# A Digital Platform Architecture to Support Multi-Dimensional Surplus Capacity Sharing

Henrique Diogo Silva[1], António Lucas Soares[1,2], Andrea Bettoni[3], Andrea Barni Francesco[3], Serena Albertario[4]

[1] INESC TEC, Porto, Portugal
{henrique.d.silva, asoares}@inesctec.pt
[2] University of Porto, Porto, Portugal
[3] SUPSI, Manno, Switerland
{andrea.bettoni,andrea.barni}@supsi.ch
[4] Holonix Srl, Meda, Italy
serena.albertario@holonix.it

**Abstract.** The highly disruptive transformation that digital platforms are imposing on entire sectors of the economy, along with the broad digitalization of industrial business processes, is impacting on supply chains around the world. To take advantage of this new aggregated market paradigm new business models with a heavy focus on servitization are deviating the value proposition of businesses. In this paper, we describe the reference architectural framework designed to support a digital platform fostering the optimization of supply chains by the pairing of unused industrial capacity with production demand. This framework aims at harmonizing stakeholder requirements with specifications of different levels in order to set up a coherent reference blueprint that serves as a starting point for development activities. A four-layer approach is used to articulate between technical components, in the data and tools layers, and the ecosystem, with the business and interfaces layers. The overall architecture and component description is presented as extensions of the initial set of affordances.

**Keywords:** Digital platforms, Digital platform architecture, Manufacturing as a service.

## 1 Introduction

### 1.1 A Subsection Sample

One of the more relevant effects of the platform paradigm in the economy is the separation of physical assets from the value they create, the separation of function from the form [22]. In the industrial sector, this switch is evidenced by the widespread shift of income generation from the sale of physical products to the charging of customers for the availability of functionalities of a product [31]. From the perspective of companies that chose to invest on hefty fixed assets like top-of-the-line laser cutting machines or a 5-axis CNC machine this selling of capacity allows for better resource distribution while for other businesses it provides facilitated access to costly equipment that can help in alleviating initial costs of business or even the ability to meet seasonal peak demands. The growing willingness of companies to both buy and sell manufacturing capacity has precipitated the development of the Manufacturing as a Service (MaaS) paradigm [4] that both boosts and leverages the platform economy.

The explosion of the platform business has had a profound impact on businesses structures. The traditional pipeline perspective where processes were arranged step-by-step with producers at one end and consumers at the other has given way to a new platform mediated structure [22]. In this new paradigm, the linearity of the value chain is twisted and tangled to the point where the boundaries of user and producer are regularly crossed or in some cases do not even exist.

Having this landscape as the starting point, and taking digital platforms as stimulants for the transition of industry businesses towards service-oriented approaches [7, 12, 19, 32] it becomes clear that a platform centered ecosystem is needed in order to advance the MaaS business model further. In [4] authors lay out their vision for a digital platform in the MaaS realm that leverages this disruption of the value chain and fluidity of user roles. By adopting a holistic perspective of the network, and going beyond the simple matchmaking of manufacturing resources, the sharing potential is extended to the whole manufacturing ecosystem value network. The fulfillment of this vision, in turn, requires a platform that can establish the bridge between the expected affordances of digital platforms and the cross-sectoral environment, in an ecosystem that is able to generate added value. By bringing together tools and ecosystem, we are promoting a better and more sustainable use of resources, the reintegration in the loop of unused manufacturing capacity, leading to the creation of local, more efficient value networks, and the seamless involvement of different actors along the value network for cross-fertilization of product-service solutions and underlying technologies.

Leveraging the ensued entanglement of the value chain, this paper aims at describing the design approach and resulting core components that will constitute the backbone architecture of a MaaS platform. This platform's main goal is to provide the context and services for manufacturing organizations to exchange surplus capacity along the production, engineering, design and innovation dimensions. The paper is divided into a first section that puts into perspective the manufacturing domain that will represent the platform's ecosystem, as well as the features the platform is expected to support, followed by the core section where the components that make up each one of the four layers are described in detail.

