AIOTI Testbed Methodology

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AIOTI Testbeds Group

Executive Summary

This report presents a methodology for the collection, curation, assessment and dissemination of testbeds within AIOTI.

A testbed is defined as a platform (hardware and / or software) implemented on a trial basis in order to explore and evaluate a set of technologies as a solution to a set of use cases, business challenges and / or domain-specific needs.

The report provides a structured approach and strategic narrative to AIOTI members and other external-to-AIOTI stakeholders on the topic of IoT and Edge computing testbeds to support the vision of AIOTI.

The methodology endeavours to fulfil the following aims:

1. Collate, categorise and manage information on testbeds operating amongst the AIOTI members;
2. Capture important learnings and results from each of these testbeds;
3. Identify key rationale for testbed deployment; such as real-world proving of technologies, use cases and business improvement, along with co-existence and interoperability requirements;
4. Identify emerging technologies and market verticals / application domains for AIOTI where testbed proving is deemed strategically necessary;
5. Report on testbed performance and identified/document best practices;
6. Report on potential gaps between important testbeds identified (in 3 and 4 above) and those already existing (1 and 2 above) and propose new or augmented testbeds as appropriate.

In developing this methodology several related and pre-existing testbed activities have been considered from the EU Living Labs initiative, the IEEE Future Networks Testbeds Working Group, the EU Fed4Fire initiative and the Industrial Internet Consortium (IIC).

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1. Introduction

Testbeds can be considered as implementation platforms that are applied to explore, create, implement, and evaluate: use cases, business challenges, domain-specific topics, technology challenges, technology improvement by integration of add-on features and promotion.

The main objective of this report is to provide guidelines to AIOTI members and overall AIOTI stakeholders on the AIOTI Testbed methodology. AIOTI members can use this methodology to explore, create, implement, and evaluate testbeds. The steps of this AIOTI testbed methodology are:

- Strategic considerations and stakeholder requirements;
- Collection of existing testbeds;
- Select testbed, supporters and define process;
- Testbed pre-piloting (Exploring);
- Testbed piloting (Create, Implement, Evaluate).

2. Terminology

Testbed
: A platform (hardware and / or software) implemented on a trial basis in order to explore and evaluate a set of technologies as a solution to a set of use cases, business challenges and / or domain-specific needs.

Solution-centric (testbed results)
: Addressing real-world use cases and related business goals.

Horizontal (testbed results)
: Addressing process (development, deployment, best practice) aspects and technology challenges (readiness, integration, performance).

Pre-piloting (Testbeds)
: Exploring the adequacy and feasibility of a technology applied in-field to specific use cases and markets.

Piloting (Testbeds)
: Implementing and evaluating a solution from the perspective of business case and operational viability to understand the benefits vs costs, risks and potential operational disruption. The outcome enables a decision on whether to develop a fully operational solution beyond the pilot stage.

Digitalization
: The application of digital technologies (specifically ICT) to transform existing business processes and models into new forms, enabling new business opportunities, greater levels of efficiency or deeper insights into business operation.

Edge (compute)

Edge computing is a distributed computing paradigm that brings computation and data storage closer to the sources of data, in the geographically diverse field of device operations. Typically, to improve response times, network bandwidth usage and data privacy / security.

Cloud (compute)

Cloud computing is a distributed computing paradigm where on-demand availability of computer system resources, especially data storage (cloud storage) and computing power is provided (without direct management by the user) from a centralised source location (data centre). The sharing of centralised resources achieves economies of scale and can deliver significant performance capabilities.

Internet of Things (IoT)

The creation of an interconnected network of physical objects (devices), each embedded with one or more of: sensors, compute processing ability, software, and other technologies. The subsequent network of devices then enables devices to exchange data with each other and other systems over the Internet or other such communications networks. The ultimate goal of this is to enable remote monitoring, diagnostics, automation, big data gathering and analytics.

Distributed Ledger Technologies (DLT)

DLT refers to the digital infrastructure (software, communications and cryptography) and protocols allowing simultaneous access, validation, and record updating in an immutable manner across a network that's spread across multiple entities or locations. A DLT protocol (of which there are many) enables the secure functioning of a decentralized digital database which eliminates the need for a central authority to keep a check against manipulation.

3. Related testbed methodologies

In developing a methodology for the AIOTI Testbeds group, we considered two closely related and pre-existing testbed activities from the Industrial Internet Consortium (IIC) (https://www.iiconsortium.org/) and the EU Living Labs initiative (https://enoll.org/).

3.1 Living Lab methodology

Living labs has several definitions, see [Live Lab U4IoT]. A key one is that a Living Lab is a multi-stakeholder organization initiated to work on innovation projects that follow the principles of open and user innovations and focus on real-life experimentation.

Figure 1 shows the common elements that are central to the Living Labs methodology, which are:

- Multi-method approaches, where different user-centred methodologies are combined and customized in order to best fit their purpose;
- User engagement: involve users already at the beginning of the process;
- Multi-stakeholder participation: refers to the need of participation of all stakeholders needed in the value chain, such as representatives of public and private sector, academia and citizens;
- Real-life setting: activities take place in real-life settings to get thorough insights on the insights;
- Co-creation: strive for mutually valued contributions from all stakeholders being actively engaged in the process from the beginning.

