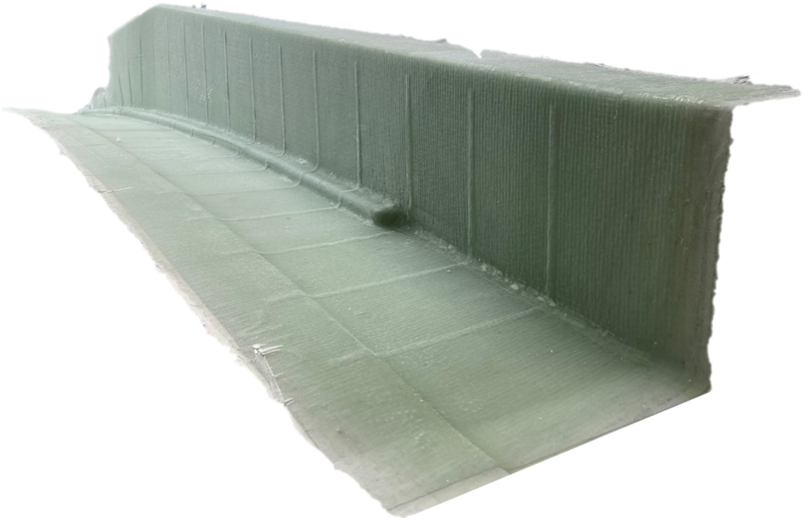

Fig. 10. Complex GFRP component manufactured using the FuVak process

3 Summary and Outlook

The study presented a novel improvement of the VARI process, the FuVak process, which represents an important technological step towards a faster and more reproducible manufacturing process. It is based on the use of reusable silicone vacuum hoods with integrated flow channel structures [3].

To determine design guidelines for functionally integrated silicone vacuum bags, a test setup was developed in which varying flow channel geometries were investigated. This has shown how the flow of resin on the infusion channels and their surroundings occur. The most important information are that while a very fast flow is possible, it leads to a low-quality part due to trapped air both in the lower layers of the fiberglass textile lay-up and on the "weld lines", where parallel resin flow fronts meet. A cross-section that allows a more controlled infusion was found, allowing a compromise between process speed and quality of the final laminated material. The lower flow speeds allow the resin to impregnate the lower layers of the fiberglass lay-up before any air is left trapped by the complete covering of the upper layers. Additionally the flow front takes a wedge-shape, instead of parallel expanding fronts. This avoids the trapping of air in weld lines, also leading to higher quality parts. Further-more, a channel with varying cross section, like a node point, leads to different resin flow speeds along its length, which can open new possibilities to control the resin flow in more complex scenarios.

The previously determined preferred variant for infusion channel design was validated on the mold of a real component used in the train industry. This application-typical component had increased size and geometric complexity. The FuVak process could successfully control the flow front on this part, even when the flow passed through sharp corners, leading to good impregnation on the majority of the part. Nevertheless, it was also shown that there is a need for further research in order to realize high-quality impregnation over the entire component structure as well as a reduction in cycle time. For this purpose, it is essential to have calculation methods for a realistic modeling of the infiltration process with a high predictive capability [7, 9]. These calculation methods have to be modified and validated to the proposed FuVak process, since no disposable flow aid layer is used and the channel cross-sections and density are very different from the conventional process. Such calculation methods are currently in development by the authors and will be the topic of future publications.

In addition, the component size and geometry complexity are to be further increased as part of further research activities. For this purpose, a silicone vacuum hood with integrated channels has already been designed, which will be used to produce an exemplary train front mask with a component area of approx. 11 m^2 ($3.1 \times 3.4 \times 3.0$ m^3) and to validate the FuVak process in greater depth (see Fig. 11).

If the further research activities on calculation methods and component complexity are successfully realized, the FuVak process will provide an improved VARI technology for the re-producible and cost-effective production of complex FRP structures with significantly lower wasted materials, as well as a suitable calculation approach for process design.