# 2 The Manufacturing Digital Platform Landscape

## 2.1 Digital platform affordances

The development of the sharing economy is a clear example of how digital platforms have played a fundamental role in the development of the market [29]. Scholars point to six crucial affordances that stride the balance between the rigidity of the technological and the human components of platform ecosystems [23]: (1) generation of flexibility; (2) matchmaking; (3) scale and reach extension; (4) transaction management; (5) trust building; and (6) community creation support.

Digital platforms have the capacity to generate flexibility, not only in how and when users can interact with the platforms [15] but also the flexibility between user roles within the platform has shown a measurable impact in interactions and consumptions. Authors such as [8] and [24] point to ability to regularly access sharing economy platforms as an essential component of its success as a business model, while [2] show how the ability to easily change roles within the platform between client and producer has the beneficial effect of incentivizing the engagement on different levels.

To match users is one of the main functions of a digital platform along with pulling them to the platform and facilitating their actions and interactions [22]. The ability to perform matchmaking based on a set of attributes then becomes a fundamental function of digital platforms) [3, 25]. Different mechanisms for matchmaking currently exist based on the algorithmic assignment and powerful searching and sorting [29] with the automation of the process becoming the entire value proposition of some platforms. For industry-focused platforms, perspectives like the one presented by [4] are starting to rethink this process beyond the matching of manufacturing resources to the whole manufacturing ecosystem value network.

The scale and reach brought about by the facilitated access to an extensive network of organizations, consumers, and resources that compose a platform's ecosystem is also one of its main competitive advantages [9]. By striking the balance between the benefits of network externalities and the automation capabilities, made possible by its technological nature, platforms are able to create a scaling loop that, after crossing the initial hurdle of the point of critical mass, can grow indefinitely [5, 10, 14];

The management of the transactions involved in the transmission and securing of goods, information or labor is another widespread functionality of sharing economy platforms [30]. In this sense, platforms double up as marketplace and bookkeeper by bringing both parties together while also keeping records of all transactions, ensuring the validity of all the exchanges [6, 33];

Trust and trustworthiness are a contested point in the digital realm. Where anonymity has always been an obstacle in the conduction of transactions through this medium [16], and in-person meetings made for the more trustworthy method, in the last decades the advent of several trust-based mechanisms has started to invert this trend. The popularization of features like user profiles as extensions of resumes [20, 27], the utilization of subjective and non-subjective user reviews system [13] along with the implementation of more strict governance directives for the management of platform's communities [18, 26] have tipped the scales in favor of the digital. When thinking about the impact of trust in digital platforms it's also essential to distinguish between trust between users of the ecosystem and the trust users deposit in the platform itself, as both play an essential role when it comes to the adoption of these systems.

The human component of digital platforms is what truly elevates them to the status of sociotechnical constructs [1, 28]. Community building structures that serve as venues for community interactions and participation play an import role in onboarding new users and the facilitation of new relationships between them [21]. This is a crucial aspect to keep in mind at the platform design stage as previous studies suggest that, for sharing economy platforms, not only economic profit but also community involvement play a critical role as motivators in platform adoption [6, 11], even in platforms with minimal community interaction capabilities.

### 2.2 Examples of MaaS Platforms

In the following section, an analysis of platforms that currently operate under a MaaS approach has been carried out in order to understand the current value propositions of these leading, state-of-the-art platforms. All the identified platforms were developed in the American market context, where most of their business is still located, and their focus can be divided into MaaS platforms that focus on production, platforms that focus on sharing, and platforms that focus on by-product management.