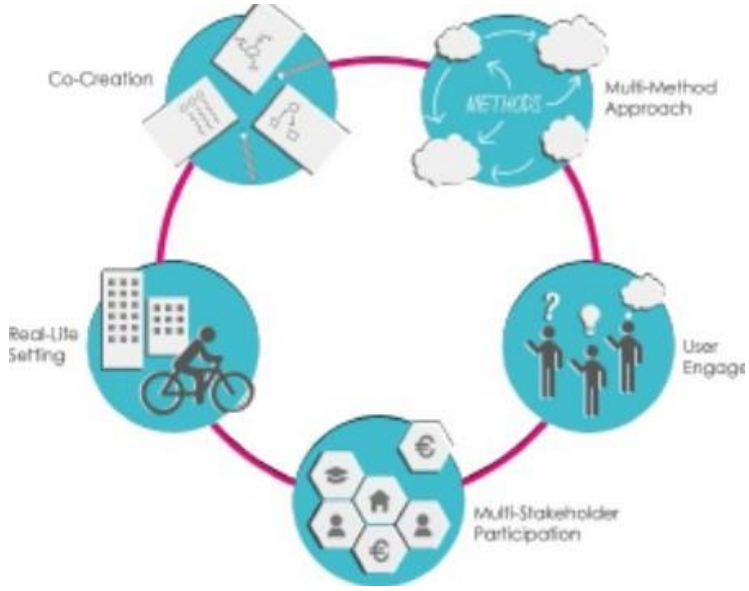

Figure 1: Living labs Common Elements of Living Labs, from [Live Lab U4IoT]

Figure 2 shows the four Living Labs testbed phases, see [Live_Lab_SmartIES] which are:

1) Planning: In this phase the testbed planning takes place, where it is important to gain as much information as possible about the underlying circumstances for the project;

2) Concept design: This phase focus on the collections of opportunities and on generating the basic needs that different stakeholders have of the product or service;

3) Prototype design: This phase starts with the process of identifying the needs of stakeholders the innovation, e.g., what needs are then important for the users? One way of doing this is to keep the concept design, with the key needs related to it, visible for the users during the data collection activities. Moreover, in this phase the design of the innovation broadens to include basic functions, workflows, and interfaces;

4) Innovation design: This phase is analysing results from the usability evaluation in order to generate changes in the needs of and in the innovation. Note that small changes and adjustments in the needs are quite common, especially in relation to the needs in the innovation, as it develops and users' understanding of structure, content, workflow, and interface, is significantly increasing;

5) Commercialisation: This phase can be viewed as a go to market activity, in which the aim is to introduce the innovation to a potential buyer and assess its potential on the market.

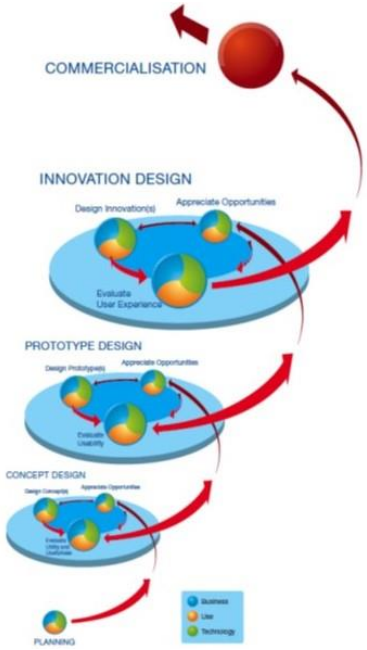

Figure 2: Living labs testbed process, from [Live_Lab_SmartIES]

In each Living lab phase or cycle, shown in Figure 2, four stages are carried out, see Figure 3:

1) Explore: needs, values, dreams and ideas are explored;

2) Co-create: concepts, prototypes and innovations are co-created, designed and developed;

3) Implement: concepts, prototypes and innovations are implemented and tested in real world context;

4) Evaluate: concepts, prototypes and innovations are evaluated with a formative approach and looking for ways to improve that.

Figure 3: Living Lab Stages, from [Live_Lab_U4IoT]

Living Lab testbed activities follow five key principles that provide the foundation for design of Living Lab operations. These principles should be supported by all operations that provide the foundation for design of Living Lab operations. The principles can be used to differentiate between Living Labs and non-Living Labs and also on how the Living Lab value can be assessed.

The five Key Principles are depicted in Figure 4 and are:

a) Value: Providing a superior value for customers and users is a key aspect for business success;

b) Influence: One key aspect of the influence principle is to view users as active, competent partners and domain experts;

c) Sustainability: Creating a sustainable environment includes economical, ecological and social aspects, which makes it a complex and multifaceted task;

d) Openness: Current innovation landscape has changed, where many companies open up their innovation processes since innovation stakeholders have become more mobile, venture capital more abundant, and knowledge more widely dispersed across different types of organisations;

e) Realism: One of the key aspects of the Living Lab approach is that innovation activities should be carried out in a realistic, natural, real-life setting.

Figure 4: Living Lab Key Principles, from [Live_Lab_SmartIES]

3.2 IEEE Future Networks Testbeds Methodology

The IEEE Future Networks Testbeds Working Group has been established to assist the IEEE community with strong support for measurement and calibration capabilities of testbeds; develop best practices and testing standards.

It is currently developing the development of future testbed requirements, by cooperating with the vendor and research community, based on existing testbeds. Their methodology covers the following steps:

- Analyse vendor and research community requirements;
- Collect information on existing testbeds, serving as a facilitator to set a testbed federation within the IEEE community.

Disseminate, e.g., via venues, testbeds under different stages (use-case scenarios, trials, proof-of-concept deployments):

- Create the IEEE Federation of Future Networks testbeds, comprising advanced research, experimentation and evaluation.

The IG has proposed a vision for the next 10 years, with specific short, mid and long-term goals:

- Short-term (3 years): Develop a bank of data sets from each of the participating testbed and pilot roll-out programs regarding technical challenges and relevant statistics, serving as facilitator of data, testbeds and other information to the overall community;
- Mid-term (5 years): Work with other entities and IEEE WGs, to integrate stakeholders requirements and KPIs, towards a next generation (beyond 5G/6G) of testbeds;

- Long-term (10 years): develop novel testbed federations beyond 5G/6G with the aim of influencing a next generation of network architectures.

