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ORIGINAL RESEARCH

The D-BEST Reference Model: A Flexible and Sustainable Support for the Digital Transformation of Small and Medium Enterprises

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Abstract *Nowadays, to remain competitive, manufacturing companies must address the Industry 4.0 paradigm, particularly the cyber-physical system (CPS) revolution, following sustainable challenges. Digital innovation hubs (DIHs), as ecosystems that provide technical knowhow, experimental skills, and specialist knowledge, are progressively gaining a strategic role in supporting such a transition, especially in European small and medium enterprises (SMEs). Several projects have been funded by the European Commission to support the growth and action of DIHs. However, which among the four main functionalities (networking, skills and training, test before investing, and access to funding) each DIH is capable of addressing in its daily support action to companies is still unclear. Thus, it is important to configure the service portfolios of DIHs (i.e. the set of services that each DIH can provide based on its characterising assets, knowledge, and capabilities). In this paper, the data-driven business–ecosystem–skills–technology (D-BEST) reference model is proposed and then tested through a survey. The model triggers the identification and materialisation of service-based collaboration processes among DIHs based on their service portfolio analysis and supports the modelling of Collaborative Networks 4.0, in which DIHs are a strategic player because of their 'by-design' innovation characteristics. Finally, through the extended adoption of the models developed by different emerging DIH networks, flexibility and interoperability can be reached, fostering the adoption of a unique digital platform to showcase and offer assets, triggering the creation of multiple inter- and intra-communications and collaborations among stakeholders belonging to the DIH ecosystems, and favouring the exchange and development of joint services.*

Keywords Digital innovation hub · Digital transformation · Flexibility · Interoperability · Reference model · Service portfolio configuration · SME

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Introduction

As declared by the European Commission (EC) (2020b), digital transformation is key for Europe to remain competitive at the international level. Both private companies and public sector organisations must incorporate digital technologies into their businesses to exploit their benefits in terms of efficiency and innovation (McDermott et al., 2001), while managing to remain economically (Kak & Sushil, 2002) and environmentally sustainable (Rosa et al., 2020). Also, in the manufacturing sector, the role of digital technology is changing fast from being a driver for slightly improving efficiency to becoming a key enabler and catalyser of innovation, disruption (World Economic Forum, 2016), and flexibility (Singh et al., 2021; Sushil, 2015). In 2016, the EC indicated the four main key elements of the digitising European industry (DEI) strategy: digital innovation hubs (DIHs), partnerships and platforms, skills and jobs, and regulatory framework (European Commission, 2016). Three years after the kick-off of the DEI strategy and eGovernment Action Plan, meaningful improvements were registered by the European economy. However, the digitalisation level remained irregular (being linked to the sector, country, and size of company), and companies often had difficulties even in understanding their *status quo* in terms of digital maturity level (De Carolis et al., 2017; Sassanelli et al., 2020b). Only 20% of the SMEs in Europe are highly digitised, and the overall adoption rate of eGovernment services is only 53% (European Commission, 2020b).

Mostly analysing the application domains of the cyber-physical system (CPS), technical knowhow, experimental skills, and specialist knowledge often embody relevant hurdles in companies and especially in SMEs (Macedo et al., 2021). Moreover, numerous boundary challenges and hurdles (e.g. always mutating customer needs, cultural revolution, and evolving norms, protocols, and competences) concur to hindering the digital revolution. In this context, manufacturing companies managers and policy makers must cope with these challenges to unveil and allow for the exploitation of the benefits that digital technologies provide to society and industries (European Commission, 2020b; World Economic Forum, 2016). The EC is currently discussing with the Parliament the draft for the plan concerning the period 2021–2027, highlighting and recommending the central role of European DIHs to foster the digital transformation process (European Commission, 2020b), indicating them as a means to appropriately foster product advancements, process enhancements, and business model adjustment to the digital revolution. DIHs are defined as support facilities that assist companies (particularly SMEs, start-ups, and mid-caps) in improving their effectiveness and competitivity through innovations, fostering the employment of the latest digital technologies (European Commission, 2018a, 2018b). These organisations include diverse stakeholders belonging to an assorted ecosystem in a people–public–private partnership (Angeles et al., 2022).

The EC also defined four main functions (i.e. networking, skills and training, test before investing, access to funding) that can characterise DIHs (European Commission, 2020b) and allow them to better manage manufacturing flexibility (Sharma & Sushil, 2002; Sushil, 2016) in their technology-based product development processes (Dwivedi et al., 2021; Singh & Sushil, 2004). However, which among the four main functionalities (networking, skills and training, test before investing, and access to funding) each DIH is capable of addressing in its daily support action to companies is still unclear. Different DIHs have been demonstrated to play different roles in supporting European companies along their digital transformation journeys, addressing a specific combination of the four typical categories of their characterising functions (Asplund et al., 2021). For this reason and to achieve DIH sustainability (Zamiri et al., 2021), the EC also promotes cooperation among DIH networks, funding the establishment of extensive pan-European DIHs that can cover a wider spectrum of assets (capabilities, skills, technologies, and knowledge) and provide, also through the development and provision of dedicated digital platforms, a more complete set of services to their potential users (technology providers and users), for example, networks such as DIH4CPS (Sassanelli et al., 2020a; Semeraro et al., 2021) and HUBCAP (Badicu et al., 2021; Larsen et al., 2020; Macedo et al., 2021; Weiß et al., 2021).

Literature unveils that so far, no suitable models have been created to both support the achievement of this scope (i.e. to foster the development of a network of DIHs in the cyber-physical energy system (CPES) domain by both developing suitable DIH service models and detecting and creating service-based cooperation processes among them) and consistently represent the services to be provided by a DIH in the CPES domain. Among the models already proposed in the literature, the most adopted is the ecosystem–technology–business (ETB) model (Butter et al., 2019), which was developed in the past through work conducted in several I4MS projects and then evolved into the ecosystem–technology–business–skills–data (ETBSD) model, as detailed in Sassanelli et al., (2020a, 2021). However, the ETBSD model still needs its dimensions to be further detailed and lacks a mechanism to allow for its sustainable evolution. Moreover, the IoT Digital Innovation Hub Network (AIOTIDIHN, 2019) proposed a model to represent its service portfolio in the specific context of the IoT. Finally, through the S3 platform, the EC attempted to list and showcase all the DIHs existing in Europe so far and classify all their related services independently from sectors and technologies (European Commission, 2020a). However, the S3 platform does not provide updated information about DIHs that could also systematically describe the assets offered by each DIH.

Therefore, by addressing the previous gaps and the twofold aim of configuring the service portfolios of DIHs in a systematised, flexible, and interoperable way and by modelling the collaboration among DIH networks, in this paper, the ETB model was customised for the CPES domain, which improved the ETBSD model in the final data-driven business–ecosystem–skills–technology (D-BEST) model. To test its effectiveness, the model was applied to the DIH4CPS project (2020) to support the development and modelling of its related network. The service portfolios of both single DIHs and the overall network were configured, unleashing the identification and materialisation of service-based collaboration processes among them. The D-BEST model was conceived to support the CPES technology area, whose aim is to bolster companies from whatever sector in improving the quality and efficiency of their solutions (products, services, and systems) with up-to-date embedded ICT components and systems and to support ecosystem creation and development for full of promise platforms. The D-BEST reference model can also model Collaborative Networks 4.0, in which DIHs, being knowledge brokers and sources, are strategic players with strong opportunities for triggering generalisation, flexibility, and interoperability in DIH ecosystems.

This paper is structured as follows: Sect. 2 introduces the contexts in which this research aimed to operate, that is, DIHs. Section 3 explains the research methodology adopted to build the proposed D-BEST model. Section 4 presents the results, focusing on the D-BEST model in all its characteristics. Section 5 describes the results of the validation of the model, consisting of a twofold survey run in the DIH4CPS network and a comparison with the other two models (AIOTIDIHN and EC's S3 platform) already existing in other digital domains. Finally, Sect. 6 presents the conclusions and reports the related limitations of this study and the perspectives for future research.

Research Context: Nature and Characteristics of DIHs

DIHs have been demonstrated to play different roles in supporting European companies along the digital transformation journey, addressing a specific combination of the four typical categories of their characterising functionalities (test before investing, skills and training, support to find investments, and innovation ecosystem and networking) (Asplund et al., 2021; European Commission, 2020b), to be effective to cope with the managerial paradox towards flexibility (in managing business complexity, uncertainty handling, organisational reorientation, and structuring decisions across organisational functions) (Shukla et al., 2019), and to socially enrich industrial organisations as industrial districts (Appolloni et al., 2022). The behaviours of DIHs can differ depending on their nature (i.e. their public or private organisations and structures), which leads them to ensure a fit with their current service and capabilities portfolio, or on the choices or needs they must address to meet the expectations of their stakeholders. According to Crupi et al. (2020), SMEs' paths towards digital transformation are deeply related to the characteristics of DIHs and their relationships with their stakeholders. The heterogeneity of such ecosystems fits with the main aims of the EC [through actions such as *ICT Innovation for Manufacturing SMEs* [I4MS] since 2013 (I4MS, 2020) and *Smart Anything Everywhere* [SAE] since 2015 (European Commission, 2018b)], which are to foster their development, to expand the already extant network of DIHs, and to launch an integrated, flexible and interoperable platform for DIHs from different, mostly digitally underdeveloped, industries and regions.

The result envisioned by the EC is an extensive pan-European ecosystem of DIHs. Each DIH will have a different nature, will be located in different regions, and will focus on diverse industries and digital technologies. The resulting pan-European DIH can activate innovation-driven collaboration and cooperation dynamics through the joint development, provision, and matchmaking of services among its partners. The successful achievement of this result will prevent single DIHs from striving to concurrently fill all four functions; instead, DIHs will focus more on their most characteristic function.

In this context, a model that can instantiate DIHs to configure their service portfolios, analyse their nature, and model the collaboration of multiple DIHs is needed. Therefore, the D-BEST model is presented in Sect. 4 as a reference model for fully configuring the service portfolio of any DIH in a flexible way (at any degree of extension, from CCs up to pan-European DIHs) and mapping the connected skills and competencies needed to deliver them.

Research Methodology

To address the main gaps in service portfolio management (Schepers et al., 2008) and in the configuration of DIHs, in this research a dedicated methodology was developed consistently with different research traditions (Nunamaker & Chen, 1990) during the conception and development of the D-BEST model. Briefly, being inspired by the research of Pezzotta et al. (2018) and Sassanelli et al. (2019), this research is categorised as interpretivist, which means that it applied qualitative methods and inductive logic (Williamson, 2002). Thus, it is like action research but with higher aspirations to contribute to theory development. It is also an applied engineering-based research (Potts, 1993) implicating theory/concept building together with testing in an interactive way with practice (Ellström, 2007; Svensson et al., 2007). The methodology is tested in real-world settings, in keeping with the systems-development field (Nunamaker & Chen, 1990). Theory building, observation, and experimentation embody the methods used to develop a prototype that represents, along with the research time lapse, both a proof of concept and a basis for prosecuting research in a qualitative iterative process (Williamson, 2002).