Xometry is current the largest on-demand manufacturing platform, claiming to produce components faster and more effectively than traditional methods. Xometry's service is based on a proprietary software platform which offers on-demand manufacturing to a diverse customer base, ranging from startups to Fortune 100 companies. It provides product designers and engineers an efficient way to source high-quality custom parts, with 24/7 access to instant pricing, expected lead time and manufacturability feedback. Its nationwide network of over 2,300 partner manufacturing facilities enables the platform to maintain consistently fast lead times while offering a broad array of capabilities, including CNC Machining, 3D Printing, Sheet Metal Fabrication, Injection Molding, and Urethane Casting. Xometry has over 10,000 customers, including BMW, General Electric and NASA. When a producer registers its account on the platform, it has to enter several details on its profile. The details entered during this phase, such as the types of machines owned, functional materials, part size constraints, etc, are used to match the company with ideal production opportunities. Before a company can become an official partner of the Xometry network, it has to complete a trial for Xometry, which consists of producing a specific product that, depending on its specifications, is used to evaluate the level of competence and quality. The parts that are chosen by Xometry based on the production capacity of the company are sent via e-mail directly to the company.

In this same space, Mink is a cloud manufacturing platform that allows users to choose, customize and purchase a designed product, before starting its remote fabrication. At its core, the Mink Engine algorithm is capable of transforming uploaded geometries into packets that are understandable and executable by a dedicated manufacturing system. From a series of templates it is possible to edit every single parameter (dimensions, materials, finishes and so on) in order to obtain several product configurations, with the disassembled final product shipped to the customer. The main goal of the platform is to create the first shared and remote driven production system, where the orders and the subsequent production processes are started by users directly from the Mink platform without having people working at the remote plant.

The FLOOW2 platform, on the other hand, is not focused on the production component, but the sharing of resources. FLOOW2 is a B2B sharing platform specialized in providing access to expertise, goods, and services, in sharing and reuse assets according to the principles of the circular economy. The platform managers claim they have allowed meeting the supply and demand of 25,000 types of goods and services. Most common transaction on the platform involves the sharing of cars, meeting rooms, magnetic resonance imaging machines, and communication specialists.

The 3DEXPERIENCE Marketplace is a platform developed by Dassault Systèmes, that tries to join the production aspects and the sharing components of the previously presented platforms by allowing companies to connect data, ideas, solutions, people, projects, and services. The platform aims to respond to the growing demand for product customization, which generates the need for greater flexibility and shorter response times, and therefore the need to quickly reach a vast network of certified and specialized suppliers in a particular market. Dassault Systèmes has hundreds of certified partners all over the globe which can act through the platform specialized mainly in 3D printing, CNC machining, injection molding, and laser cutting.

The Austin and Ohio materials marketplaces are two examples of platforms that aim at bringing together businesses of all sizes along with entrepreneurs in the City of Austin and Ohio, respectively, to create closed-loop systems in which one company's waste is another company's raw material. They aim at creating a closed-loop, collaborative network of businesses, organizations, and entrepreneurs where one organization's hard-to-recycle wastes and by-products become another organization's raw material. Hosted on the Materials Marketplace software platform from the U.S. Business Council for Sustainable Development, these online tools enable participating companies and project staff to quickly post available or wanted materials, identify reuse opportunities, and exchange underutilized materials. In the same vein, the SYNERGie 4.0 project offers project management, and reporting functionalities to capture and store information about a company's resources and to quickly identify commercial opportunities for reuse. Used in nine countries around the world, it allows users to characterize, search, and match the company's resources within site and across multiple sites. Input from the world's most experienced industrial symbiosis expert team supports the identifications.

### 2.3 Landscape Overview

This analysis portrays a landscape in which most of the existing B2B platforms in the MaaS field aim at providing intermediary brokerage services for the provision of finished goods. The more holistic approach presented in this paper differs from these examples in three levels: (1) by focusing on the process and the associated resources rather than on the product being delivered; (2) by acting as a facilitator and not an intermediary; and (3) by not focusing on a specific manufacturing sector.