The IG interacts with the following stakeholders:

- Equipment Vendors—one of the main objectives for equipment vendors to participate in testbed construction and operations is to satisfy the requirement to show interoperability at the neutral "playgrounds," especially before the formal standardization. Another objective is to enable collaboration of testbed operators with the equipment vendors and supplier community especially in what concerns the support of logistics, equipment and other resources;
- Network Operators —Agile development cycles drive the need for scaled experimentation in order to evaluate technologies;
- Standardization Bodies — in order to accommodate key requirements and to allow testbeds to be evaluated and compared;
- Academia/Research—supporting novel ideas in a way that is integrated with real-world problems;
- Local/National Governments —Evaluation of societal benefits (that impact regulatory decisions);
- Military—Requires platform for dual-use technology evaluation;
- Open-source Communities —Have a significant interest to increase the participation base by adoption of common development grounds. Given the nature of this community, they also have significant interest to develop features and capabilities.

3.3 Fed4FIRE - the Largest Federation of Testbeds in Europe

Fed4FIRE[1] is the largest European Federation of Experimental facilities and testbeds In Europe, providing access to varied testbed and living labs environments in Europe, remotely and locally.

The main idea behind the Fed4FIRE Federation of testbeds is to enable easy and efficient usage of already available experimental resources by the entire research and innovation community in broad area of Future Internet and Communications Technologies (ICT) as well as various vertical application sectors applying the ICT, such as Energy, Health, Automotive, Transport, Media, etc. To ensure it, the Fed4FIRE project worked on establishing the federation of testbed for benefit of both testbed providers and experimenters by taking into consideration their particular requirements and interests.

In order to meet the mentioned requirements, the future experimental facilities have to ensure the following:

[1] https://www.fed4fire.eu/

- Simple, efficient, and cost-effective experimental processes considering requirements and constraints of both experimenters and facility owners;
- Common frameworks that will be widely adopted by different experimentation facilities and used by different experimenter communities;
- Increased trustworthiness and efficiency of the experimental facilities, including a sustainable environment for the needed testbeds continuously ensuring their updates in accordance with actual experimenters needs.

3.4 Industrial Internet Consortium (IIC) Testbed Methodology

This Section provides a brief overview of the IIC testbed methodology, based on [IIC-TB-Method-2020], which is used as one of the key references in the process of developing the AIOTI Testbed Methodology.

Figure 5 depicts two dimensions used by IIC to categorize testbed results, IN (1) Solution-centric testbed results and (2) horizontal testbed results.

The Solution-centric results are the ones that drive the testbed project and address the business goals, while the Horizontal testbed results focus more on the Industrial IoT development and deployment process of the testbed project. Examples of results for each of these two testbed results dimensions are listed in [IIC-TB-Method-2020]. Note that these two testbed results dimensions are not disjoint. As can be seen in Figure 5, at their intersection the testbed learnings are about deploying technologies that are common across IIoT testbed and applications, where their deployment depends on challenges that are usually specific to each testbed.

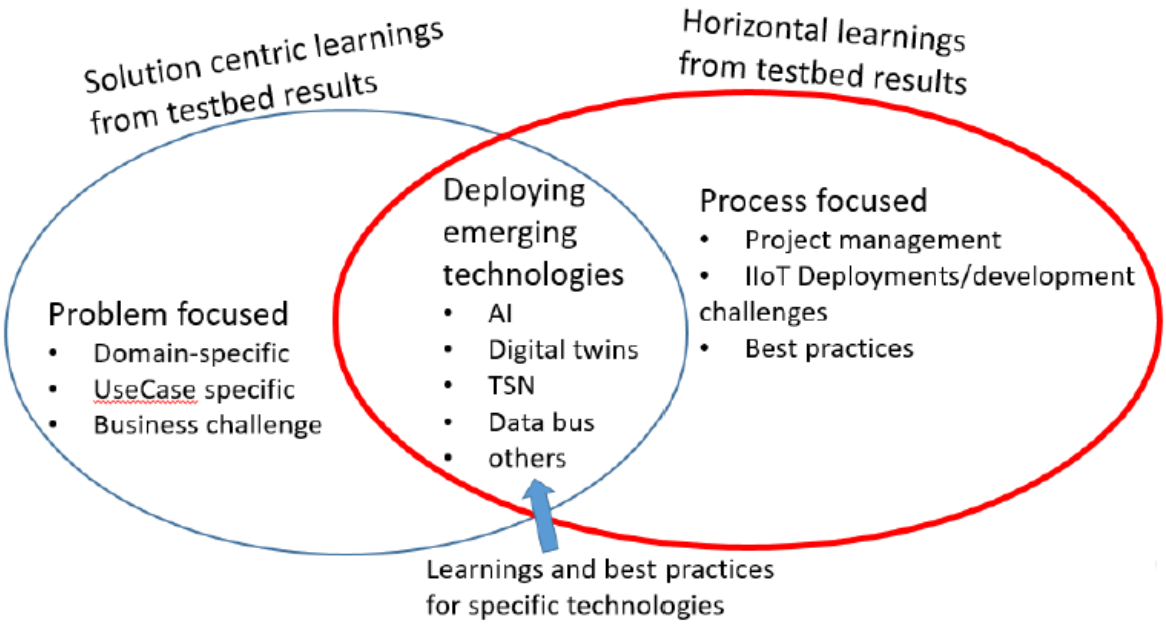

Figure 5: Solution-centric and horizontal testbed results, from [IIC-TB-Method-2020]

Figure 6 provides a brief overview of the IIC's testbed process, which comprises three phases:

1) Pre-pilot phase that evaluates the technology and adequacy and feasibility of how to apply a technology in the field. Usually, the following questions need to be answered during this phase:

    - How feasible and appropriate is the applied IoT technology on solving the problem, within its operational constraints?
    - What are the operational Issues In the process of deploying a particular technology?
    - How a particular solution be managed in the long-term?

2) Pilot-phase that (1) evaluates a solution from business viewpoint and assess its operational viability, as for example being part of a go-to-market strategy and (2) validates the solution design and viability production conditions, (3) enables understanding of the costs, risks and potential operational disruption focusing on whether developing a fully operational or business solution beyond the pilot will bring the expected value or improvement;

3) Testbed in-production phase, where the testbed is being deployed and operated in order to provide insights and learnings, coming from positive or negative experiences, and to produce valuable lessons and best practices for starting an IIoT project.