In summary, the research design is depicted in Fig. 1, where the match among the phases of this research approach and the design research methodology (DRM) framework of Blessing and Chakrabarti (2009), which was used as the main reference, are elucidated. The research

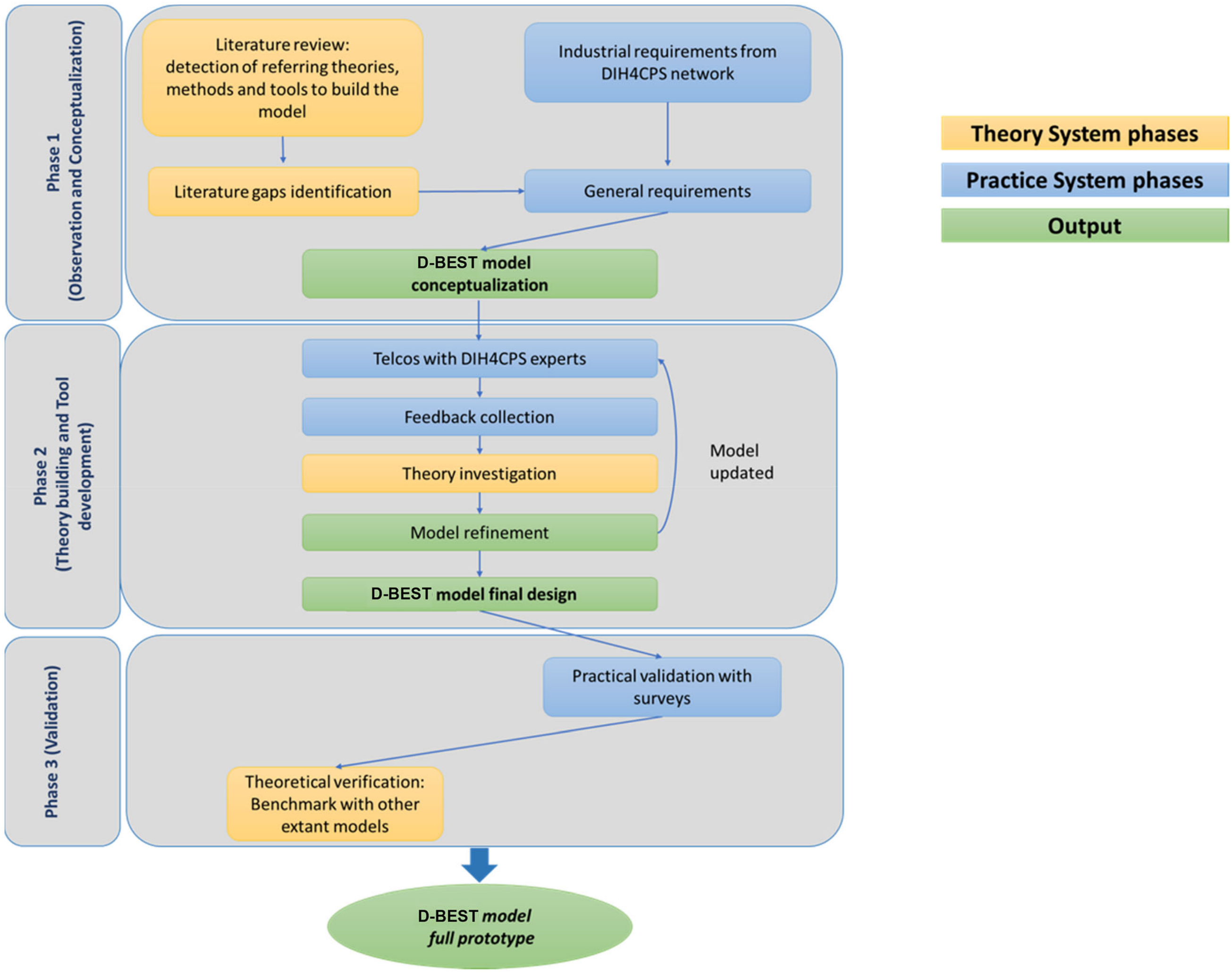

Fig. 1 Research methodology

methodology is constituted by three main phases: 1. model conceptualisation; 2. model development and theory building; and 3. model validation.

Model Conceptualisation

The first phase, which corresponded to the Design Clarification and Descriptive Study 1 phase proposed in the DRM framework, was dedicated to observing systems from both theory and practice to undertake the initial conceptualisation of the D-BEST model. This part of the development process follows a bottom-up approach, analysing theory and practice and providing a model as the output.

In particular, theoretical system observation is articulated in discrete steps. First, since the model built and proposed in this section is dedicated to the specific entity of DIHs, a literature review was conducted, starting with the concept of DIH. Its aim was to have a theoretical perspective on the conception of the model and detect the types of services needed to foster the adoption of digital technologies in European manufacturing. Then, to support the development of the model and provide evidence for the industry-oriented approach, referring theories and methods were identified and selected from the literature (mainly the commonly used ETB model in several previous European projects) and used to start creating the D-BEST model. The concept of the model was previously grounded in the literature presented by Sassanelli et al. (2020a) and by Sassanelli et al. (2021).

Model Development

Proceeding to phase 2, theory building and model development were carried out (corresponding to the Prescriptive Study phase of DRM) according to interactive research principles in this case as well, with the aim of progressively improving, through the DIH4CPS experts' (from DIHs, SMEs, consultancy, academy, etc.) feedbacks, the initial concept of the methodology, and to obtain the final consolidated methodology.

The methodology was progressively assessed and discussed through 11 online Telcos (each one lasting around 1 h). Together with the potential users of the model (provided by the DIH4CPS consortium), the D-BEST model was iteratively improved and detailed. Therefore, the final design obtained was considered to further structure and build the twofold survey, among service providers and customers, which is useful for the validation of the model.

Model Validation

The final phase of the research design, which corresponded to the Descriptive Study II phase of the DRM framework, was dedicated to assessing the suitability of the model to its scope and referring context (i.e. to configure the DIH4CPS network service portfolio with the aim of supporting European SMEs to adopt CPS technologies). This is a top-down approach to validate, improve, and re-structure the model built in the first two phases. In detail, the practical testing of the methodology was conducted according to two common means of validation: a twofold survey and a comparison with already extant models supporting DIHs to configure and assess their service portfolios from the IoT digital technology domain.

Survey Development

The survey was developed to validate the final design of the D-BEST reference model and to further improve it based on its results. The DIH4CPS consortium reviewed the macro-classes, types, and classes of services constituting the D-BEST model to better understand the main information needed from single users to configure the service portfolio of the DIH belonging to the DIH4CPS network. Indeed, the resulting survey represented the tool needed to use the model in practice and gather the required information to instantiate the objective DIHs.

The survey was progressively assessed and discussed through four online Telcos (each one lasting around 1 h). Together with some of the potential users of the survey (provided by the DIH4CPS consortium), the survey related to the D-BEST model was iteratively improved and detailed. The objective of this survey was to gather a set of services in the DIH4CPS network. This allowed for not only defining the service catalogue and identifying the different competencies and skills already in the DIH4CPS network but also realising the main services needed by companies dealing with CPS technologies.

Also, the survey was conducted using a twofold approach, launched, and submitted to two different groups: service providers and customers. The first (top-down) approach consisted of submitting the survey developed to the service providers of the DIH4CPS pan-European network (i.e. regional DIHs and academic institutes and companies providing services). The scope of this action was to define the related as-is service portfolios. Through this survey, the set of classes of services identified by the D-BEST model was proposed to service providers who were asked to identify the relevant services they were offering and to add other services if needed.

The second (bottom-up) approach involved submitting the survey to the SMEs belonging to the same network and asking for services, that is, the service customers, to understand the services that needed to conform more to the CPES domain. Through this survey, the set of classes of services identified by the D-BEST model was proposed to service customers who were asked to identify the services they would need for their businesses and would like to be available in the DIH4CPS ecosystem and to add other services if needed.

Survey Execution

A list of e-mails was prepared, and the survey questionnaire was sent to each e-mail recipient (introducing its scope and expected output and the deadline for completing the survey). The invitation was sent to multiple contacts in each organisation to ensure that different employees from the same organisation collaborated to answer the survey while making sure that each employee answered the questionnaire only once. To support this, e-mails were divided into main and secondary contacts.

Surveys Analysis

The results of this survey are presented in sub-Sect. 5.2. For each macro-class of services, the partners that contributed more are identified, and the service instances provided and requested more in the DIH4CPS network are revealed.

First, the analysis of the results consisted of mapping the services actually needed to support the adoption of CPS in the DIH4CPS network. Second, matchmaking with the service providers was performed to understand the needs that could be internally satisfied and addressed. This would enable a pan-European cross-collaboration and sharing of knowledge, competencies, technologies, and all other types of assets required.

Finally, if any of the services identified to be necessary are not addressed inside the DIH4CPS network, new directions can be defined to fill these gaps and find new suitable external stakeholders.

An analysis of the survey results will also be provided to the partners involved. It can be used to support their businesses and networking inside the DIH4CPS network, enabling better exploitation of the opportunities from its assets.

Comparison with Other Models in the Digital Domain

The final step in improving and validating the D-BEST model was a comparison with the model proposed in the AIOTIDHIN in the IoT domain and the categories of services presented in the S3 Platform from EC.

Evolution of the D-BEST Model

The evolution of the D-BEST model is presented in this sub-section, starting from the concept delivered by the observation phase [presented in Sassanelli et al. (2020a) and grounded in the literature presented by Sassanelli et al. (2021a, 2021b)]. This artefact was used to perform iterative brainstorming workshops with the DIH4CPS experts during the development phase and was brought to the release of the full prototype of the D-BEST model obtained after the validation phase. Today, with the work done in the DIH4CPS project, the D-BEST model extends and customises the ETB to the particular domain of the CPES (I4MS, 2020).

Since the beginning of their development, the ETB and D-BEST models have been used as twofold approaches: bottom-up (referring to the investigations of the extant theory [literature analysis] and practice [using both workshops and brainstorming sessions]) and top-down (conducting a survey involving experts, both academics and practitioners, to validate and further refine it). This twofold approach was maintained throughout the entire research process to further improve and customise the D-BEST model, with the scope of providing continuity to the type of research traditions adopted from its conception.

As a result, the D-BEST reference model is structured on five main macro-classes (Fig. 2), detailed on three levels (macro-classes, types, and classes of services) and embodying the principal domains in which the DIH can act, offering services to its users.

The D-BEST model proposed in this article is the most recent improvement of the model developed starting from the previous ETB I4MS service model (European Commission, 2018b), developed during the Access to I4MS (XS2I4MS) proposal (a support action to enhance the I4MS ecosystem) (EFFRA, 2015) and adopted in all DIHNET.eu projects (DIHNET.eu, 2020). Over the years, the three categories of the ETB model have been detailed on the basis of the experiences of DIH stakeholders and past experimental research within the framework of several projects from the EC's I4MS calls.

The main difference between the ETB and D-BEST models is the introduction of the data and skills macro-classes of services, as the ETB classes were not enough to totally and comprehensively cover all the potential services that a DIH could offer in the digital domain. These two new classes embody the key modules of the digitised context in which innovative technologies, such as CPS and artificial intelligence, can be needed. DIHs must play a strategic function in informing the decision makers of European manufacturers concerning the chances that digitisation can offer to their company. DIHs should not only impel technology adoption into their ecosystems in an easy way but also supply their stakeholders with reliable staff with consistent skills to use and take advantage of digital technologies. This is consistent with the target of devoting as a minimum 10–20% of the efforts used in application experiments to skill improvement (European Commission, 2018b). These services would not only empower European companies employees but also improve the operative working processes and concur to both portfolios and business models digitisation. Based on this, a special attention was given to the skills and data dimensions in the D-BEST reference model, adding services that can enrich companies with new competences to handle new technologies and take advantage of the data connected to them.

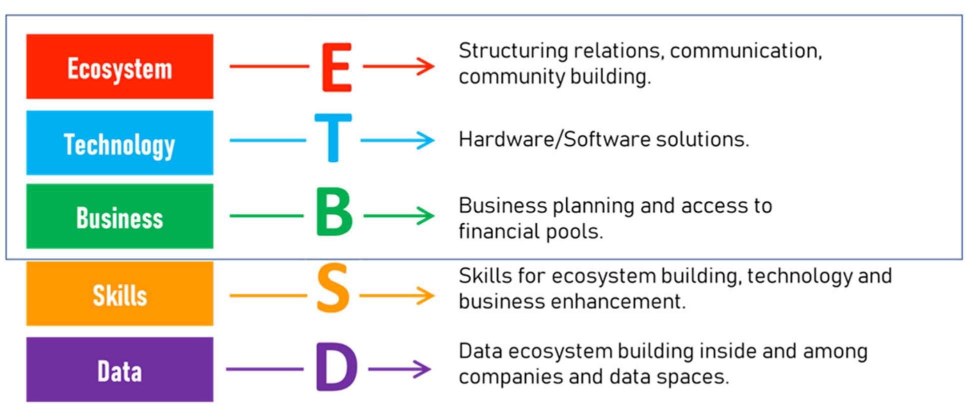

Fig. 2 Extension of the ETB model to the D-BEST reference model (adopted by Sassanelli et al., 2020a)

Moreover, after adding the skills and data services (Sassanelli et al., 2020a), single-service classes were further categorised and detailed, characterised in terms of:

- Tailored and detailed service instances,
- The service provider (European DIH network, single DIH, technology provider company, and university and research centre),
- The service customers (technology end-user company, single DIH, technology/solution provider company, and university and research centre),
- The service output (e.g. events, financing, education, assessment, consultancy, assets and ideas sharing),
- The service value proposition (i.e. visibility, access to partners, funding, access to knowledge, market analysis, access to services, and collaboration), and
- The EU DIH functions (networking, skills and training, test before investing, and access to funding).

Dealing with the service provider, the D-BEST reference model can include services provided by DIHs to their local/regional ecosystems (sometimes also delivered by their members). In some cases, it happens that the services belonging to a specific DIH portfolio can be sold by those members but provided by other users. For this reason, the DIH business model is highly important. This is also linked to the fact that a service could be internal or external to the network of DIHs. Whether the service is external, it is provided externally to anyone interested (perhaps for a fee). Otherwise, when a service is internal, it is provided exclusively to the extant partners of the network.