With these three points, a platform can be designed that provides customized services that adapt to different users needs in cross-sectorial domains, covering the whole spectrum of value chain activities. With the switch of focus to the process and resources, organizations can leverage the ecosystem for the optimization of each component of their business in a plug-and-play fashion, and by acting as a facilitator, the platform promotes direct interactions between the players involved in transactions. Also, we envision a set of services that build upon those provided by the presented platforms to provide added value. Among these are the matchmaking and reputation mechanisms that respectively reflect the matchmaking and trust building affordances. By leveraging state-of-the-art technologies such as distributed ledger systems, along with established standards like the semantic-WEB, more transparent and robust systems can be made to power these types of services.

## 3 A MaaS platform supporting sharing of unused resources

### 3.1 The MANU-SQUARE Platform

Building on the MaaS concept, the MANU-SQUARE project [4] aims at establishing a European ecosystem of organizations and other relevant stakeholders that, in a marketplace environment, can act as both supplier and client. Through this approach, the platform moves available capacity closer to production demand, further disrupting the traditional linear value network, allowing for the rapid and efficient creation of local value networks for innovative providers of products and services and the optimization and reintroduction in the loop of unused capacity that would otherwise be lost.

The MANU-SQUARE platform goes far beyond the partner search and matching, and supply-chain/virtual enterprises formation proposed in the last 20 years of virtual enterprise literature in three crucial points: (1) extending the sharing potential to the whole manufacturing ecosystem value network; (2) by focusing on surplus capacity; while (3) adopting a multi-dimensional and cross-sectoral vision of capacity.

Current approaches to the sharing of manufacturing capacity have narrowed down their scope to both specific sectors of the industrial ecosystem, and the sharing of unused production resources. This limited view of surplus capacity leaves out, however, much of the wealth that the European industry has been building through the years. Our vision scopes this vision back up to not only include all the actors that make up the European manufacturing value chain, such as manufacturing organizations, knowledge providers, innovation facilitators, etc. but also to enlarge the concept of capacity beyond production to surplus know-how, technology, and by-products.

This broader scope carries with it the necessity of an architecture able to cope with an increasingly nuanced system. To answer these demands, tried and true standards, such as semantic infrastructures, need to be articulated with state-of-the-art technologies like distributed ledger systems, to produce new and better trust-based, platforms for negotiation, networking and community building.

In this sense, the value proposition of the platform become:(1) from a user's perspective, be able to, among a European-wide pool, quickly find trustworthy suppliers according to a set of requirements. This matchmaking would help to manage fluctuating production demand or build/extend production capacity without owning production means relying on a structured RFQ and information sharing system and a transaction management system. (2) From a supplier's perspective, access to a broader cross-sectorial market becomes the main value proposition. This wider access gets complemented by the ability to sell unused capacity, access to up-to-date client information, structured and trustworthy processes for the dissemination of documentation such as RFQs, plus reputation management, and transaction management systems.

### 3.2 Stakeholders & Functionalities

The vast literature on stakeholder analysis has yet to catch up with the platform reality. Very much focused on stakeholders for small and medium enterprises (SMEs), [34] define five stakeholders roles: Innovation Commercialiser; Innovation Funder; Innovation Generator; End User; and Platform Operator. On a 2017 report, the World Economic Forum divides the roles in a platform ecosystem into four, non-mutually exclusive, categories: Orchestrator; Producer; Consumer; or Infrastructure provider.

From this theoretical underpinning, and supported by interviews and workshops with industry players, eight stakeholder typologies were identified.

**Manufacturing** organizations, consisting of producers of products, components, and technology, are the leading stakeholder group. A second group of stakeholders consists of **Service and knowledge providers**, ranging from IT Laboratories, legal and consultancy organizations to research institutes and universities. By integrating joint research projects and offering their services through the platform, these stakeholders become critical in the development of new and improved value chains. In this same vein, **start-ups** and **innovation facilitators** also become essential users of the platform. By bringing together innovation/technology hubs that facilitate and promote innovation along with start-ups and innovators that are actively seeking different types of support to develop, materialize, and industrialize different product/service concepts the platform can realize more meaningful relationships.