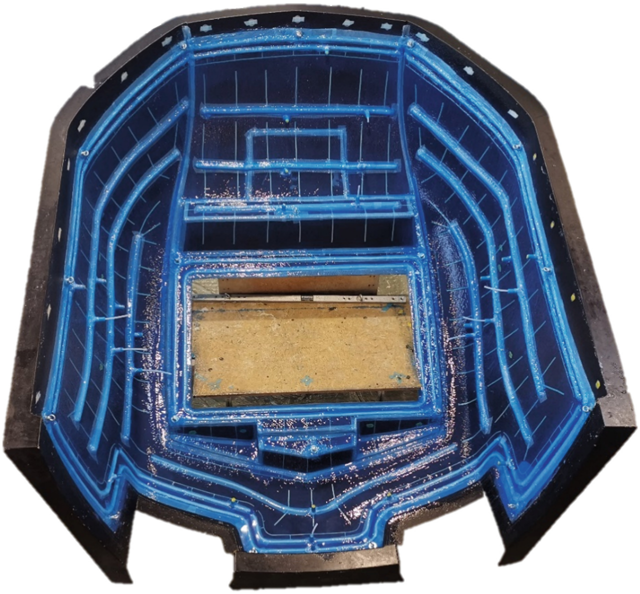

Fig. 11. Reusable silicone vacuum hood with integrated channels for the production of a GFRP train front mask using the FuVak process

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Challenges and Opportunities of Industry 4.0 at Mold Production Engineering and Management

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Abstract. The performance of technology-enabled service ecosystems can be an alternative to the traditional system view. Service-Dominant Logic can offer a theoretical foundation that elucidates the performative nature of markets, technologies, and business models, overcoming boundless views of rationality in business model development through unification rather than division. Based on this theory, it is our intention to present a unification proposal for the mold-making industries. By transforming this sector of activity into Industry 4.0 with its integrated services. Unification enables them to respond quickly to the needs of the increasingly demanding and uncertain market. So, the aim of the paper is to propose a conceptual model, based on the Service-Dominant Logic theory that contributes to the development and innovation of the mold-making. In this paper, two pathways are proposed: Pathway 1: Private Connectivity Solution and Pathway 2: Network Connectivity Solution. The implementation of these two pathways integrated compose the teorical model that aims to contribute to increasing the responsiveness of mold-making, guaranteeing quality and delivery times. Value Creation Innovation Processes can positively improve the mold industries. In addition, each resource operating in a mold industry at the collaborative service's ecosystem-level can increase the company's annual revenue, compared to a company that has not started down the technology ecosystem path. Consequently, the companies' profits can increase.

Keywords: Industry 4.0 · Mold · Project · Production · Industrial engineering

1 Introduction

Products satisfy the daily needs of people in different fields of application. One product can be a service, a physical good or a mix of both [1]. Each physical good can result from the transformation of one or more materials (e.g., polymers, metals, ceramics, composites) and sometimes it needs one or more cut technologies (e.g., laser, plasma, water jet, electrical discharge machining, flame cutting) [2]. Different manufacturing processes can be used to obtain the shape of a physical good [3–5]. Manual processing

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(e.g., hand contact molding, vacuum, and pressure bagging, spraying or projection, autoclave molding), semi-automatic processes (e.g., resin injection, hot and cold pressing, compression molding) and automatic processes (e.g., injection molding). The transformation of the raw material into a physical good may only result from primary molding (e.g., rotational molding, injection molding, extrusion), or may also require secondary molding processes (e.g., thermoforming, blow molding). Most of the processes used require molds (e.g., sand, steel, wax). Steel molds are used to produce hollow, massive physical goods with or without intricate details [3, 4, 6–8]. Since the amount of plastic in the oceans is currently a concern, naturally the mold making industries, particularly those that produce plastic injection molds, must adapt to these new demands and design new solutions that continue to ensure the mass production of physical goods with alternative materials to plastic (e.g., bioplastic, magnesium), to remain competitive, having the need to adjust processes and thinking philosophies. So, the production of physical goods will continue for decades to satisfy the most diverse needs of the world's population. To satisfy these needs, it is necessary to produce large series of physical goods. That's why are used adequate processes to large series, like injection molding (e.g., bioplastic, plastic, magnesium) [9, 10]. Therefore, the production of molds for material injection is fundamental for guaranty the mass production of a huge variety of physical goods, namely for the aeronautic, aerospace, and automotive industries [11, 12].