Moreover, the survey further contributed to improving the D-BEST model and its structure (e.g. eliminating one type of services from the business macro-class in this step).

Finally, the comparison with the model proposed by AITODIHN contributed to the validation of the model, and checking the S3 platform led to the idea of mapping the set of services proposed on that platform based on the D-BEST structure.

The Pilot Case: The DIH4CPS Project's Network

The DIH4CPS project (2020) is an innovation action (IA) project that received funding from the European Union's Horizon 2020 programme. DIH4CPS's objective is to develop an embracing, interdisciplinary network of DIHs and solution providers, focusing on CPES, intertwining competences and assets from different domains, and linking regional clusters with pan-European DIHs. The DIH4CPS Network will become a sustainable network, instantiated within the I-VLab organisation, remaining active well beyond the duration of the DIH4CPS project. A customised business model will be developed, combined with professional exploitation and sustainability support, to ensure smooth integration and, therefore, the overall sustainability of the network. DIH4CPS will validate its ecosystem with 13 member DIHs, providing the European industry with unprecedented ease of access to world-class domain expertise in the development of CPS and smart embedded systems, and with 11 initial application experimentations across multiple key sectors. In the future, open calls will be launched by the project, with special emphasis on the integration of DIHs complementary to the DIH4CPS network, thus extending the overall network according to the needs evidenced by the results of the D-BEST model application.

The D-BEST Reference Model

The D-BEST reference model was structured at three levels: macro-classes, types, and classes. Each of the five macro-classes included in the model can be derived in (2nd level) *types* of services, as shown in Fig. 3. The *types* of services embody the groups of services offered by the DIH to its stakeholders in each of the five specific macro-classes (1st level). Moreover, each *type* of service is exploded in (3rd level) *classes* of services actually delivered by the DIH (as detailed in sub-Sects. 4.1–4.5).

Finally, a deeper characterisation of the classes of services was required. In Annex 1, from Figs. A1 to A20, each service class is detailed according to several characteristics, which are grouped and listed in Table 1.

Ecosystem Macro-Class

The objective of the ecosystem macro-class is to generate, encourage, enlarge, and put in contact the local SME constituency, including SME digital transformation diverse stakeholders such as technology providers and users, competence centres, market development experts, regional development associations, and education and training laboratories. It is composed of three types of services: community building, DIH innovation development, and ecosystem governance.

The 'community building' type of services (Fig. A1) is divided into three classes.

1. *SME and people engagement and brokerage*, which are aimed at either generating a network around the DIH that bonds the members of the innovation ecosystem or raising awareness about the DIH's activities or connecting suppliers with customers, collaborators, business support services, capital providers, and others (academic institutions and HR). Instances of this kind of services are as follows:

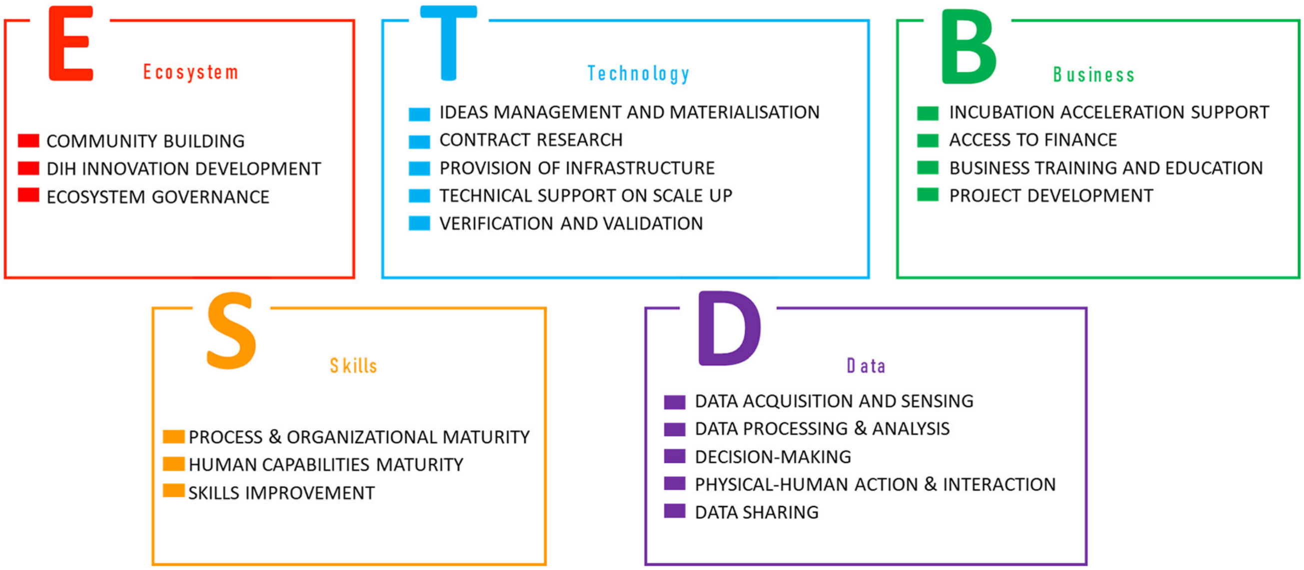

Fig. 3 Types of services in the D-BEST reference model

- Events (DIH annual conferences, industrial events, academic conferences and workshops, sectorial fairs, online events, etc.)
- Offering of the DIH product and service portfolio

2. *Innovation incitation, awards, and challenges*, which are aimed at either stimulating and rewarding collaborative innovation and problem solving or offering shared areas to foster collaboration and innovation or offering innovation spaces to encourage innovators and other ecosystem members to interact and share ideas and spaces for experimentation and pilot manufacturing. Some instances of this class of services are as follows:

   - Organisation of challenges for collaborative innovation inside the network
   - Provision of awards for collaborative innovation inside the network
   - Offering of innovation spaces to impel innovators and other members to interact and share ideas

3. *Technology scouting*, in which technologies are delivered to companies looking for innovative technologies for incorporation into their portfolios. Instances of this class include the following:

   - Scouting of technologies and their proposals to companies
   - Use of technology scouting platforms
   - Identification of emerging technologies
   - Communication of technology-related information to organisations

The ‘DIH innovation development’ type of services (Fig. A2) is divided into two classes:

1. *Communication and trend watching*, which are aimed at fostering the communication inside the ecosystem of practical experiences in the domain (through sharing best practice experiences, inviting experts in business and entrepreneurship or industry sectors to give talks and interact with [potential] customers and partners [study visits and roadshows]) and providing indications on the referring market (through the provision of up-to-date information about market trends, the assessment of market potential [business model], the use of trend intelligence platform, and the development of trend reports). Instances of this class include the following:

   - Sharing of best practice experiences
   - Invitation of experts in business and entrepreneurship or industry sectors to give talks and interact with (potential) customers and partners
   - Defining and updating the DIH business model
   - Market potentiality assessment
   - Use of trend intelligence platforms
   - Provision of trend reports

2. *Visioning and strategy development*, which are aimed at supporting start-ups and SMEs in building and developing their visions and strategies and large corporations that require innovative thinking to remain competitive in the marketplace. An instance of this class of services is as follows:

   - Customer support in shaping the organisational vision and strategies and in remaining competitive in the marketplace.

Table 1 Structure of the D-BEST model

Macro-class	Type of service	Class of service, service instances, and description	Service provider	Service customer	Category of service output	Service value proposition	EC classification of DIH functions	Internal/ external service
Ecosystem (E) Technology (T) Business (B) Skills (S) Data (D)	E: Community building, DIH innovation development, and ecosystem governance T: Ideas management and materialisation, contract research, provision of infrastructure, technical support on scale-up, verification, validation, and demonstration B: Incubation acceleration support, access to finance, business training and education, and project development S: Process and organisational maturity, maturity of human capabilities, and skills improvement D: Data acquisition and sensing, data processing and analysis, decision-making, physical-human action and interaction, and data sharing	–	Global DIH4CPS network Existing DIH Technology/solution provider Academic partner	Technology users (SMEs and mid-caps) Existing DIH Technology/solution provider Academic partner All users of DIH4CPS	Assessment Awards Consultancy Events Funding Network empowerment Scouting Sharing of physical assets Sharing of ideas Support (technological, business, management, etc.) Technology Training	Visibility Access to partners Funding Access to knowledge Market analysis Access to services and collaboration	Networking Skills and training Test before investing Access to funding	Internal External Internal and external

The 'ecosystem governance' type of services (Fig. A3) is divided into two classes:

1. *Service impact assessment*, which is aimed at the assessment of the services provided to the ecosystem through key performance indicators (KPIs). Instances of this class are as follows:
   - Development of KPIs allowing for the assessment of the performance of the provided services
   - Use of defined methods to evaluate the impact of the services delivered
   - definition of guidelines and/or checklists for service assessment
2. *Ecosystem management*, which includes engagement rules, statute, and governance structure, is aimed at easing relationships both within the DIH ecosystems and between the DIHs of the network. Instances of this class are as follows:
   - Definition of intellectual property (IP) rules
   - Definition of rules on how to manage internal collaborations
   - Definition of rules on how to engage external users

Technology Macro-Class

The scope of the technology macro-class is to support the entire digital technologies lifecycle, starting with its conception and idea generation and the design and proof of concept development, up to the creation of the minimum viable product prototype and the launch on the market. It can be interpreted from the technology providers' and users' viewpoints through the steps of the access–experiment–experience spiral model. This macro-class in split into five main types of services, specified in more detailed *classes* of services.

The first type is *idea management and materialisation* (Fig. A4), divided into two classes:

1. *Ideas generation, assessment, and feasibility study*, which are aimed at gathering innovation ideas, and refining and targeting them in a collaboration environment through a preliminary feasibility analysis. Instances are
   - Generation and assessment of new ideas,
   - Use of concept generation methods,
   - Use of concept evaluation methods, and
   - Feasibility studies.
2. *Technology readiness assessment*, through which DIHs assess the products/solutions developed by start-ups and SMEs. An instance of this class of service is
   - Technology readiness level assessments of product/solutions developed by start-ups and SMEs.

The second type of services, *contract research* (Fig. A5), is divided into two classes:

3. *Strategic and specific research and development (R&D)*, which includes collaborative R&D projects to sustain the conversion of ideas into demonstrable concepts, applying technological innovation to create new products/services or enhancing existing ones. Instances of this class of services can be
   - The demonstration of the feasibility of an idea through its short-term or provisional realisation,
   - The application of technological innovation to develop new products/services or to improve existing ones, and
   - Planning and defining new business services solutions.
4. *Technology concept development/proof of concept (PoC)*, which is aimed at planning and developing new business service solutions and verifying the feasibility of an idea or project through its short-term realisation. Instances are
   - Proof of concept development and
   - Supporting the conversion of innovative ideas into demonstrable concepts.

The third type of services, *provision of infrastructure* (Fig. A6), includes only one related class:

1. *Access to infrastructure and technological platforms*, which include services aimed at providing a large range of infrastructures in several ways. Instances are
   - Renting of equipment,
   - Provision of platform technology infrastructure,
   - Provision of access to laboratory facilities, and
   - Provision of infrastructure and support for low-rate production.

The fourth type of services is *technical support on scale-up* (Fig. A7), which can be divided into two classes:

1. *Concept validation*, which includes services aimed at validating the concept previously developed engaging external stakeholders in an industrially relevant setting. Instances are
   - Development of minimum viable products (MVPs) to be validated with real customers and/or in industrially significant setting and
   - Support for the exploration of ideas and emerging technologies.

2. *Prototyping*, which is aimed at designing prototypes to investigate ideas and emerging technologies before starting production by also considering potential chances given by small series production. An instance of this service is
   - Designing prototypes to investigate ideas and emerging technologies before starting production.

The fifth type of services related to the technology macro-class is *verification, validation, and demonstration* (Figure A8), which can be divided into two classes of services:

1. *Product qualification and certification*, which include services aimed at providing support for the development of MVPs that can be validated with real customers and/or in an industrially significant setting. Instances include support in certifying that the product has passed
   - Functional tests,
   - Performance tests, and
   - Quality assurance tests.
2. *Product demonstration*, which is aimed at proposing showrooms and demo-cases to demonstrate a product in front of clients. Instances are
   - The promotion of showrooms and demo-cases to demonstrate a product in front of clients,
   - Organisation and promotion of events where a product is demonstrated in front of clients, and
   - Organisation and promotion of online product demonstration.