In order to build self-sustaining, thriving communities of both customers and suppliers on the platform, achieving a critical mass of users is essential. This continuous task of community building is supported by two stakeholder roles: **multipliers**, **investors**. Clusters and sectorial network organizations, industry associations and investors that are looking for new business and investment ideas are essential elements in enabling access to larger a pool of ideas and business opportunities.

Also, in supporting roles of the central platform functionalities, **auditors and regulators**, plus **consumers** are relevant stakeholder groups. Regulatory compliance and audit authorities place complex sets of constraints on organizations. With these supervisory bodies as platform stakeholders, organizations can take advantage of the privileged contact in order to facilitate compliance, that can even lead to added value for customers in the case of certifications. On the other hand, the presence of consumers in the platform becomes relevant for the development or improvement of products and services. Information on the behavior and preferences of customers that play the role of both real evaluators and co-designers of innovative business ideas and products/services can be a principal added value for the identification of opportunities.

Based on the previously mentioned theoretical underpinnings and defined stakeholders, a set of 14 functionalities are described in Table 1. Table 1 maps the relationships of each functionality to the relevant affordance.

**Table 1.** Platform functionalities

| Functionality | Description |
|---|---|
| **Matching** | |
| Production capacity matching | Matchmaking between suppliers of available manufacturing capacity and customers that aims to exploit that capacity. The platform recommends potential compliant suppliers, filtering them according to user selected parameters. |
| Know-how capability matching | Matchmaking among suppliers of available knowledge and customers that require support in the related field of expertise. |
| By-product matching | Matchmaking between manufacturers whose manufacturing processes generate one or more by-products, and customers that can exploit these by-product as an input resource. |
| **Optimization** | |
| Sustainability assessment | The platform supports the optimization of matchings according to an environmental sustainability assessment of shared capacities, capabilities and by-products. |
| Ecosystem optimization | The platform supports the ecosystem optimization, ranking suppliers and suggesting the most sustainable matchings. |
| **Management** | |
| User profile management | The platform supports each user in the development of its profile in order to reduce user efforts for data entering while optimizing the matching process. |
| Reputation management | The platform allows for both user subjective and quantitative, KPI based evaluations of involved parties in transactions, for establishing a reputation level of users |
| Certifications management | The platform allows Auditors and Regulators to certify players through a verified and secure certifications management system. |
| Trust management | The functionality supports the management of information across the platform giving users the right to define the level of accessibility to provide to their information. |
| Communication support | The platform supports communication among platform users, streamlining connections and mediating the interactions among parties. |

| | |
|---|---|
| Innovation management | Starting from a user introduced idea, different users can provide tracked and structured contributions. The platform administrates the flow of contributions. |
| RFQ management | The platform provides the infrastructure to enable the definition and management of quotations, managing the level of visibility of the quotations and partners exchanging requests and transactions. |
| Transactions management | The platform supports the creation of traceable transactions across the platform value network. |
| Platform expansion | The platform supports the expansibility of its core functionalities through a complete expansion SKD. |

**Table 1.** Mapping of functionalities and relevant affordances.

| | Generation of flexibility | Matchmaking | Scale and reach extension | Transaction management | Trust building | Community creation support |
|---|---|---|---|---|---|---|
| Production capacity matching | | • | • | | | |
| Know-how capability matching | | • | • | | | |
| By-product matching | | • | | | | |
| Sustainability assessment | | • | • | | | |
| Ecosystem optimization | | | • | | | |
| User profile management | | | | | • | |
| Reputation management | | | | | • | • |
| Certifications management | | | | | • | |
| Trust management | | | | | • | • |
| Communication support | | | • | | | • |
| Innovation management | | | • | | | • |
| RFQ management | • | | | • | | |
| Transactions management | • | | | • | | |
| Platform expansion | • | | | | | |

### 3.3 Platform Architecture

Given the socio-technical nature of digital platforms, the architecture design process needs to take into account not only all the technological underpinnings that serve as a platform infrastructure but also all the social and business elements that eventually will develop into the ecosystem. In many ways we may akin the process of platform design to city planning: infrastructure is an intrinsic and essential component of the project, but if focused to the detriment of other components, it may give way to problematic cities. Expansion, of both population and industry/services, equal distribution of services and natural resources and the development of functional transportation networks, are some of the challenges that can be exacerbated by this lack of human perspective.