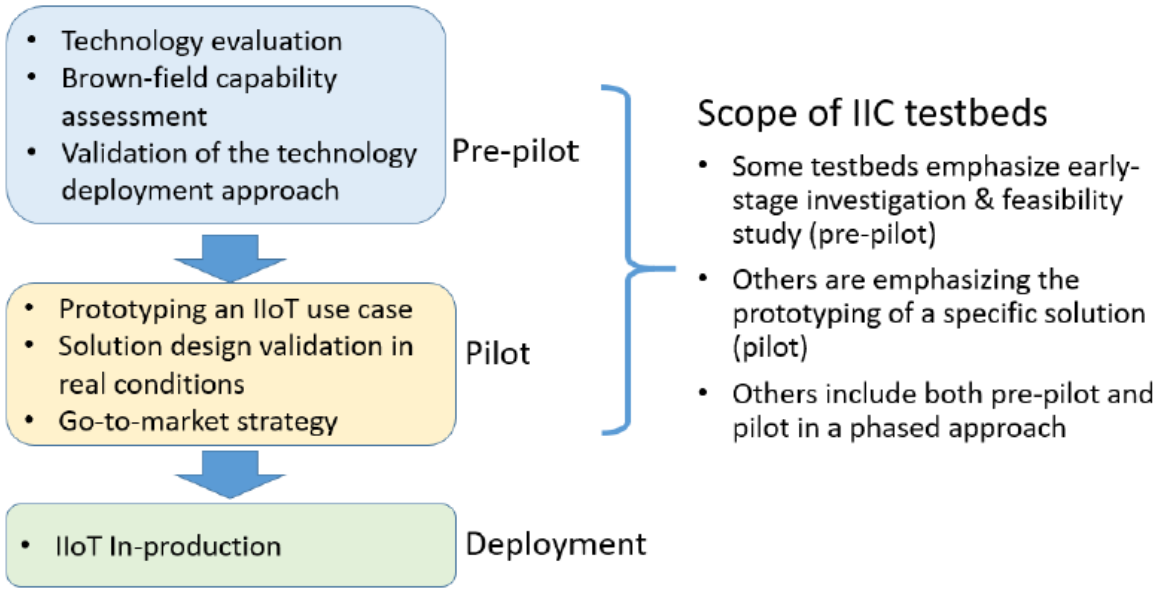

Figure 6: The scope of IIC testbeds, from [IIC-TB-Method-2020]

4. AIOTI Testbed Methodology

The AIOTI Testbeds IG provides an overarching strategy, narrative, and oversight to the topic of IoT and Edge computing testbeds for AIOTI. As such, the IG carries out the following functions and endeavours to fulfil the following aims:

1. Collate, categorise and manage information on testbeds operating amongst the AIOTI members;
2. Capture important learnings and results from each of these testbeds;
3. Identify key rationale for testbed deployment; such as real-world proving of technologies, use cases and business improvement, along with co-existence and interoperability requirements;
4. Identify emerging technologies and market verticals / application domains for AIOTI where testbed proving is deemed strategically necessary;
5. Report on testbed performance and identified/document best practices;
6. Report on potential gaps between important testbeds identified (in 3 and 4 above) and those already existing (1 and 2 above) and propose new or augmented testbeds as appropriate.

The methodology described in this Section enacts these functions and aims to provide a structured process.

The Venn diagram in Figure 7 below - based on the IIC approach - shows two distinct rationales for testbed deployment:

1. To address specific real-world problems; such as in a particular market domain or use-case. Or to create a new business model or add value to or improve a specific business case;
2. To improve or add value to an existing process or validate a new technology prior to further development and / or commercial deployment.

The emerging technologies referred to in point 4 above exist in the intersection between these two rationales, as illustrated in Figure 7 and may be proven through both Solution-centric (real-world use cases) testbeds and Horizontal (Process / technology focused) testbeds.

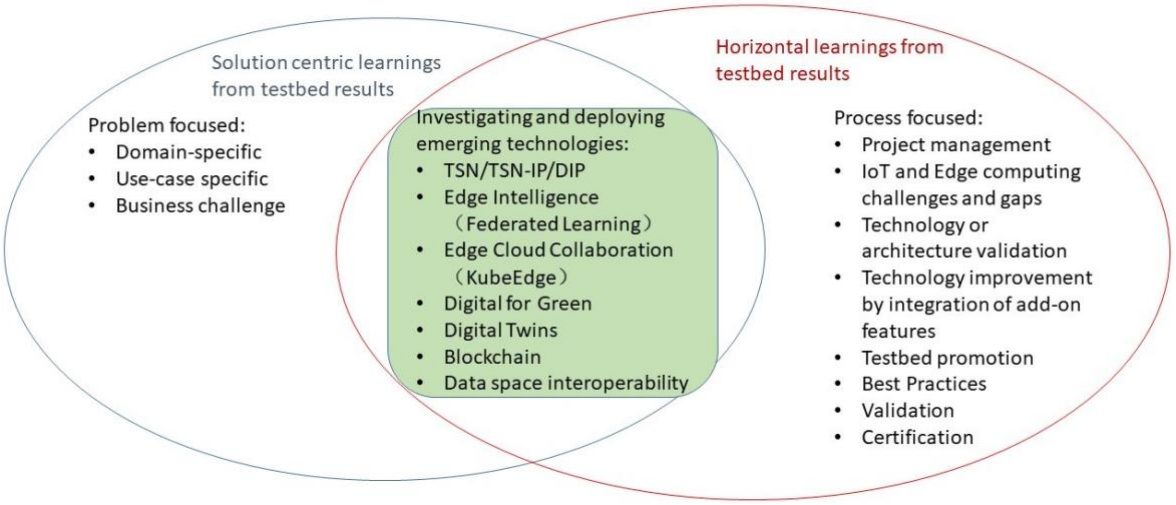

Figure 7: AIOTI Solution-centric testbed results and horizontal testbed results

The Testbed IG methodology consists of five distinct activities as illustrated in the diagram shown in Figure 8.