Business Macro-Class

The business macro-class occurs in advanced scenarios (with high technology readiness level [TRL] solutions), detecting, modelling, and supporting viable business models, proposing fundraising services (e.g. private matchmaking or access to public funding opportunities). It can be divided into four types of services, as detailed in the several classes of services.

The first type of services is *incubation acceleration support* (Fig. A9), which can be divided into four classes of services:

1. Basic facilities, aimed at providing access to physical infrastructures useful for supporting incubation. An instance is
   - The provision of access to physical infrastructures (offices, meeting rooms, co-working areas, libraries, etc.).
2. Specialised facilities, aimed at providing access to specialised infrastructures. Instances are the provision of access to
   - Laboratories and data ecosystem,
   - Telecommunication infrastructures and video conferencing, and
   - High-powered computing.
3. Business development, including coaching and mentoring, entrepreneurs in residence, and dedicated programmes to aid entrepreneurs in the process of business development. Instances are the provision of
   - Coaching and mentoring to entrepreneurs with dedicated programmes (innovation funnel, scenarios communication, and business assessment) and
   - Access to the data ecosystem.
4. Guidance, involving services aimed at offering technical/fiscal/legal advice and regulatory assistance. Instances are the provision of
   - Fiscal and/or legal advice,
   - Regulatory assistance, and
   - Back-office services (administrative, secretary services, etc.).

The second type of service, *access to finance* (Fig. A10), is divided into two classes of services:

1. Financial engineering, services aimed at giving help in solving financial issues and/or counsel on innovative financial products. Instances are the provision of
   - Support in solving financial issues and
   - Advice on innovative financial products.
2. Connection to funding source services for facilitating access to diverse funding sources (EU, national, regional, and private) to achieve an effective mix of funds. Instances are the facilitation of access to
   - Different funding sources (EU, national, regional, and private), and
   - An effective mix of funds (conversation, lobbying, and projects).

The third type of services is *business training and education* (Fig. A11). It is composed of two classes of services:

1. Methods and tools, and business operations modelling, aimed at offering training in business skills and entrepreneurship (e.g. formal courses, workshops, and seminars) and influencing academia
2. Secondment, services aimed at either easing the exchange of personnel and core competencies among

organisations or orienting partners to the needed training organisation. Instances are:

- Personnel (e.g. researchers) and core competences exchange programmes among organisations (including intellectual property rights [IPR]),
- Orienting partners to the needed training organisation.

The fourth type of services is *project development* (Fig. A12), divided into three classes of services:

1. Identification of opportunities, aimed at supporting the identification of new business opportunities. An instance is
   - help in the detection of new market/business chances through a strategic analysis of the ecosystem and trend watching.
2. Creating consortia, services aimed at impelling cooperation and collaboration among organisations for exploiting common opportunities. An instance is
   - Support in cooperation and collaboration among organisations for exploiting common opportunities (e.g. business, research, funding, matchmaking, and open innovation)
3. Development of proposals, aimed at providing technical assistance to comply with specific proposal requirements. An instance is
   - Provision of technical assistance in the proposal development process to comply with specific proposal requirements (e.g. for project funding).

Skills Macro-Class

The objective of the skill macro-class twofold. The first is to assess the status quo of those companies willing to approach digitisation concerning both process/organisation and skills maturity and to then define a consistent roadmap to enhance it. The second is to aid skill empowerment on one side through educational programmes, up-skilling, and re-skilling training, and on the other through knowledge transfer mechanisms (as sharing channels, structure contacts, and collaborations for scouting and brokerage). Three main *types* of services are described in the following classes of services:

The first type of services is *process and organisational maturity* (Figure A13), divided into two classes of services:

1. Maturity assessment, services aimed at assessing company readiness and maturity for Industry 4.0 (tech, organisational, and ecosystem readiness). An instance is
   - The assessment of maturity companies (e.g. assessment of company readiness for Industry 4.0).
2. Maturity strategy development, services aimed at defining a roadmap starting from the characteristics of the single enterprise or part of it. An instance is
   - Definition of a roadmap based on the maturity model assessment.

The second type of services is *human capabilities maturity* (Fig. A14). It is divided into two classes:

1. Human skills maturity, services aimed at supporting capabilities screening through on-site visit(s), interviews, and so on, and at defining the actual level of skills maturity in Industry 4.0. An Instances is
   - The assessment of human skills maturity (e.g. regarding skills in Industry 4.0).
2. Skills strategy development, aimed at either providing a gap analysis between the 'as is' and the desired level of skills, or defining and supporting the implementation of an action plan. Instances are
   - The analysis of the gap between the AS-IS and the desired level of Industry 4.0 skills and
   - The definition of an action plan and support in implementing the desired level of Industry 4.0 skills.

The third type of services is *skills improvement* (Fig. A15). It is divided into three classes of services:

1. Human up-skilling and re-skilling training, services providing lifelong training on technical and soft skills focused on AI at the corporate, operational, and technology-specific levels. An instance is
   - The organisation of dedicated human up-skilling and re-skilling trainings, courses, and workshops.
2. Educational programmes, services aimed at attracting and skilling next-generation talents, forming Industry 4.0 employees and workers. An instance is
   - The definition of educational programmes, allowing for the attraction and formation of next-generation talents (forming Industry 4.0 employees and workers).
3. Scouting and brokerage, aimed at supporting the identification of the channels, structure contacts, and collaborations intended for knowledge transfer and so on. An instance is
   - The support for knowledge transfer through internal channels, structure contacts, and collaborations.

Data Macro-Class

The data macro-class is crucial for fully taking advantage of the potentialities of digital technologies through services related to diverse phases of the data life cycle: from data acquisition and sensing to data processing and analysis, up to decision-making and data sharing, also including aspects such as physical-human action and interaction. It is composed of five types of services.

The first is *data acquisition and sensing* (Fig. A16), divided into two classes of services:

1. Data acquisition, services oriented at data in motion models and services for Industrial IoT. An instance is
   - The provision of support in data acquisition through data in motion models and services.
2. Data protection, services oriented at data anonymisation, confidentiality, encryption, and privacy preservation services. An instance is
   - Support in data anonymisation, confidentiality, encryption, and privacy preservation services.

The second type of services related to *data* macro-class is *data processing and analysis* (Fig. A17). It is divided into two classes of services:

1. Data storage, services oriented at storing data in local or distributed form and representing related knowledge. An instance is
   - The provision of data spaces, data lake, linked data, distributed storage, and knowledge representation services
2. Data analytics, services aimed at analysing data through different approaches. An instance is
   - The provision of data analytics services (semantic analysis, data discovery, advanced data analytics [edge and cloud analytics]).

The third type of services is *decision-making* (Fig. A18). Also, in this case, there are two classes of services:

1. Cognitive big data architectures, services aimed at configuring and deploying architectures for big data. An instance is
   - The configuration and deployment architectures for big data (cognitive big data architectures).
2. Decision support and development, services aimed at supporting decision-making and developing through data analysis. An instance is
   - The provision and development of decision support services, including cognition, prediction and prescription, simulation, machine learning, reinforcement, DNNs, and formal logics.

The fourth type of services is *physical-human action and interaction* (Fig. A19). It is declined in three classes of services:

1. Collaborative intelligence, services aimed at supporting for improving the human–machine interface and interaction. An instance is
   - The provision of support/consultancy services for the human–machine interface, human–robot interaction, human–data interaction, and multi-lingual AI.
2. User experience, services aimed at supporting and enhancing the user experience, navigation, and exploration. An instance is
   - The provision of support/consultancy services for user experience, navigation, and exploration.
3. Feedback loop, services aimed at supporting systems' control and actuation of feedback loops. An instance is
   - The provision of support/consultancy services for feedback looping (control/actuation, cognitive mechatronics, and question answering).

The last type of service is *data sharing* (Fig. A20). It can be divided into three classes of services:

1. General data protection regulation (GDPR) and data sovereignty compliance, which consultancy services for personal and non-personal data sharing and exchange business process modelling, rules of governance, and contracts. An instance is
   - The provision of support/consultancy services in GDPR and data sovereignty compliance.
2. Data spaces, supporting the creation and development of data models and ontologies for trusted and secure data exchange. An instance is
   - The provision of support in modelling data and ontologies for trusted and secure data exchange.
3. Data platform, supporting the development of hardware and software architectures and components and providing connectors services. An instance is
   - The support and provision of hardware and software architectures and components and the provision of connectors services.

Validation and Discussion: Results from Surveys and Comparison with Extant Models in the Digital Domain

Results from Surveys

In this sub-section, results from the survey run in the DIH4CPS network are presented. The twofold survey was aimed at supporting both service providers' and customers' businesses and networking inside the DIH4CPS network, enabling a better exploitation of the opportunities from belonging to the network. In particular, the model enables.

1. Service providers (top-down approach; questionnaire in Annex 2):
   - Map of services provided in the DIH4CPS network to support CPS adoption in a unique service portfolio
   - Matchmaking among the different service providers to evaluate and understand possible cross-collaborations and business opportunities for complementary activities
   - Defining and proposing new business directions to fill the gaps when any of the services listed in the survey is not addressed inside the DIH4CPS network
2. For service customers (bottom-up approach; questionnaire in Annex 3):
   - Map of the services actually needed to support the CPS adoption raised in the DIH4CPS network,
   - Matchmaking with the service providers to understand the needs that can be internally satisfied and addressed, enabling a pan-European cross-collaboration and sharing of competencies, technologies, and so on.
   - Defining new directions to fill these gaps and find new suitable external stakeholders when any of the resulting needed services is not addressed inside the DIH4CPS network.

The results from the service providers and customers are presented in detail, raising the aspect listed above. For each macro-class of services, the services offered in the DIH4CPS network and those requested by service customer were compared.

First, the heterogeneity of the 23 service providers who participated in the top-down survey is notable. Figure 4 (left side) shows that the general mission of almost 50% of these partners is to be a DIH, often concurrently playing other roles (competence centres [CC], academic partners, technology providers, research technology organisations [RTOs], or other [i.e. sustainability promoters of manufacturing companies]). Instead, the right side of Fig. 4 presents evidence to the fact that in the DIH4CPS project,12 partners played the role of DIH and 9 partners played the role of CC (63% of the partners), whereas the remaining 37% were technology providers (6), RTOs (2), and an SME (1).

On the other hand, 10 service customers who completed the bottom-up survey questionnaire were all categorised as SMEs in the DIH4CPS project.

In the following paragraphs, how these stakeholders contribute to each of the services constituting the D-BEST model is shown with the twofold aim of clarifying both the extant service portfolio of the DIH4CPS service providers and the needs requested by SMEs (i.e. the service customers of the initial application experiment in the project).

Ecosystem Class

The first question of the survey related to the ecosystem class concerns the 'community building' type of services and the 'SME and people engagement and brokerage' type of service. Therefore, this question was aimed at investigating, for service providers, what services are provided by organisations (specifically those asking for a referring webpage/document) and, for service customers, what the core business of the company is, what the referring market/industry is, and what products/services/product–service systems are delivered, respectively. The answers received indicated that almost all service providers had a webpage, where their service portfolios were listed, and that for service customers, both the referring market and portfolios of solutions (which they wanted to develop or already offered) were quite heterogeneous.

Related to the same class of service, a second question was aimed at understanding the kind of events providers and customers use to organise to connect the members of their ecosystem (Fig. 5). In this case, the respondent was asked to select only the most important option, but in the future rounds of the survey, multiple choices could be provided to extensively cover the types of events organised by the different stakeholders.