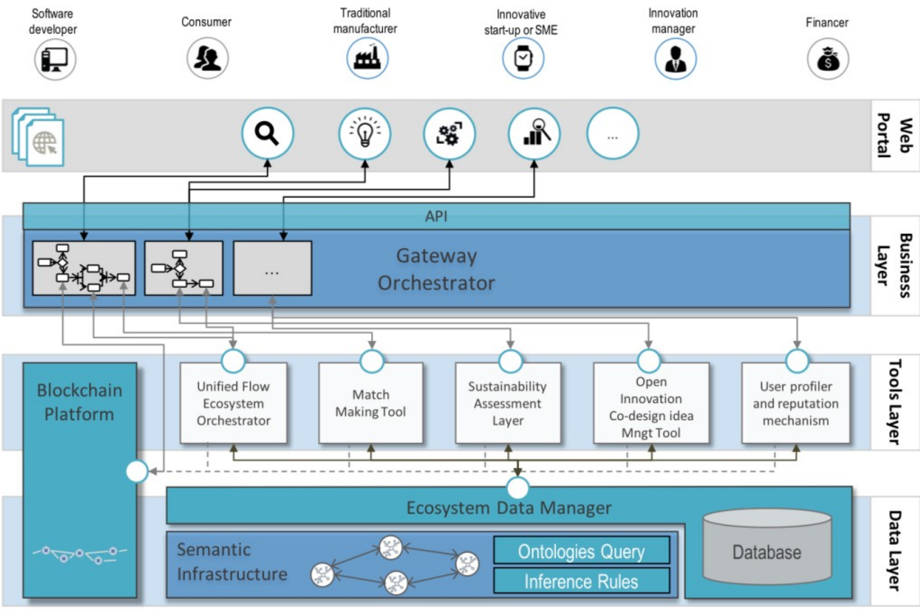


**Fig. 1.** Low-level platform architecture

The adopted four-layer architecture, shown in Fig. 1, can further be divided into two groups. A first group, consisting of the Data and Tools layers, corresponds the technological, infrastructure backbone of the platform, while a second group, corresponding of the Business and Web Portal players, are responsible for the ecosystem management, the human and business component of the platform.

Each of these four layers houses components that, through their interplay, allow for all the functionalities of the platform.

The Data layer sits at the heart of any information system. Where more traditional paradigms of data storage/management were a static abstraction where value was derived from the read/write logic, with the development of technologies like the semantic-WEB and distributed ledger systems, in between reads and writes we can gather context, inferences, and accountability. Through this layer, we leverage a semantically described ecosystem of actors, interactions and resources flow to feed an inference reasoning engine capable of uncovering non-trivial and previously unknown opportunities. The developed MANU-SQUARE core ontology, presented by [17], acts as the first step in the description of a MaaS ecosystem and along with standard services and interface options such as an RDF data store and a SPARQL endpoint, it will feed other platform tools with rich data for other functionalities.

The Blockchain platform, although still part of the Data layer, spills into the tools layer, due to its very nature. At a high level, this component works to ensure provenance, immutability, and finality of data, by guaranteeing that only mutually agreed upon transactions become part of a consensual and cryptographically secure shared ledger. Features like these make blockchain, and distributed ledger technologies in general, an ideal fit for digital platforms where affordances as trust and trustworthiness are a must, even more, when considering how they can be articulated with other components. Acting as the single point of trust for the ecosystem, from simple operations such as logging user access or storing stakeholder's reputation data in a immutable manner, to automating complex transactional operations that involve the exchange of sensitive information, the integration of the blockchain platform will help to fill trust building, transaction management and flexibility generation functionalities.