In common with best practice defined by the Industrial Internet Consortium (IIC) and explained in Section 3.4 above, our methodology described here is a superset of the 3 stages; Pre-Pilot, Pilot and Deployment:

A - Strategic considerations and stakeholder requirements:
A set of agreed strategic requirements and testbed rationale for relevant stakeholders covering both Solution-centric and Horizontal-centric testbeds;

B - Collection of existing testbeds:
Creation of a testbed reference catalogue following the collation and categorisation of existing testbeds operated amongst the AIOTI community. This provides a baseline of relevant testbed activity to build upon going forward;

C - Testbed pre-piloting (Exploring):
By identifying a set of target use cases, market verticals and emerging technologies, we can build a set of testbeds opportunities for feasibility evaluation and further development. These 'pre-pilot' stage testbeds may then feed into existing pilot stage testbeds or be deployed as stand-alone testbeds when ready;

D - Select testbed, supporters and define process:
This step is a major part of our methodology. By considering the strategic requirements and stakeholder testbed rationale defined in A versus the existing testbeds collated in B we aim to select testbeds that satisfy such requirements, whilst identifying worthy pre-pilot testbed opportunities and recommendations for augmented existing testbeds or new testbeds;

Some process definition is also expected to best present our recommendations.

E - Testbed piloting (Create, Implement, Evaluate):
Implementing the outputs from step D takes several forms.

Evaluating the selected testbeds and reporting (internally to AIOTI and externally through promotional dissemination) on their performance against defined metrics is a baseline expectation. However, in this step, we also expect to engage with other AIOTI working groups to discuss recommendations for further testbed activities as discussed in D above. Although the implementation of testbeds is the responsibility of individual organisations in each relevant working group, the Testbeds IG is responsible for providing key recommendations and justifications in support of new testbed activity.

Finally, this activity will also include outreach to other stakeholder organisations such as SDO/Alliance/OSS/GAIA-X.

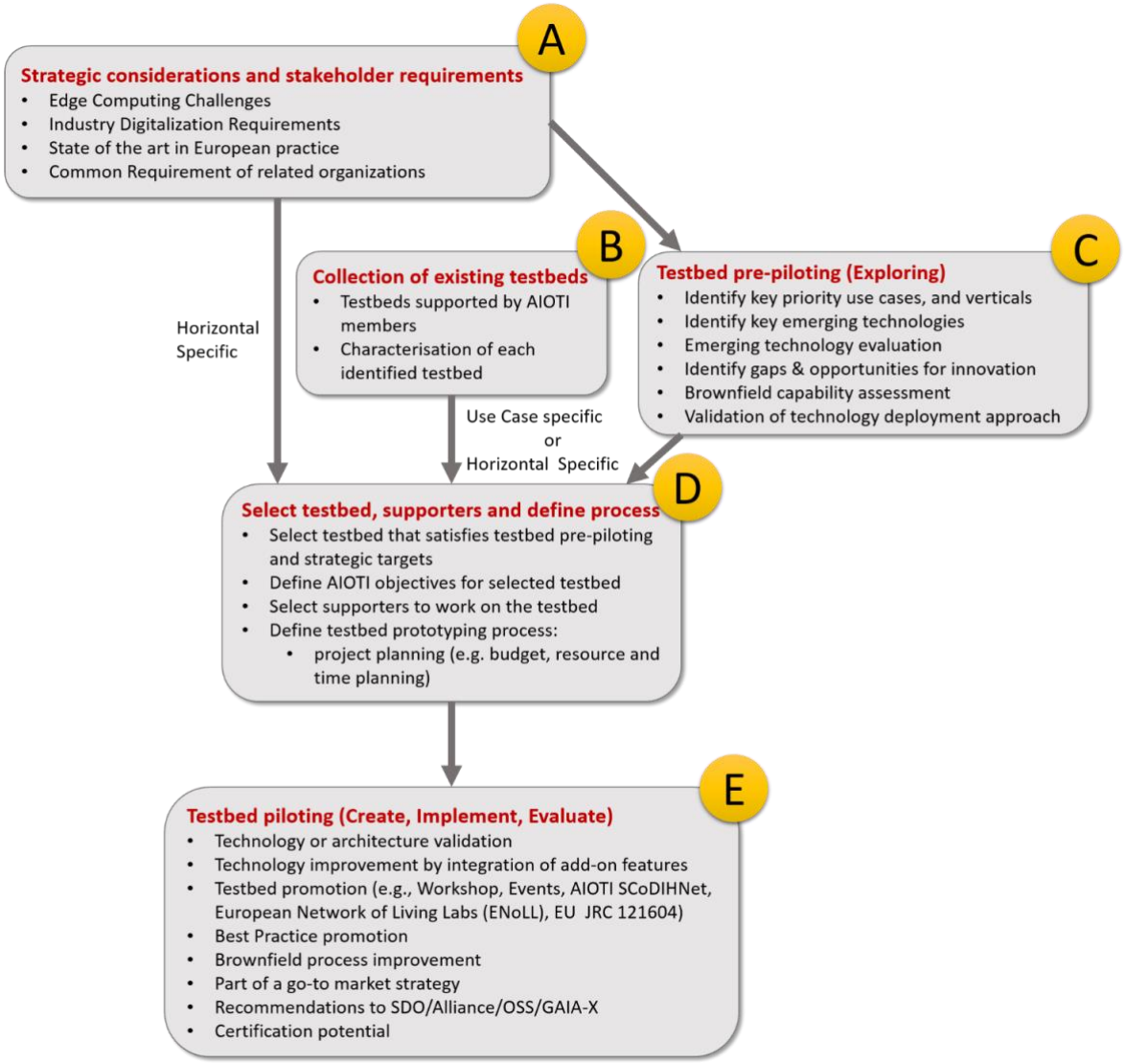

Figure 8: Overview of the AIOTI Testbed methodology

4.1 Strategic Considerations and Alignment with the AIOTI Vision

The Testbeds IG work is based on testbeds (at different stages) owned by members and as such, the members agree to share at least partially their testbed learnings, processes, solutions. The aim of this methodology is to promote and accelerate development of testbeds within the context of AIOTI, based on AIOTI stakeholder solutions and requirements.