Technology Class

The first type of services addressed by the survey was 'ideas management and materialisation'. Two classes of services, 'ideas generation, assessment, and feasibility study' and 'technology readiness assessment', concur to this type of services and are assessed together through a single question, question 15 (Fig. 6). Results raise the perfect syntony among providers and customers who give more importance to feasibility studies and technology readiness assessments on products/solutions developed by

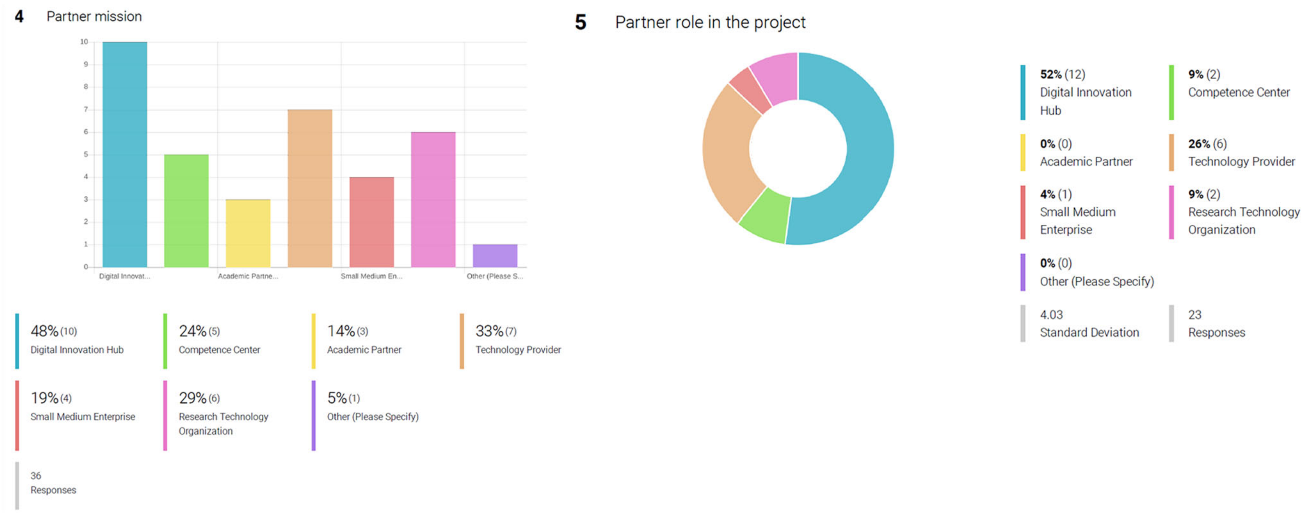

Fig. 4 Questions 4 and 5 providers (service providers' missions and roles in the project)

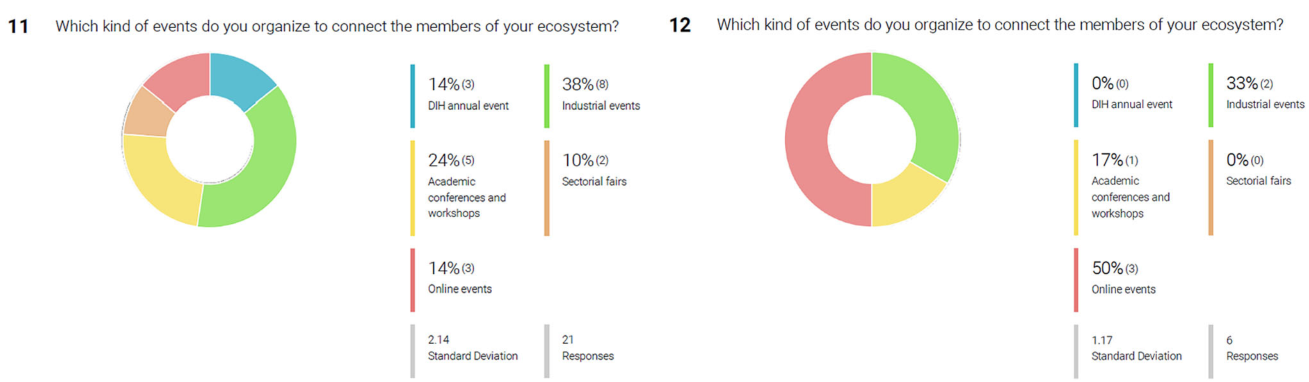

Fig. 5 Question 11 (providers) and 12 (customers; ecosystem—community building: SME and people engagement and brokerage)

start-ups and SMEs. Customers would also need concept evaluation methods (33%) not extensively offered by providers (13%), who instead generate and assess new ideas (52%). Providers also offer enterprise modelling techniques (as-is to-be).

Business Class

The first type of services related to the business macro-class is 'incubation acceleration support', which is divided into four classes of services: basic facilities, specialised facilities, business development, and guidance. All these were investigated through question 21 (Fig. 7). The answers revealed that providers mainly offered coaching and mentoring of entrepreneurs with dedicated programmes (48%) and training courses on business improvement (other, 4%) but also provided access to (co-working) physical infrastructures (39%) and telecommunication infrastructures and video conferences (22%), belonging to the 'basic and specialised facilities' class. Moreover, 35% of providers did not offer this kind of services. Instead, while 38% of the customers did not need these services, those who required some support asked for coaching and mentoring for entrepreneurs with the dedicated programmes (38%) and access to high-powered computers (25%) and data ecosystems (25%). Customers did not need (co-working) physical infrastructures.

Skills Macro-Class

In the skills macro-class, three types of services were identified. The first, *process and organisational maturity*, was composed of two classes of services, maturity assessment and maturity strategy development, and addressed by question 26 (Fig. 8). The results showed that 30% of providers did not support this kind of services. The remaining providers' supply process and organisational maturity mainly assessed the maturity of companies (e.g. assessment of company readiness for Industry 4.0) (52%) and then defined a roadmap based on the maturity model

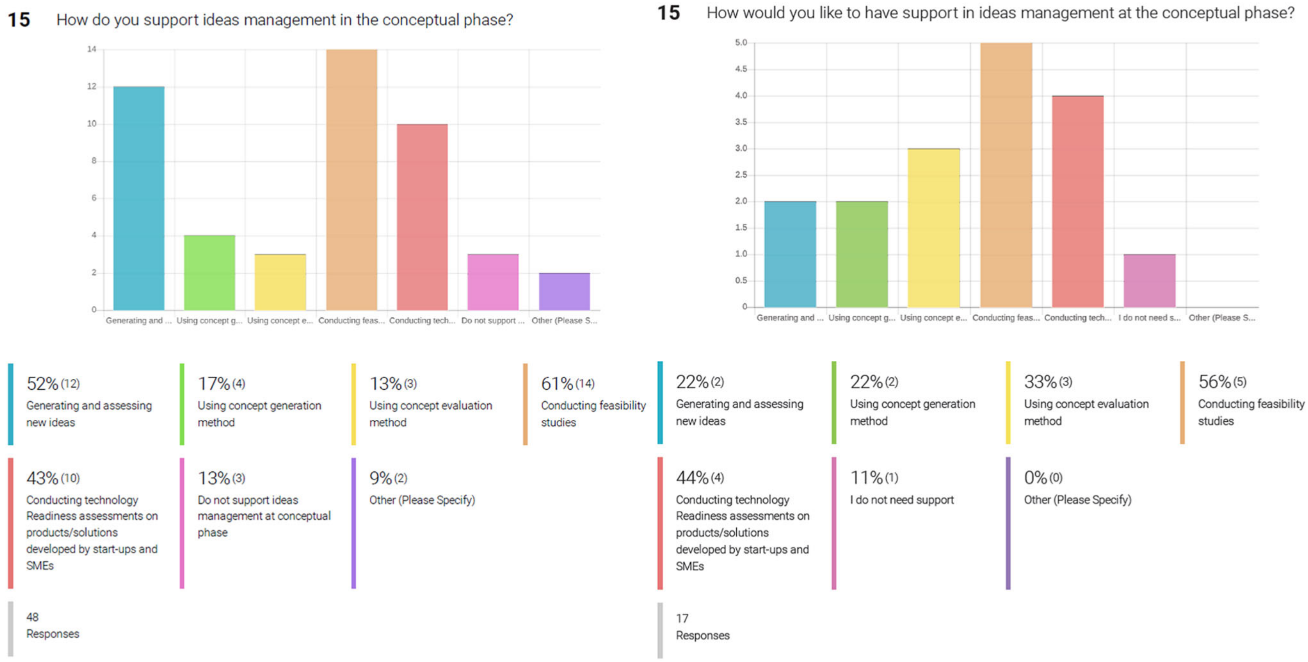

Fig. 6 Question 15 (technology—ideas management and materialisation: ideas generation, assessment, feasibility study, and technology readiness assessment)

Fig. 7 Question 21 (business—incubation acceleration support: basic facilities, specialised facilities, business development, and guidance)

assessment (35%). Instead, customers (43% of whom did not need this kind of support) mainly asked for the definition of a roadmap (57%) and secondarily asked for maturity assessments (29%).

Data Macro-Class

The last macro-class of services is *data*. It is composed of five types of services, each one addressed by a question (questions 29–33). As an example, the first type, *data acquisition and sensing*, involved two classes of services (*data acquisition* and *data protection*) assessed together

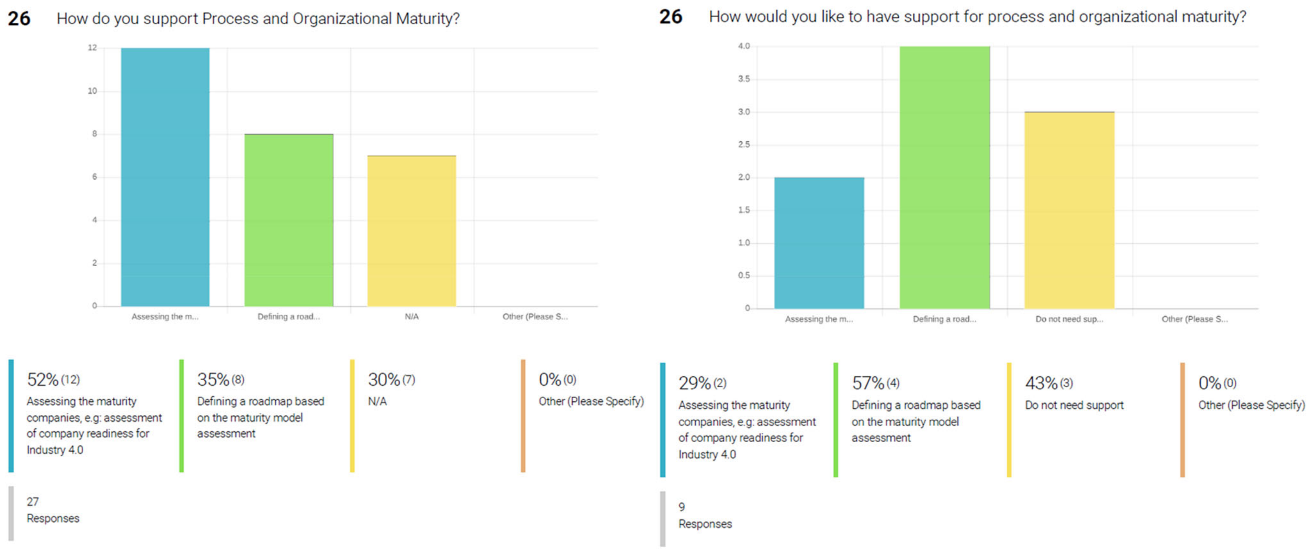

Fig. 8 Question 26 (skills—process and organisational maturity: maturity assessment and maturity strategy development)

using question 29. Results showed that both providers (57%) and customers (63%) gave more emphasis to *data acquisition* services through data in motion models and services.

DIH4CPS Network Service Portfolio

In this sub-section, the service portfolio of the DIH4CPS network is presented. Results were obtained from the results of the survey proposed to the service providers of the network.

Tables 2, 3, 4, 5, 6, report the service portfolio of the DIH4CPS network according to service macro-class. Each table presents the total number of sets of services provided by the service providers of the DIH4CPS network and the details of the services provided by each category of providers, grouped according to their roles in the project.

In addition, a graphical representation of the DIH4CPS service portfolio is provided as evidence of its composition and distribution among the five classes of the D-BEST model. The representation is given for all service providers (Fig. 9) and only for DIHs and CCs (Fig. 10). Technology providers, the research technology organisations, and small and medium enterprises were omitted for the sake of brevity. To summarise the service providers' results, all the macro-classes of services are covered by the DIH4CPS network. Half of the service portfolio of the network is composed of ecosystem and technology services, and skill services are still at an embryonal stage. In addition, by examining the type of stakeholders, the following findings were obtained:

- DIHs' service portfolios are similar to those of the network.
- Taking into consideration the technology providers' portfolios, business services give up space mainly in favour of data services and partially in favour of skill services.
- The same occurred in the cases of the two RTOs.
- In only one SME among service providers, technology macro-class occupied the main position, leaving the

Table 2 DIH4CPS service portfolio: ecosystem macro-class

Service type	Total E	Community building	DIH innovation development	Ecosystem governance
Surveys' Questions	7-8-9-10-11-12-13-14	7-9-10-11-12	8	13–14
Stakeholder				
All (21)	249	112	79	58
DIH & CC (14)	167	75	54	38
Technology Providers (6)	57	27	16	14
Research Technology Organization (2)	24	11	7	6
Small Medium Enterprise (1)	5	3	2	0

Table 3 DIH4CPS service portfolio: technology macro-class

Service type	Total T	Ideas management and materialisation	Contract research	Provision of infrastructure	Technical support on scale up	Verification, validation and demonstration
Surveys' Questions	15-16-17-18-19-20	15	16	18	17	19–20
Stakeholders						
All (21)	233	45	72	33	40	43
DIH & CC (14)	154	29	45	27	24	29
Technology Providers (6)	52	9	18	6	12	7
Research Technology Organization (2)	17	6	7	0	2	2
Small Medium Enterprise (1)	10	1	2	0	2	5

Table 4 DIH4CPS service portfolio: business macro-class

Service Type	Total B	Incubation acceleration support	Access to finance	Business training and education	Project development
Surveys' Questions	21-22-23-24-25	21	22	23–24	25
Stakeholders					
All (21)	180	41	28	71	40
DIH & CC (14)	145	35	24	55	31
Technology Providers (6)	21	3	2	10	6
Research Technology Organization (2)	10	3	2	4	1
Small Medium Enterprise (1)	4	0	0	2	2

Table 5 DIH4CPS service portfolio: skills macro-class

Service Type	Total S	Process & Organizational Maturity	Human Capabilities Maturity	Skills Improvement
Surveys' Questions	26-27-28	26	27	28
Stakeholders				
All (21)	78	20	25	33
DIH & CC (14)	53	15	15	23
Technology Providers (6)	17	3	7	7
Research Technology Organization (2)	8	2	3	3
Small Medium Enterprise (1)	0	0	0	0

remaining space to ecosystem, business, and data services. In this case, skill services were not provided,

- In general, skill serices appeared more needed by technology providers than by customers.