Specifically, injection molding requires steel molds composed of a huge variety of systems and components to produce big series of physical goods. They are the most complex molds, with various systems and components (e.g., bi-material, different colors in simultaneous, different materials – plastic, bioplastic, magnesium sulfate injection).

Nowadays, a company specialized in the design, management, manufacturing, and optimization of injection molds is currently dealing with strong daily pressure. This pressure results from the current international market demands, high quality, and tight tolerances at components machining. And because to do one injection mold, it is necessary different enterprises specialized in different processes to do systems and mold components (e.g., hot channels; machining).

Each mold must be done in the shortest possible time. So, the unification of industries is extremely important for mold-making companies. To develop projects and manage to produce molds, it is not enough the transformation to industry 4.0, to acquire sophisticated machines, equipment, and software. It is indispensable to be able to take advantage of their functionalities and potentialities. The efficiency of industries of mold making should be improved.

The growth of these companies has resulted from the urgent demand for molds by international customers, and the need to design and produce more and better, with competitive prices. Naturally, the market urges companies to adopt work methodologies that allow them a comprehensive view of the project and production of each mold, so that they are prepared to make changes, without compromising delivery times. Such a requirement implies that they plan and control the production of each mold.

Industry 4.0 can allow the consultation of information stored in databases not only to plan and control the project and the production of each mold, internally, but also, the integration of information that allows companies to share some services that contribute to finish a project within the deadline established with the customer. The efficiency and mold-making performance can improve from technology-enabled service ecosystems.

2 Mold Production Engineering and Management

The mold is a hollow block that is filled with molten material in a liquid or malleable state (e.g., plastic, glass, metal), where the molten and homogenized material hardens inside the mold, adopting the shape of the physical good. In the process of molding physical goods, two-part molds or part molding can be used, creating only one section of the physical good. Molds are an increasingly used and indispensable type of tool in all branches of industrial activity, due to quality control and reliability, geometric tolerancing and their transportation. Among their great advantages are economic issues and the fact that they allow the construction of parts of extreme dimensions with great precision and accuracy. In production planning designing to order is suitable for design industries [13–15].

Designing and producing a mold for injection molding can be a very complex and demanding process, physically and mentally, depending on the shapes of the physical goods to be injected into the mold [6, 10, 16]. In this process there are a vast number of departments with a strict description of activities and functions to be performed. To minimize failures, and so that when there is a need to consult specific information of the mold to be produced, there is interconnection of departments and ease of communication of information and interpretation of work done and work to be done, network collaboration is fundamental.