4.1.1 Key considerations

For each testbed assessed, the following elements need to be considered:

- Value-proposition and clear use-case definitions aligned with the European competitiveness domains and AIOTI working group objectives. Ensuring that the proposed testbed can bring the broadest value to the AIOTI community and beyond;
- Relevance in the context of the AIOTI vision. The testbed should align with the AIOTI vision, in particular in regards to IoT; Edge computing; sovereignty and interoperability;
- Accessibility and access to AIOTI partners.

4.1.2 Strategic alignment

In assessing such testbeds, the following strategic considerations have been identified within AIOTI, which must be addressed to accelerate the adoption of IoT and Edge computing. These topics are important requirements for all testbed activities:

1. Edge Computing Challenges:

   Such as: Massive distributed computing, Low power / wide area operation, Latency, Security;

2. Industry Digitalization Requirements:

   Impacts such as: New business models, such as PaaS, New process models, such as Digital twins, Domain transformation (Industry re-modelling & blurred boundaries), Enablers such as: Platforms, Middleware, Cross-domain & complimentary technologies;

3. State of the art in European practice:

   Selected testbeds should be aligned with current best practice in Europe. Ideally, they should build on the current state of the art and push boundaries. Some examples of potential areas are: Scalability, Network / device management, Service deployment, Resource monitoring and scheduling, Data integrity, Meta-data, Security, Resilience, Discovery and Self-healing;

4. Common Requirements of related organizations:

   Where possible testbeds should exploit existing conventions or best practice and observe common approaches or requirements adopted by relevant organisations, such as The IoT forum (iotforum.org), Next generation IoT (ngiot.eu), International Data Spaces Association (internationaldataspaces.org), GAIA-X (data-infrastructure.eu) or the European Cyber Security Organisation (ecs-org.eu).

4.1.3 Operational considerations

The AIOTI Testbeds IG aims to create a robust, reliable and well documented range of testbeds, with a forward-looking development of appropriate future testbeds. In order to realise this vision, there is a need to address a few challenges:

- **Automated Testbed collection:** The IG has provided a first catalogue of Testbeds based on surveys disseminated to partners. A specific semantic and Web-based mechanism for collecting information is desirable in future. This could be provided via the AIOTI Website to members, providing an automated way to register new testbeds. This also implies the integration of a semantic description mechanism (that facilitates the registration and categorization of new testbeds);
- **Operation and Components Harmonization:** The overall testbeds activity will benefit from a common platform integration and development mechanism. This requires the identification, by AIOTI stakeholders, of common/core operation elements; guidelines; policies, pre-standardisation aspects to observe. The harmonization is a continuous process that requires best practice guidelines and joint periodic meetings;
- **Benchmarking and KPI definition:** A means to categorise each testbed on a common set of measurement axes is required. This will facilitate the comparison and evaluation of testbeds in Section 4.3;
- **Certification criteria:** It may, at some time be valuable to create a certification activity, where selected testbeds can be identified as having met a specific baseline set of criteria and thus worthy of special notification; an 'AIOTI Certified Testbed'. This concept is only flagged at this stage, but may be revisited in due course;
- **Accessibility:** The broad use of available testbeds requires an integration of different open-source solutions and licensing (to boost Interoperability) and an agile methodology that can boost updates.

4.2 Collection of existing testbeds

During mid-2021, the Testbeds IG created a testbed collection document, asking all partners in AIOTI to contribute with information about the testbeds and demonstrators they have been working on.

The report describes each testbed and includes specific information concerning target use-cases, EU competitiveness domains addressed and whether the testbed is open to other partner access.

The aim of the report is to support the overall methodology described herein and to provide a dissemination vehicle for the testbeds amongst the AIOTI community and beyond.

The Testbed Catalogue is available in online [2]. Specific metadata is described in the document. This catalogue will be further updated and eventually converted into an online tool (see Section 4.1).

[2] https://aioti.eu/wp-content/uploads/2022/02/AIOTI-Testbed-Catalogue-2021-Published.pdf

4.3 Testbed selection, supporters and process definition

In this activity, we categorise and select the testbeds which satisfy both our strategic considerations defined in Section 4.1 and the pre-piloting targets defined in Section 4.4.

This sub-set of the collated testbeds, which align best with the above requirements are to be the subject of our piloting activity in Section 4.5.

For each selected testbed, the IG will assign appropriate objectives and agree a team of supporters to collaborate on the testbed and form a project plan to ensure that the testbed is able to deliver against the objectives and into the piloting stage.

It is understood that the testbed is owned and managed by the existing AIOTI members already involved, however, the Testbeds IG should be responsible for the execution of these selection and piloting activities.

4.4 Testbed pre-piloting (Exploring)

For AIOTI, the testbed pre-piloting consists of two parts:

(Part 1) Identification of the important AIoTI use cases and target verticals, together with relevant emerging technologies which may support these;

(Part 2) Exploration of the feasibility and relevance of candidate solutions (Testbeds) to the target applications defined in

We appraise each testbed against the use cases, target verticals and emerging technologies defined in (Part 1) above together with the strategic considerations defined in Section 4.1 in order to gain an understanding of the pilot feasibility and any gaps and opportunities for innovation or extension.

In addition, it should become clear what, if any, operational issues might exist in deployment of the testbed and how the solution might be deployed in the longer term.

In summary:

Step 1. Identify the key AIOTI use cases and target verticals;

Step 2. Identify any strategically important emerging technologies;

Step 3. For each testbed, make an evaluation against the above criteria and the strategic considerations defined in Section 4.1;

Step 4. Identify gaps & opportunities for improvement and innovation prior to piloting;

Step 5. Assess the potential for "brownfield opportunities". Whereby the testbed may be built onto through additional work or partner collaboration to increase its value or address the gaps and opportunities identified in point Step 3 above;

Step 6. Carry out a validation of the technology deployment approach.