For service customers, an analysis was performed to determine the necessary (Fig. 11) and unnecessary services (Fig. 12). The analysis revealed the following:

- The services needed by customers (SMEs) in decreasing order are technology, ecosystem, business, data, and skills.
- The services declared to be unnecessary are as follows:
    - o Data services: all except data acquisition and sensing
    - o technology services: provision of infrastructures, validation, verification, and demonstration

Table 6 DIH4CPS service portfolio: data macro-class

Service Type	Total D	Data acquisition and sensing	Data processing & analysis	Decision-making	Physical-human action & interaction	Data sharing
Surveys' Questions	29-30-31-32-33	29	30	31	32	33
Stakeholders						
All (21)	122	20	27	25	28	22
DIH & CC (14)	73	11	15	14	19	14
Technology Providers (6)	32	6	8	7	6	5
Research Technology Organization (2)	13	2	3	3	3	2
Small Medium Enterprise (1)	4	1	1	1	0	1

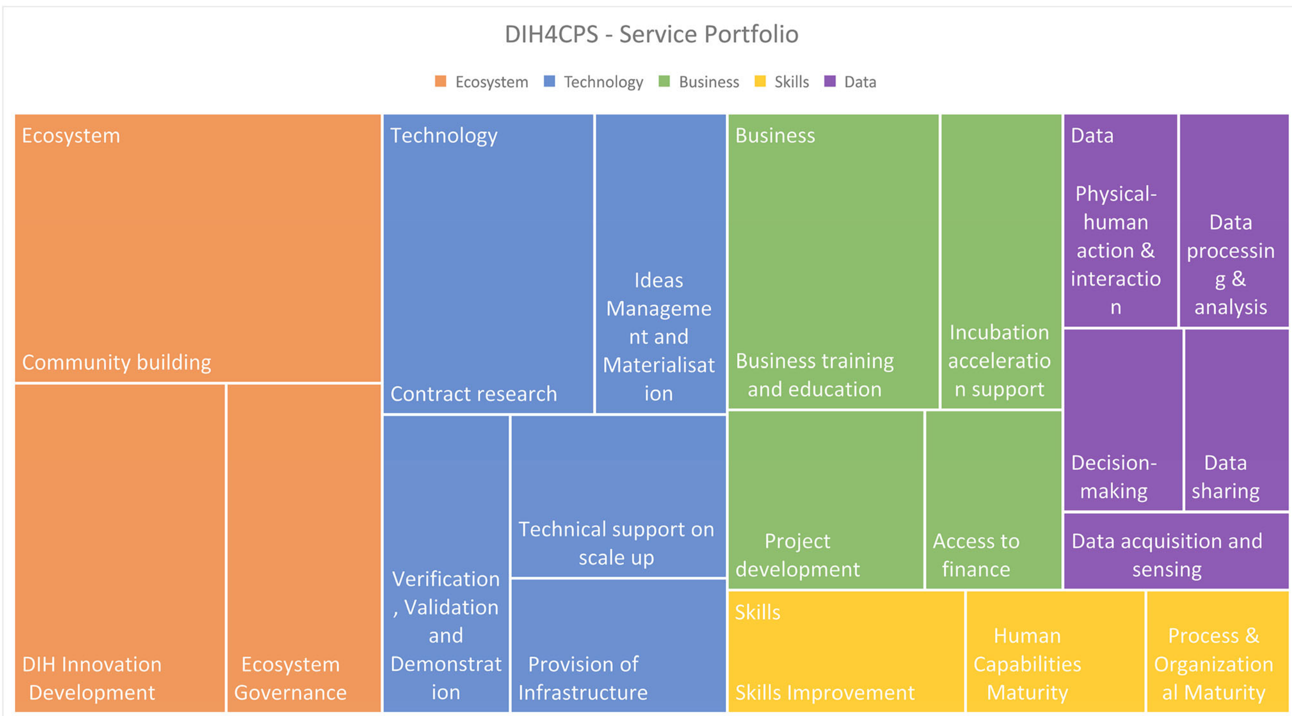

Fig. 9 DIH4CPS service portfolio composition of the five macro-classes of the D-BEST model

- o Business services: access to finance and incubation acceleration support
- o Skills: process and organisational maturity, and human capabilities maturity

- The comparison between the services needed and not needed revealed an uncertainty concerning specific services (business [*access to finance and incubation acceleration support*]), technologies (*data sharing and decision-making*), and skills (*human capabilities maturity*).

Comparison with the AIOTIDIHN Model and Link to the S3 Platform

Finally, the reference model validated through the survey was compared with the Network of IoT Digital Innovation Hub (AIOTIDIHN) model and the list of services from the S3 platform of the EC.

The white paper from AIOTIDIHN (2019) discussed the services that DIHs can provide to their customers. The AIOTIDIHN plays a key function in creating the network of developers, deploying, employing, and supporting the adoption of IoT technologies in European companies. IoT technologies produce a huge quantity of data that needed to

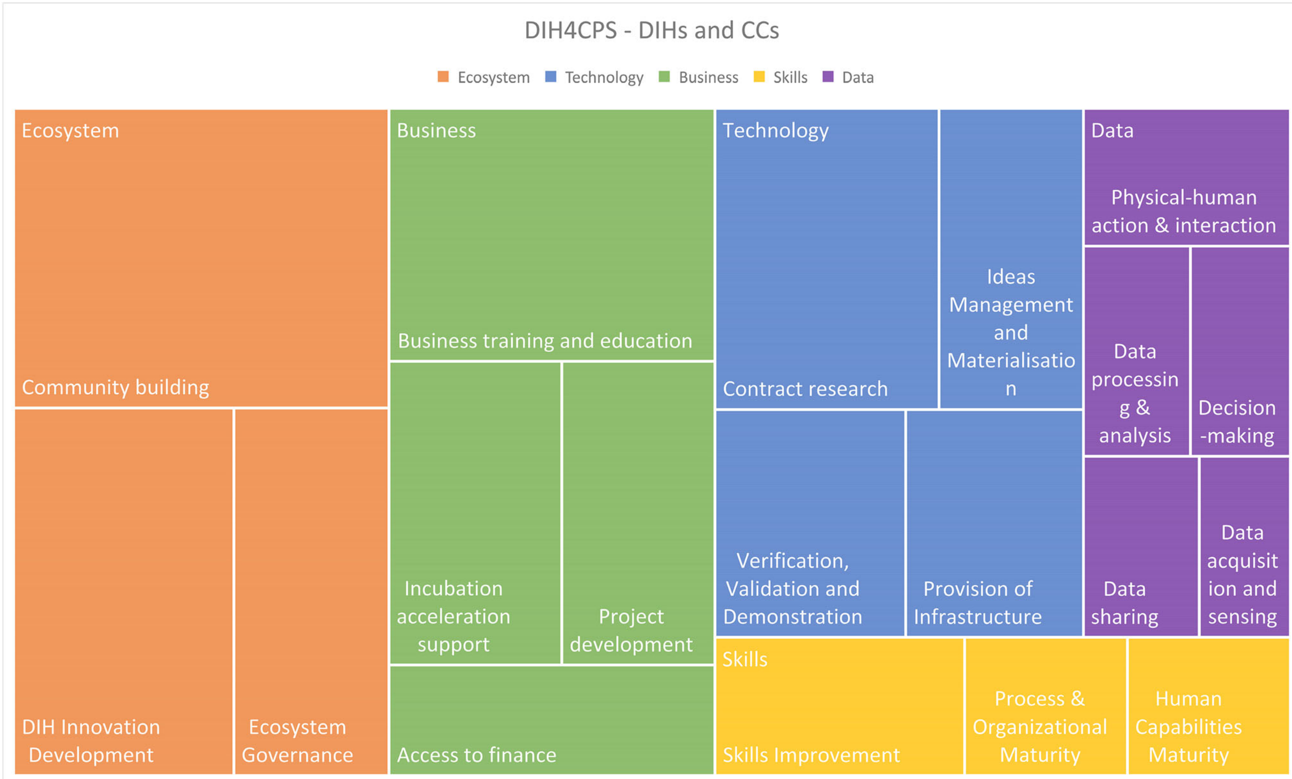

Fig. 10 DIH4CPS service portfolio composition among the five macro-classes of the D-BEST model: DIHs and CCs