The existence of production planning and control is extremely important in mold production systems. Production can be harmed individually or collectively. The lack of production planning and control, as well as the lack of efficiency and compliance with demands, tend to be increasingly harmful to Organizations. Verifying directly (e.g., financially) and indirectly (e.g., deadlines). Sometimes this indirect harmful form, tends to be the most serious in the sense that it is silent. Because it may not be as direct in the verification of loss of customer credibility, demotivation of teams, missed deadlines and in more critical cases loss of the customer/project itself, as well as increased psychosocial risks in the organization. Lean tools can be considered important for the improvement of planning and control of the mold production, as well as, in all the Organization in general. They can also contribute to the increase of profitability, improvements in meeting deadlines and the planning initially defined for each project, and the creation of workplaces duly safe and organized, and with a global efficiency of the mold production process of excellence (i.e., above 85%), the result of availability (90%), efficiency (95%), and quality (99%) [17, 18]. Nevertheless, the diversification of solutions destined to guarantee the workflow, through an assertive production planning and control, to obtain more profitability in the execution of all processes. It is also necessary to create work methodologies to check the acceptance capacity of new projects, plan their distribution internally and among the various partners. On the other hand, it is necessary to improve the planning, programming and control of the project and the production of the molds, in which it is possible to verify the internal capacity of the execution of the several injection molds processes. Therefore, the transformation of the mold sector into Industry 4.0 (e.g., robots exchanging tools) is urgent [19]. On the other hand, Augmented Reality (AR), the interaction between a virtual platform and the real environment, using a set of devices consisting of cameras, computer, screen, creates a junction between the real environment and the virtual environment, which will lead to a real-time interaction. The screen can be exchanged for AR glasses. AR, enables a simpler and immediate understanding of selected tasks even for less experienced operators, minimizing errors and delays in mold manufacturing and maintenance, ensuring greater predictability in the duration of critical tasks [20, 21]. It is also advocating the importance of multiple skills of the work team, that employers can have. Initiatives to improve the skills focus on data science and advanced analytics [12, 13], advanced simulation [22] and virtual mold modeling [23–25], network communication [26–28], human-machine interfaces [29], digital-to-physical transfer technologies (CAE, CAD/ CAM, CNC programing for machines, CIM) [30–33], management systems [4, 34, 35], real-time inventory and logistics systems [36–38], AR [20], Work-Related Musculoskeletal Disorders (WMSDs) [39] and teaching and learning infrastructures [40–43].

The conceptual view proposed gives an understanding of the dynamic interaction of entities and their complexity in the ever-widening space of objects, people and entities being interconnected. And a representation of the system that could be implemented at mold-making by the conceptual model. That model consists of concepts used to help people know, understand, or simulate the subject of that the conceptual model represents. It is also a set of concepts that can used to implement the propose presented.

3 Technological Platforms Applied to the Mold Industry

3.1 Functionality and Components Required

Today a close collaboration between all stakeholders of the mold making industry and the standardization bodies can ensure the needs and requirements of the sector in an efficient way. A close relationship for knowledge transfer about technological processes, laboratory studies, or even about regulatory and commercialization aspects. Thus, two pathways of technological connectivity are proposed to the mold-making: Pathway 1 – private connectivity solution and Pathway 2 – network connectivity solution. The first pathway refers to efficient internal communication, between departments. The second model represents the communication through industrial networks, to carry out joint work, technology-enabled service ecosystems. Both pathways should work simultaneously, internally and in a group. Below are the functionality and components needed for mold making industries to implement the internal connectivity technology. The private connectivity solution for mold industries 4.0 is shown in Fig. 1. A solution for private and autonomous deployment, within the premises of each industry. The main highlights are four work zones:

(1) comercial – in the first work zone, a specific need arises and the customer's request via email and respective delivery of the 3D model of the physical asset (e.g., component for the aircraft industry) for which the mold is desired. The customer is identified, as well as all the requirements and specifications required. A mold identification is assigned (QR Code). Next, the production capacity is analyzed (an