To illustrate how the process should be carried out, we provide a worked example below based on the Industrial Internet Consortium (IIC) Time Sensitive Networking (TSN) flexible manufacturing testbed. See [IIC-TSN-testbed].

4.4.1 Example: IIC TSN Manufacturing testbed

Step 1 & Step 2: "Manufacturing operations requires tight coordination of sensing and actuation to safely and efficiently perform closed loop control. To address these needs of IIoT all the way to the control system, the IEEE organization has been working to update the standards for Ethernet and wireless (IEEE 802) to support TSN. The technology will be used to support real-time control and synchronization of high performance machines over a single, standard Ethernet network, supporting multi-vendor interoperability and integration. When appropriate, the TSN Testbed will integrate industrial automation protocols which are adopting TSN, such as OPC UA (Unified Architecture). The TSN Testbed includes such things as developing simple applications and data definitions to be communicated utilizing TSN over OPC UA Pub-Sub, to be implemented by TSN Testbed participants. … The Time Sensitive Networking (TSN) Testbed is envisioned in addition to manufacturing, to be useful in a wide range of applications, including Utilities, Transportation and Oil and Gas.", from [IIC-TSN-testbed].

Step 3: Not considered in this example

Step 4: "CHALLENGE: Manufacturing operations requires tight coordination of sensing and actuation to safely and efficiently perform closed loop control. Typically these systems have been deployed using non-standard network infrastructure or air-gapped (unconnected) standard networks. This approach leaves devices and data much harder to access and creates a technical barrier to IIoT which is predicated on the ability to consume data anywhere throughout the infrastructure.", from [IIC-TSN-testbed].

Step 5: "COMMERCIAL BENEFITS: TSN will open up critical control applications such as robot control, drive control and vision systems to the industrial internet. This connectivity then enables customers, suppliers and vendors to more readily access data from these systems and to apply preventative maintenance and optimization routines to these systems. … Another benefit was to generate feedback and requirements to various standards groups working on TSN, in particular enhancements to the Ethernet standards. It is one thing to build a standard and it is another to implement and use it.", from [IIC-TSN-testbed]. The following companies/organisation supported this testbed Bosch Rexroth, Cisco, Fraunhofer IPMS, Ixia, ISW, Kalycito, Moxa, SoC-e, SICK AG, Texas Instruments, TRUMPF, Xilinx, Accessible Engineering Innovation (AEI) Corporation, Analog Devices, Avnu, B&R Automation, Belden/Hirschmann, Calnex, HMS Industrial Networks, InnoRoute, Kontron, Molex, National Instruments, NetTime Logic, Phoenix Contact, Renesas Electronics, Schneider Electric, TSN Systems, TTTech, WAGO.

Step 6: The key Business value profile for this profile process efficiency. Process efficiency is an objective that requires significant reliance on operational experts and must cope with brownfield conditions and operational disruption in the field. The testbed learnings cover extensively some related aspects: (a) project planning challenges, (b) dealing with human aspects, (c) handling brownfield constraints and demonstrating value in the field and to management

4.5 Testbed piloting (Create, Implement, Evaluate)

In this activity, we evaluate the testbed operation and disseminate the results. The evaluation is conducted from both a business and operational perspective, so as to demonstrate a 'go-to-market' strategy. This dual approach aims to validate the solution design and deployment feasibility alongside the deployment cost, risk and operational disruption. The goal is to ascertain whether the solution is likely to bring the expected value or improvement when in production after the pilot stage.

The major process steps are:

Step 1. Validation of the technology and architecture solution;

Step 2. Potential for technology improvement through further integration of additional features or technology;

Step 3. Testbed promotion (in e.g., Workshop, Events, AIOTI SCoDIHNet, European Network of Living Labs (ENoLL), EU JRC 121604);

Step 4. Best Practice promotion; what can we learn and how do we disseminate this?

Step 5. Brownfield process improvement. What are the recommendations for building on the existing capability and can we cross reference with other activities or testbeds?

Step 6. Definition of the go-to-market (commercial deployment) strategy

Step 7. Recommendations to SDO/Alliance/OSS/GAIA-X;

Step 8. Certification and benchmarking potential. To be defined in future; both Prototyping and demonstration (of use cases) and Benchmarking (of Functional & Non-functional test campaigns)

As in Section 4.4 above, we illustrate how the process should be carried out with a worked example based on the Industrial Internet Consortium (IIC) Time Sensitive Networking (TSN) flexible manufacturing testbed below. See [IIC-TSN-testbed].

4.5.1 Example: IIC TSN Manufacturing testbed

Step 1: As emphasized in the elaborated technology: "Time Sensitive Networking to support real-time control and synchronization of high performance machines over a single, standard Ethernet network, supporting multi-vendor interoperability and integration. When appropriate, the TSN Testbed will integrate industrial automation protocols which are adopting TSN, such as OPC UA. The TSN Testbed includes such things as developing simple applications and data definitions to be communicated utilizing TSN over OPC UA Pub-Sub, to be implemented by TSN Testbed participants", from [IIC-TSN-testbed]. For details see [IIC-TSN-brochure].

Step 2: Key TSN Testbed features:

- Combine different critical and best-effort traffic flows on a single IEEE 802.1 network
- Demonstrate real-time capability and vendor interoperability using standard, converged Ethernet
- Show ability for IIoT to incorporate highly performance and latency sensitive applications
- Provide integration points for smart edge-cloud control systems into IIoT infrastructure & application
- Mixed reconfigurable manufacturing with robotics, multi-axis motion machines, vision, IO and machine health/diagnostics
- Integration at M2M level and IIoT level", from [IIC-TSN-brochure].