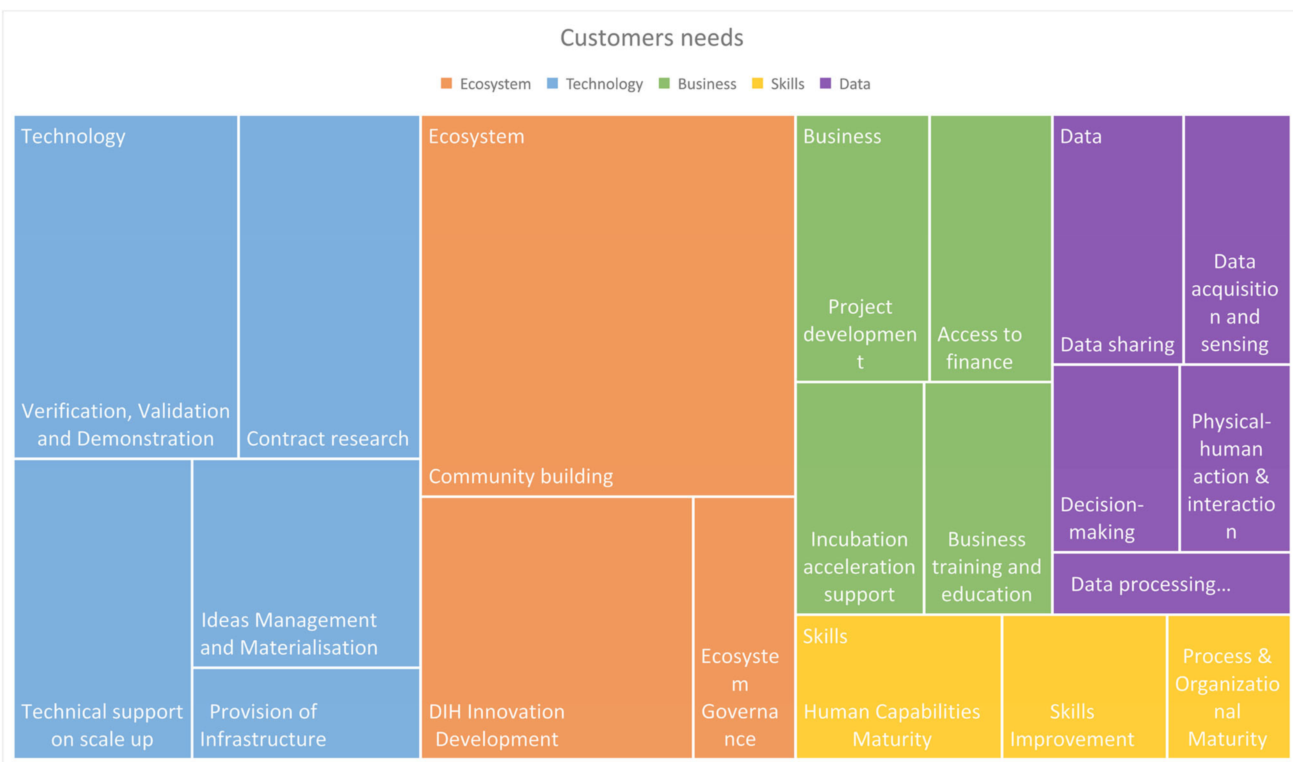

Fig. 11 DIH4CPS project: customer needs

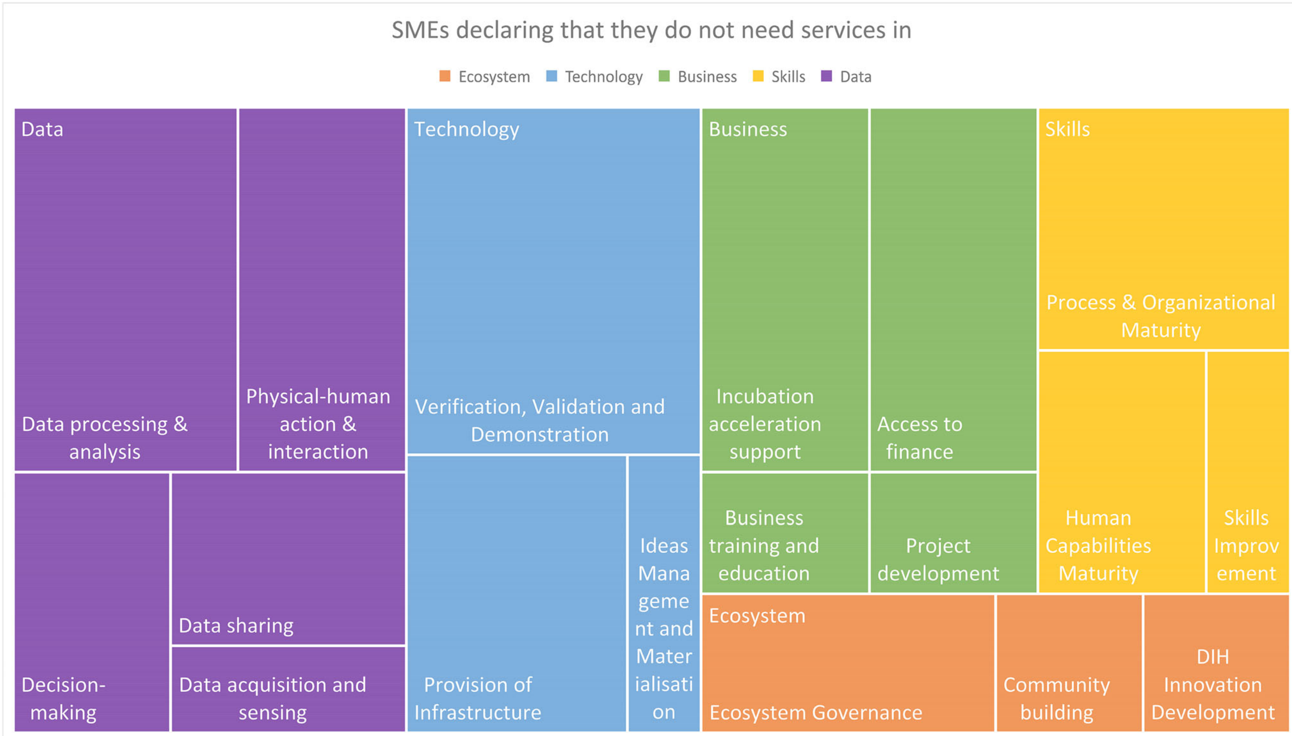

Fig. 12 DIH4CPS: services declared to be unnecessary by customers

be examined to provide valuable services to end users. In addition, the IoT/data platform is strategic to foster industry digitalisation and DIHs provide access to such platforms to advance and experiment on innovative services. IoT DIH has two types of users (Finally, the services that DIHs should offer to industries IoT technologies are structured into five main categories (1. strategy, 2. collaborative R&D [expertise and technological infrastructures] up to industrialisation, 3. business, 4. finance, and 5. skills/talents).

Therefore, the AIOTIDIHN list and descriptions further validate the D-BEST model. Comparison with the D-BEST model structure revealed a strong compatibility between the two models. In the model proposed by AIOTIDIHN, the finance aspect is highlighted more, whereas in the D-BEST model, the data macro-class is more remarkable.

Finally, the services composing the D-BEST model (presented in sub-Sect. 4) were compared with the categories of services listed in the S3 platform from the EC (European Commission, 2020a). The DIH tool is an online catalogue gathering main information (contact data, description, link to national or regional initiatives for digitising industry, market and services, and service examples) related to DIHs in Europe. Its purpose is to bolster companies to obtain access to the needed assets (services, competencies, technologies, knowledge, etc.) to digitise their products and services. The S3 platform is also aimed at showcasing, through its platform, all these assets provided to support European DIHs to network with each other and with other stakeholders belonging to their ecosystems (RTOs, universities, service and technology providers, and users) to communicate their expertise (European Commission, 2020a). The list of services categorised on the platform is grouped into awareness creation; ecosystem building, scouting, brokerage, and networking; visioning and strategy development for businesses; collaborative research; concept validation and prototyping; testing and validation; pre-competitive series production; commercial infrastructure; digital maturity assessment; incubator/accelerator support; voice of the customer/product consortia; market intelligence; access to funding and investor readiness services; mentoring; education and skills development; and other.

Also, in this case, a strong compatibility was found with the D-BEST model structure. A re-mapping of the S3 platform list of services in the structure of the D-BEST model could be performed and could open new opportunities to further apply the D-BEST reference model in the EU context.

On the basis of these results, by using the taxonomy provided by the D-BEST model, a further analysis can be made with the aim of analysing the information retrieved from the S3 platform about the offer of the DIHs in Europe. However, in performing this activity, the problem of language could arise when the DIH websites must be explored (as regional entities). In addition, it seems that a huge number of the DIHs on S3 no longer existed or had been merged with other organisations. Therefore, a platform governance mechanism should be introduced to update the information that could be found on S3.

Discussion

The main aim of the D-BEST model is to aid the DIH services portfolio configuration to be catered to bolster companies in employing digital technologies, gathered under the concept of Industry 4.0. The model can also iteratively model of Collaborative Networks 4.0, in which DIHs, being knowledge brokers and sources, are strategic players with strong opportunities for triggering generalisation, flexibility, and interoperability in DIH ecosystems (Sushil, 2017). The model can also be exploited to categorise DIHs extant services, detecting redundancies and lacks; to define new services (to-be) to be offered in the future; and to recognise chances for cooperation of three types (joint provision, joint development, and joint matchmaking) among DIHs and their stakeholders to be materialised in a pan-European DIH (Sassanelli et al., 2020a).

To provide evidence of the theoretical and practical relevance of the D-BEST model, the main scope of the project for which it was developed (DIH4CPS) must be recalled. DIH4CPS is a project funded by the EC to strengthen a pan-European DIH network, synchronising the heterogeneous smart specialisations of its poles. Each of these poles are DIHs acting at a regional/national level with their stakeholders and it could happen that the services that each of them is able to provide are actually delivered by its users. Nevertheless, the pole either is the owner of the dissemination and communication of the service, of the creation of the audience, of its selling, or develop a new service together with the user (under a cross-fertilisation fashion). The DIH4CPS network has to supervise these dynamics, detecting redundancies, market rivalries, and lacks to be filled owing to the use of the D-BEST reference model. Indeed, as reported in the recent draft by the EC (European Commission, 2020b), the services of the DIHs should be complementary and not redundant to commercial services. Considering especially the macro-class ecosystem of the D-BEST model and the 'innovation ecosystem and networking' DIH function suggested by the EC in the draft, we must consider that a hub works also as a broker and matchmaker between the needs of certain users and potential providers (Bandera & Thomas, 2019). Providers can be involved in the 'test before invest' or 'skills and training' functions and hence offer technology, skills, data, and business services. Hubs may prefer to local SMEs as providers and, if these are not available, to other European SMEs, according to their procurement rules, and equal opportunities must be granted to all potential providers. These companies do not require to belong to the network of DIHs but could be involved through subcontracting.

Finally, concerning the S3 platform governance and maintenance issue raised in the previous sub-section, a solution could be to propose a new unified digital platform structured based on the D-BEST reference model. If the different digital platforms [proposed by the different IA projects funded by the EC, e.g. DIH4CPS, HUBCAP project (2020), AI REGIO project (2021), DIH4AI project (2021), and DIH4INDUSTRY (2021), and populated in the recent years with current and updated information regarding the offers of DIHs constituting their networks] will be unified and integrated in a unique platform, integrability and flexibility among the different networks, and industrial and technological domains will be easily ensured owing to their common grounding structure (i.e. the D-BEST model). In this way, interoperability among the different DIH networks can favour the creation of multiple communications and collaborations among the several stakeholders belonging to the DIH ecosystems, fostering exchange and development of joint services. These conclusions pave the way for defining future activities to exploit the model as a catalyst of collaborations among the different DIH networks.

Conclusions

In this paper, the D-BEST reference model was proposed and tested to configure the service portfolio of the DIH4CPS project network and its single DIHs (DIH4CPS project, 2020). The model has the main objective of aiding the DIHs service portfolio configuration to bolster companies in adopting digital technologies, gathered under the Industry 4.0 domain, and of modelling Collaborative Networks 4.0, in which DIHs, being knowledge brokers and sources.

A system development-based research methodology, flanked by interactive and interpretative research streams, was used. A strategic role was played by the twofold survey run in the DIH4CPS network (through both top-down and bottom-up approaches). Through these, the model was validated, and the service portfolio of the network was configured. Through the survey built, conducted, and presented in this paper, an inner limitation of the model was overcome; thus, the survey offered a mechanism to allow its sustainable evolution. The survey can further improve the model over time with its twofold approach (i.e. receiving input from both the service providers and customers and allowing the possibility of verifying that over time, service demands and offers become consistent with the ecosystems of the DIHs instantiated). Concerning this, the DIH4CPS digital platform, grounded on an ontology developed to map the DIH network and gather and categorise its assets based on the D-BEST taxonomy, can further support its sustainable evolution, providing a flexible interface to use and instantiate the model.

A limitation of this paper was addressed through the theoretical comparison of the D-BEST and AIOTIDIHN models and the set of services of the S3 platform tool. Concerning this point, a strong compatibility was observed between the D-BEST reference model and the classes proposed in both the IoT domain and the more generic S3 tool of the EC. In this paper, only the results from the application of the D-BEST reference model in the DIH4CPS network are presented, limiting the application of its results to the CPES domain, which is one of the four main areas proposed by the SAE. However, the model is also currently applied in other networks of DIHs (e.g. HUBCAP in the CPES domain, AI REGIO and DIH4AI in the artificial intelligence domain, and REACH incubator for data-fuelled start-ups and SMEs). This concurrently provides evidence of the opportunity to extend its use to all the four technological areas.

As an inner limitation of the D-BEST model, the survey interviewees highlighted that the use of the model was often time-consuming for DIHs because of the uncertainties faced by managers in deciding to which dimension a given service should be allocated in its taxonomy. At the same time, it is good for DIH managers to have a wide set of possible services to use to recognise the actual offer of their DIHs or to try to develop customer journeys and service pipeline. Finally, on the basis of the D-BEST model, several future research activities can be conducted.

Further validation of the model both inside and outside the DIH4CPS constituency should be performed, extrapolating best practices and lessons learned for public recommendations. The survey conducted inside the DIH4CPS network will be run several times in the future to configure the service portfolios of the next incomers of the network through open calls and assess the evolution of the service portfolio of the extended network over time. The survey is currently used in different projects (e.g. HUBCAP, REACH, and AI REGIO), and different DIHs belonging to other technological domains could be instantiated.

The D-BEST model can be used to further support the DIH action, building the typical paths of the DIH customers, detecting collaboration among different DIHs, and building the service pipeline of DIH portfolios. This can be reached by extensively applying the D-BEST-based DIH customer journey analysis method already adopted in the DIH4CPS network (Sassanelli et al., 2021) and in the other DIH networks.

A set of performance indicators to measure collaboration effectiveness in the network of DIHs can be developed through a combination of the D-BEST model with the ECOGRAI method (Vallespir et al., 1999), also creating a basis for developing an award system in the DIH networks to foster collaboration in supporting SMEs.

A detailed analysis of the relationship between the list of services constituting the D-BEST model and the value proposition they are supposed to deliver for each stakeholder involved in the DIH network analysed (particularly the DIH4CPS network) is being conducted. This grounds the analysis under a sustainability perspective of the relationship between the services that compose the D-BEST model and the specific benefits they will provide to the different stakeholders of the network. For this purpose, by using the business model (BM) canvas template, a BM tool is also being developed in the AI REGIO project to define the DIH BM and explore how each of the nine blocks of the BM canvas can be supported by the services listed in the D-BEST model.