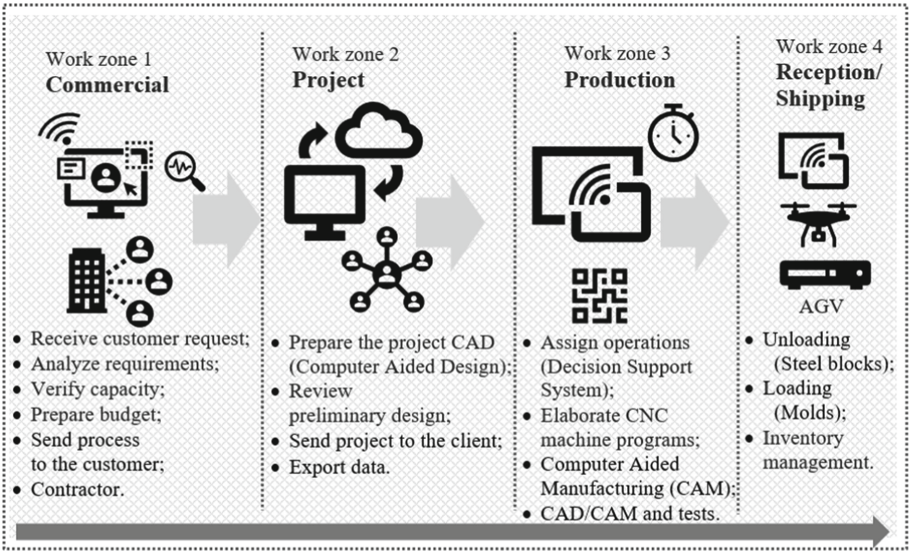

Fig. 1. Pathway 1: Private connectivity solution.

overall assessment is made of the eventual capacity to fulfill the project in the time-frame desired by the customer. It is also decided if there is necessary subcontracting of services (integrate to the proposed pathway 2). If the analysis is in favor of sub-contracting there is an evaluation of suppliers and a request for a budget. If there is internal capacity, the budget is made and, after internal approval, it is sent to the customer. Negotiations may or may not occur and the process is sent to the customer. After customer approval, the mold award is determined, external or internal execution.

(2) project – at the second work zone, if mold making in-house, the project manager analyzes with those responsible for the 3D sections of the physical asset that the customer intends to produce, or its 3D modeling is done at the software CAD – Computer Aided Design. At this stage there may be subcontracted services in some of the sections in order to avoid bottlenecks (integrate to the proposed pathway 2). This is followed by the 3D modeling of the awarded mold. During the design phase can be used the Lean philosophy (e.g., Poka-Yoke at the draw of the components). It is necessary planning a preliminary evaluation, sent to the customer where he can still introduce some changes to the mold, before its approval. Once the mold design is finished, automatically all sections will have access to the work orders.

(3) production – the detailed knowledge of the shop floor data in real time and with detail is a fundamental aspect in this cluster, allowing, not only that equipment with higher levels of intelligence can make decisions based on the state of the products they manufacture, but also so that decisions about the course of manufacturing can be made in time. What assumes a greater importance in this sector, considering the unit value of a mold, knowing also that each mold is unique.

At this stage there may or may not be CAD/CAM. If there is this need, the programming is done (integrate to the proposed pathway 2). For subsequent CNC machining and conventional milling and self-checking (integrate to the proposed pathway 2). It is not always necessary to heat treat before assembly and self-checking (integrate to the proposed pathway 2). At this work zone the final machining and self-checking is done (integrate to the proposed pathway 2). On the test date if all work orders have been fulfilled or deviations reported, the mold is ready for testing. It is checked for geometry, warping, and other possible defects. After this evaluation it may be necessary to rework the mold and perform a dimensional control (integrate to the proposed pathway 2).

(4) reception/shipping – in the final zone work, after the client's approval, the mold is shipped (integrate to the proposed pathway 2). Having resorted to subcontracting, a control is made internaly, in the sense of verifying if there is the need to make corrections, then tests are made (integrate to the proposed pathway 2). If the final control is in conformity, the mold is delivered to the customer.

3.2 Network for Mold Industries

The group connectivity solution for the 4.0 mold industries is shown in Fig. 2. A dynamic and networked solution use within the premises of each industry. The second pathway proposed results from the need to integrate and connect internal manufacturing orders (pathway 1) with outsourced services laboratory testing, scientific knowledge for research and development of new solutions, and planning and control of the design, production, and shipping of injection molds. Many companies work using obsolete conventional methods. Such methods cause disorder in the work processes, leading to lower quality products and higher prices. All these factors negatively influence the industry, leading to a loss of competitiveness and reputation in the marketplace.

It is true that these industries are equipped with (pathway 1) increasingly productive and sophisticated industrial machines, which allow to perform cuts with chip removal using conventional processes (e.g., turning, milling) and non-conventional processes (e.g., Electrical Discharge Machining, Laser, Plasma). In the last decades, the mold making industry has followed the technological evolution and integrated Computer Aided Design (CAD) with Computer Aided Manufacturing (CAM). As well as the integration of QR codes on the molds so that customers have access to mold-specific information. The transformations have been gradual. However, skilled labour is still not sufficient for all the current industry requirements (e.g. CNC programming, cience of materials, management shop floor). Since it is necessary to apply methodologies, technologies, and techniques to minimize waste and to consult updated information, in real time, to meet the deadlines for the manufacturing of a mold.