Given the modular architecture of the platform and both the data persistence methods previously presented, an extra abstraction to facilitate the access to information independently of its location is needed. By abstracting all the underlying data structures, the ecosystem data manager becomes the data broker for the platform and, by exposing a structured API to other components, allows for ubiquitous access to data, regardless of storage infrastructure, while preserving all of the inherent benefits of each storage method. Because this makes the ecosystem data manager aware of all the data flows within the platform, it will work in conjunction with the blockchain platform as a control point for data access.

The tools layer houses the modular tools that will provide many of the core services of the MANU-SQUARE platform. In an on-demand perspective, these services will be in constant communication with both the data layer and the business layer to fulfill many of the functionalities proposed in Table 1 and cover affordances presented in 2.1. The five tools that make up this layer are: (1) The Unified Flow Ecosystem Orchestrator that provides functionalities to analyze the needs of the different companies to propose ecosystem (re-)configurations that better link availability of resources with their optimal environmental performance, working closely together with the matchmaking mechanism; (2) the Matchmaking Tool that provides the production, know-how and by-product capacity matching functionalities. Feeding off of all the stakeholder profiling information, this tool is responsible for the optimal pairing of user's needs with available resources in the ecosystem; (3) the Sustainability Assessment Layer that provides functionalities to support the evaluation of the environmental impact of new chains established through the platform; (4) the Open innovation & Co-design Idea Management Tool provides the Innovation Management functionality by leveraging the open innovation paradigm; and (5) the user profiler and reputation mechanism that provide the user profile management, reputation management, and certifications management functionalities. Because establishing trust and trustworthiness between organizations is a complex, time and resource intensive process, by integrating blockchain-controlled transactions to keep track of quantitative KPIs such as on-time delivery and quality of products, beside qualitative platform user feedback, based on the perceived quality of interactions with other actors of the ecosystem, we can strike the balance between the technological with the human components of trust.

The business layer, standing between the user-facing interfaces and the core services of the platform is responsible for the orchestration between tools and the complex set of functionalities. Composed by a combination of the gateway orchestrator and a set of outward facing APIs, this engine is responsible for the implementation of business processes relevant the platform's stakeholders through the use of the tools from the Tools Layer. From a modular architecture standpoint, this layer is essential in realizing the full potential of the ecosystem as it alights the flexibility provided by the decoupling of services with the flexibility in the reorganization of services to better fit different business process needs. At its heart, the gateway orchestrator is powered by decision automation software that can interpret business processes codified in standard business process modeling notation (BPMN) and, according to the services offered by the platform, provide users with the optimal experience.

The web portal directly provides the platform expansion functionality and empowers all the remaining by representing the primary interface through which users will interact with the platform. Leveraging the ubiquitous and flexibility of the WEB platform, this layer provides both general graphical interfaces in the form of web pages as well as platform expansion points for external tools. This layer, in direct contact with the gateway orchestrator, will be able to trigger different business processes and run users through the involved tasks.

## 4 Conclusions & Next Steps

In this paper, a description of the underlying, layered architecture that serves as the backbone of a MaaS platform has been presented. An initial six affordances, drawn from the gig/sharing economy paradigm, were transposed to the industrial sector and served as guiding principles for the definition of a core set of functionalities required for the introduction of digital platforms as added value tools for the MaaS paradigm. With the actualized architecture, composed by four different layers and eighth individual tools, this framework retains the flexibility of its modular design for the application in different manufacturing sectors, business processes or use cases, all the while maintaining its reliability through the use of state-of-the-art trust-based information technologies in conjunction with tried and true standards.

Next steps will consider the development and integration of the software tools, followed by an iterative approach to the demonstration pilots made possible by the development of the architecture alongside the MANU-SQUARE project.

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