Finally, the platforms developed to showcase and sell the assets of the DIHs should be integrated to ensure flexibility and interoperability among networks, industries, and technological domains. Under this scope, the role of the D-BEST model should be investigated. The easiest way could be to connect DIH network platforms to a unified Application Programming Interface (API). However, as the DIH4CPS platform is built on an ontology based on the D-BEST taxonomy, it appears to be the most promising to be linked or extended to the new assets belonging to the dimensions of the macro-classes introduced with the other projects (i.e. Remote, and Legal and Ethics) and to support synergies among different DIH networks in a flexible and interoperable way.

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Declarations

Conflict of interest The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Ethical Approval This study used secondary data and did not involve any human or animal subjects.

References

AI REGIO project. (2021). Available at: https://www.airegio-project.eu/ (Accessed: 14 January 2022).

AIOTIDIHN (2019) *Mission and Activities of IoT Digital Innovation Hubs Network*. Available at: https://aioti.eu/wp-content/uploads/2019/10/AIOTI-WG2-White-Paper-DIH-Network-Activities-Published.pdf.

Angeles, A., Perez-Encinas, A., & Villanueva, C. E. (2022). Characterizing organizational lifecycle through strategic and structural flexibility: Insights from MSMEs in Mexico. *Global Journal of Flexible Systems Management*, *23*(2), 271–290.

Appolloni, A., et al. (2022). Green recovery in the mature manufacturing industry: The role of the green-circular premium and sustainability certification in innovative efforts. *Ecological Economics, 193*, 107311. https://doi.org/10.1016/J.ECOLECON.2021.107311.

Asplund, F., Macedo, H. D., & Sassanelli, C. (2021). Problematizing the service portfolio of digital innovation hubs. *Proceedings of the PRO-VE, 2021*, 1–9. https://doi.org/10.1007/978-3-030-85969-5_40.

Badicu, A. et al. (2021). Deploying the smart energy tool for investment simulation inside the HUBCAP Sandbox. In *Proceedings of the 9th international workshop on simulation for energy, sustainable development & environment (SESDE 2021)*, pp. 18–26. doi: https://doi.org/10.46354/i3m.2021.sesde.003.

Bandera, C., & Thomas, E. (2019). The role of innovation ecosystems and social capital in startup survival. *IEEE Transactions on Engineering Management, 66*(4), 542–551. https://doi.org/10.1109/TEM.2018.2859162.

Blessing, L., & Chakrabarti, A. (2009). *DRM, a design research methodology*. London: Springer. https://doi.org/10.1007/978-1-84882-587-1.

Butter, M. et al. (2019). Digital innovation hubs and their position in the European, national and regional innovation ecosystems. In *Redesigning organizations: Concepts for the connected society*. Springer International Publishing, pp. 45–60. doi: https://doi.org/10.1007/978-3-030-27957-8_3.

De Carolis, A. et al. (2017). Guiding manufacturing companies towards digitalization. In *23rd ICE/IEEE international technology management conference*, pp. 503–512. doi: https://doi.org/10.1109/ICE.2017.8279925.

Crupi, A., et al. (2020). The digital transformation of SMEs – a new knowledge broker called the digital innovation hub. *Journal of Knowledge Management, 24*(6), 1263–1288. https://doi.org/10.1108/JKM-11-2019-0623.

DIH4AI project (2021). Available at: https://dih4ai-portal.eu/ (Accessed: 1 March 2022).

DIH4CPS project. (2020). Available at: http://dih4cps.eu/ (Accessed: 9 May 2020).

DIH4INDUSTRY. (2021). Available at: https://dih4industry.eu/welcome/ (Accessed: 1 March 2022).

DIHNET.eu (2020). Available at: https://dihnet.eu/ (Accessed: 30 July 2020).

Dwivedi, A., et al. (2021). Addressing the challenges to sustainable initiatives in value chain flexibility: Implications for sustainable development goals. *Global Journal of Flexible Systems Management, 22*, 179–197. https://doi.org/10.1007/s40171-021-00288-4.

EFFRA. (2015). *XS2I4MS Access to I4MS, EFFRA Innovation Portal*. Available at: https://portal.effra.eu/project/1547 (Accessed: 18 December 2020).

Ellström, P.-E. (2007). Knowledge creation through interactive research: A learning perspective. In *HSS–07 Conference*, pp. 1–12.

European Commission (2016) *Digitising European Industry. Reaping the full benefits of a Digital Single Market*. Available at: https://ec.europa.eu/digital-single-market/en/news/communication-digitising-european-industry-reaping-full-benefits-digital-single-market (Accessed: 4 February 2020).

European Commission. (2018a). *Digital innovation hubs in smart specialisation strategies. Early lessons from European regions*. https://doi.org/10.2760/475335.

European Commission. (2018b). *Smart anything everywhere - digital innovation hubs - accelerators for the broad digital transformation of the European industry*. Available at: https://ec.europa.eu/digital-single-market/en/news/communication-digitising-european-industry-reaping-full-benefits-digital-single-market (Accessed: 4 February 2020).

European Commission. (2020a). *Digital Innovation Hubs - Smart Specialisation Platform*. Available at: https://s3platform.jrc.ec.europa.eu/digital-innovation-hubs-tool (Accessed: 25 November 2020).

European Commission (2020b). *European digital innovation hubs in digital europe programme - draft working document*.

HUBCAP project (2020). Available at: https://www.hubcap.eu/ (Accessed: 14 January 2022).

I4MS (2020). Available at: https://i4ms.eu/about (Accessed: 6 May 2020).

Kak, A., & Sushil, H. (2002). Sustainable competitive advantage with core competence: A review. *Global Journal of Flexible Systems Management, 3*(4), 23–38.

Larsen, P. G. et al. (2020). A cloud-*based collaboration platform for model-based design of cyber-physical systems*. Available at: https://orcid.org/0000-0001-7041-1807 (Accessed: 12 November 2020).

Macedo, H. D. et al. (2021). Facilitating model-based design of cyber-manufacturing systems. In *54th CIRP CMS 2021 - towards digitalized manufacturing 4.0*. https://doi.org/10.1016/j.procir.2021.11.327.

McDermott, C. M., Kang, H., & Walsh, S. (2001). A framework for technology management in services. *IEEE Transactions on Engineering Management, 48*(3), 333–341. https://doi.org/10.1109/17.946532.

Nunamaker Jr., J. F. and Chen, M. (1990). Systems development in information systems research, *System Sciences, 1990., Proceedings of the twenty-third annual Hawaii international conference on*, 3, pp. 631–640. doi: https://doi.org/10.1109/HICSS.1990.205401.

Pezzotta, G., et al. (2018). The product service system lean design methodology (PSSLDM): Integrating product and service components along the whole PSS Lifecycle. *Journal of Manufacturing Technology Management, 48*(2), 1270–1295. https://doi.org/10.1108/JMTM-06-2017-0132.

Potts, C. (1993). Software-engineering research revisited. *IEEE Software, 10*(5), 19–28. https://doi.org/10.1109/52.232392.

Rosa, P., et al. (2020). Assessing relations between Circular Economy and Industry 4.0: A systematic literature review. *International Journal of Production Research, 58*(6), 1662–1687. https://doi.org/10.1080/00207543.2019.1680896.

Sassanelli, C., et al. (2019). The PSS design GuRu methodology: Guidelines and rules generation to enhance product service systems (PSS) detailed design. *Journal of Design Research, 17*(2/3/4), 125–162. https://doi.org/10.1504/JDR.2019.105756.

Sassanelli, C. et al. (2020a). Towards a reference model for configuring services portfolio of Digital innovation hubs: the ETBSD model. In Camarinha-Matos, L. M. (ed.) *IFIP International federation for information processing 2020a, PRO-VE 2020a, IFIP AICT 598*. Valencia (Virtual), Spain: Springer Nature Switzerland AG 2020a, pp. 597–607. doi: https://doi.org/10.1007/978-3-030-62412-5_49.

Sassanelli, C. et al. (2021). Digital Innovation Hubs supporting SMEs digital transformation. In *27th ICE/IEEE international technology management conference, Jun 2021*. Cardiff, United Kingdom: IEEE, pp. 1–8. https://doi.org/10.1109/ICE/ITMC52061.2021.9570273.

Sassanelli, C., Gusmeroli, S. and Terzi, S. (2021). The D-BEST based digital Innovation Hub customer journeys analysis method: A pilot case. In *IFIP international federation for information processing 2021, PRO-VE 2021, IFIP AICT 598*. https://doi.org/10.1007/978-3-030-85969-5_43.

Sassanelli, C., Rossi, M., & Terzi, S. (2020b). Evaluating the smart maturity of manufacturing companies along the product development process to set a PLM project roadmap. *International Journal of Product Lifecycle Management, 12*(3), 185–209. https://doi.org/10.1504/IJPLM.2020.109789.

Schepers, T. G. J., Iacob, M. E. and Van Eck, P. A. T. (2008). A lifecycle approach to SOA governance. In *Proceedings of the ACM symposium on applied computing*. New York, New York, USA: ACM Press, pp. 1055–1061. https://doi.org/10.1145/1363686.1363932.

Semeraro, C. et al. (2021). Interoperability Maturity Assessment of the Digital Innovation Hubs. In *2nd international conference on innovative intelligent industrial production and logistics, INSTICCC, Oct 2021, La Valetta, Malta. hal-03404226*. Available at: https://hal.archives-ouvertes.fr/hal-03404226 (Accessed: 28 October 2021).

Sharma, O. P., & Sushil, P. (2002). Issues in managing manufacturing flexibility: A review. *Global Journal of Flexible Systems Management, 3*(2–3), 11–29.

Shukla, S. K., & Sharma, M. K. (2019). Managerial paradox toward flexibility: Emergent views using thematic analysis of literature. *Global Journal of Flexible Systems Management, 20*(4), 349–370. https://doi.org/10.1007/S40171-019-00220-X.

Singh, S., Dhir, S., Evans, S., & Sushil. (2021). The trajectory of two decades of global journal of flexible systems management and flexibility research: A bibliometric analysis. *Global Journal of Flexible Systems Management*, *22*(4), 377–401.

Singh, N. and Sushil (2004). Flexibility in product development for success in dynamic market environment. *Global Journal of Flexible Systems Management*, *5*(1), 1–13.

Sushil, S. (2015). Creating flexibility through technological and attitudinal change. *Global Journal of Flexible Systems Management*. https://doi.org/10.1007/s40171-015-0112-2.

Sushil, S. (2016). Strategic flexibility in ecosystem. *Global Journal of Flexible Systems Management, 17*(3), 247–248. https://doi.org/10.1007/S40171-016-0138-0.

Sushil, S. (2017). Flexible systems management as an iterative process. *Global Journal of Flexible Systems Management, 18*(2), 87–88. https://doi.org/10.1007/S40171-016-0145-1.

Svensson, L., Ellström, P.-E., & Brulin, G. (2007). Introduction - on interactive research. *International Journal of Action Research, 3*(3), 233–249.

Vallespir, B., Ducq, Y., & Doumeingts, G. (1999). Enterprise modelling and performance - Part 1: Implementation of performance indicators. *International Journal of Business Performance Management, 1*(2), 134–153. https://doi.org/10.1504/IJBPM.1999.004434.

Weiß, G. B. et al. (2021). Manufacturing process simulation in a hybrid cloud setup. In *2nd international conference on innovative intelligent industrial production and logistics, INSTICCC, Oct 2021, La Valetta, Malta. hal-03404226*. https://doi.org/10.5220/0010641700003062.

Williamson, K. (2002). *Research methods for students, academics and professionals*. Wagga Wagga: Quick Print.

World Economic Forum (2016). *Digital transformation of industries. Demystifying digital and securing $100 trillion for society and industry by 2025*. https://doi.org/10.1504/IJBPM.1999.004434.

Zamiri, M. et al. (2021). Towards a conceptual framework for developing sustainable digital innovation hubs. In *27th ICE/IEEE international technology management conference, Jun 2021*. IEEE, pp. 1–7. doi: https://doi.org/10.1109/ICE/ITMC52061.2021.9570120.

Key Questions

1. Can the D-BEST model support Digital Innovation Hubs (DIHs) to configure their service portfolios in a flexible and interoperable way?
2. How DIH assets (services, competences, skills, technologies) belonging to different DIHs networks could be integrated on digital platforms to support flexibility and interoperability?
3. Is flexibility and interoperability really important to reach DIH networks sustainability?

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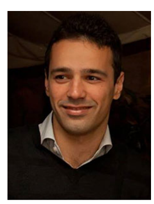

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