For the production and assembly of the systems and components of each mold to be efficient, the integration of hardware and software (e.g., CAD, CAM, planning and management) and a good organization in the infrastructures (e.g., Lean philosophy) is fundamental. Demanding multidisciplinary skills from the work team.

Contemporary mold industries need people with engineering skills in several areas of expertise intrinsic to the industrial production of molds. Namely, project management and industrial activity management, integrated with process technological innovation.

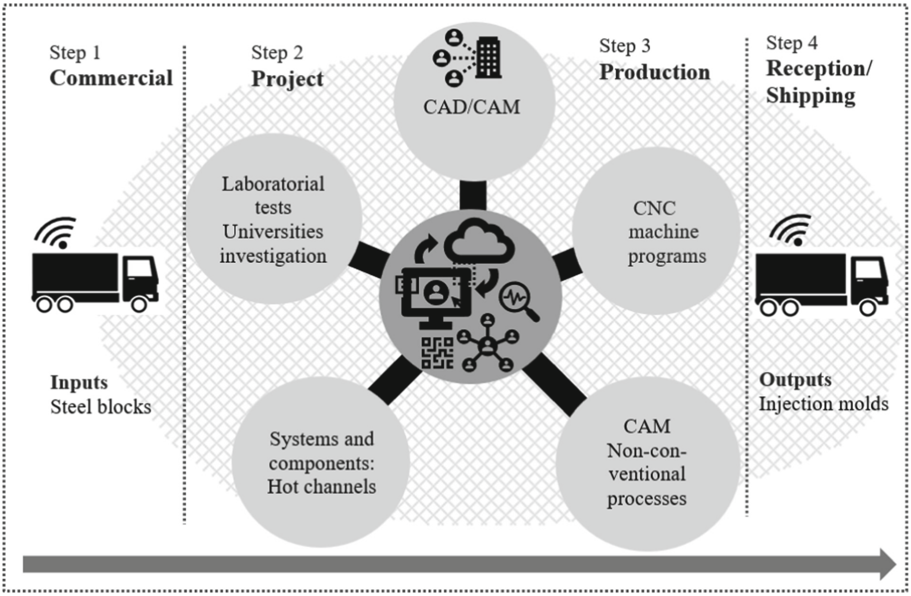

Fig. 2. Pathway 2: Network connectivity solution.

So, it's urgent, not only to implement Industry 4.0, but first of all, to increase the knowledge of the work teams in transdisciplinary areas, of the technologies applied from the project to the mold manufacturing. Updating the scientific, technical and practical domain of professionals and encouraging scientific integration with the work context. Promoting the transfer of knowledge and know-how of existing teams with future professionals, through partnerships with higher education institutions, by integrating classes in a real work context. Thus, it contributes to instill a permanent attitude of inquiry, experimentation, and teamwork, aligned with problem solving in the transformation of these industries into Industry 4.0. Simultaneously we are ensuring the training of people with the necessary skills in the mold-making, to prepare work teams for the mold industry, able to successfully perform their professional activities. Being autonomous and able to solve problems individually and in teams, essentially by the "know-how" integrated with scientific and practical competences and domains.

As a result of the partnerships the increase of interdisciplinary knowledge, both for those who already work and for those who intend to work in areas related to moldmaking. Such partnerships may also fill the current shortage of qualified labour in the mold industry, guaranteeing success in the implementation of contemporary industries (e.g., industry 4.0, industry 5.0), and so on.

3.3 Conceptual Model

The conceptual model (Fig. 3) represents the set of interdependence relations, regulated by the physical conditions that companies establish between themselves and with customer requests. To develop, test and validate innovative concepts, new products, and