Step 3 & Step 4: OUTPUTS & RESULTS

- TSN Testbed is driving accelerated market adoption of critical IIoT / Industry 4.0 technology
- Over 30 Vendors participating (chip makers, vendors of switches, automation devices and testing products)
- Fourteen Plug-fests conducted since testbed establishment in US, Austria and Germany with ever-improving levels of interoperability and functions
- Two Testbed locations at National Instruments in Austin, Texas and ISW - University of Stuttgart, Germany
- TSN Description of Converged Traffic Types White Paper - Published April 2018
- TSN Testbed results article in IIC Journal of Innovation
- Winner of 2017 IoT Solutions World Congress "Best Testbed" Award
- Winner of 2017 IIC Testbed Showcase
- Demonstrations at major shows (IoTSWC, SPS Drives, Hannover Messe, NI Week, IOT World, DE Forum, IMTS, Electronica)
- Collaboration with multiple standardization bodies: IEEE, IETF, AVNU Alliance, OPC Foundation and ODVA.

Step 5: BUSINESS VALUES DERIVED FROM DETERMINISTIC, STANDARD NETWORKS

- Higher availability of lines, machines and equipment
- Reduced time-to-market of new products
- Reduced cabling TCO
- Reduced plant downtime with support for rapid manufacturing reconfiguration
- Increased uptime through integration of plant diagnostics
- More secure operations
- Improved quality of products
- Large ecosystem of suppliers of standard components
- Open to innovations within standard networks

Step 5: TSN TESTBED PARTICIPATION BENEFITS

- Access TSN testing resources including an interoperability rack, testing tools and expert vendors, including remote access
- Test your technology in frequent plug-fests in Germany and the USA
- Collaborate on ongoing testing and strategic discussions
- Influence industrial standards shaping the future of manufacturing and other industries
- Gain broad visibility and recognition of your participation
- Participate in the TSN demonstrator showcased at global industry events
- Leverage IIC's ecosystem of technologies, industry & technical experts, resources and best practice, from [IIC-TSN-brochure].

Step 6: See Steps 3, 4 and 5, above.

Step 7: Collaboration with multiple standardization bodies: IEEE, IETF, AVNU Alliance, OPC Foundation and ODVA, see [IIC-TSN-brochure].

Step 8: Benchmarking results are introduced in: [IIC-TSN-testbed-white-paper], [IIC-TSN-testbed-Resource-Hub]

5. Conclusions and Recommendations

The methodology described herein has been arrived at through consideration of relevant industry best practice and discussion and debate within the AIOTI Testbed Interest Group.

Each of the considered testbed methodologies (Living Labs, IEEE Future Networks, Fed4FIRE and the Industrial Internet Consortium) offer different approaches, but all with a common set of attributes, which we have built upon to meet the specific needs of the AIOTI community.

It was also important that our methodology should encompass key considerations which are strategically valuable to AIOTI and our vision concerning the combination of Edge compute and IoT.

The methodology in essence describes a process for the collection of existing testbeds, evaluation and selection of these testbeds and analysis of their value potential towards both technical and business goals. Some example testbeds are also provided to illustrate this process.

The forward work program of the Testbed IG will now be to execute the methodology and arrive at a set of evaluated 'reference' testbeds and some conclusions and recommendations for further work; for example, enhancement to existing testbeds and addressing identified market-gaps through new testbeds activities. In addition, the testbeds catalogue and results of running this methodology will be disseminated widely as part of our activities to promote the AIOTI vision.

During the development of this document some further steps have been identified, which could form part of a 2.0 revision, these are listed below as recommendations for future study and discussion:

1. More quantitative analysis approach through defined measurement metadata and benchmarking
2. Testbed evaluation automation through test-tool and test-environment deployment
3. Formal certification program

References

1. [IIC-TSN-brochure] Industrial Internet Consortium: The Time Sensitive Networking – Flexible manufacturing testbed brochure, 4 July 2020: https://www.iiconsortium.org/pdf/TSN-brochure-4-07-20.pdf

2. [IIC-TSN-testbed-white-paper] IIC TSN Testbed White Paper, 28 March 2018: https://www.iiconsortium.org/pdf/IIC_TSN_Testbed_Char_Mapping_of_Converged_Traffic_Types_Whitepaper_20180328.pdf

3. [IIC-TSN-testbed-Resource-Hub] IIC Resource Hub TSN page: https://hub.iiconsortium.org/portal/Testbed/5b76ab57d01716000ff2036e

4. [IIC-TSN-testbed] Industrial Internet Consortium: The Time Sensitive Networking – Flexible Manufacturing testbed: https://www.iiconsortium.org/time-sensitive-networks.htm

5. [IIC-TB-Method-2020] "A compilation of Testbed Results: Toward Best Practices for Developing and Deploying IIoT Solutions", IIC White paper, v1.0, 20-02-2020: https://www.iiconsortium.org/pdf/Compilation_of_Testbed_Results_2020_Feb.pdf

6. [Live_Lab_U4IoT] "Living Lab Methodology Handbook", EC H2020 U4IoT report: https://u4iot.eu/pdf/U4IoT_LivingLabMethodology_Handbook.pdf

7. [Live_Lab_SmartIES] "The Living Lab Methodology Handbook", A Transnational Nordic Smart City Living Lab Pilot – SmartIES: https://www.ltu.se/cms_fs/1.101555!/file/LivingLabsMethodologyBook_web.pdf

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About AIOTI

AIOTI is the multi-stakeholder platform for stimulating IoT Innovation in Europe, bringing together small and large companies, start-ups and scale-ups, academia, policy makers and end-users and representatives of society in an end-to-end approach. We work with partners in a global context. We strive to leverage, share and promote best practice within IoT ecosystems and be a one-stop point of information on all relevant aspects of IoT Innovation to members while proactively addressing key issues and roadblocks for economic growth, acceptance and adoption of IoT Innovation in society.

AIOTI's contribution goes beyond technology and addresses horizontal elements across application domains, such as matchmaking and stimulating cooperation in IoT ecosystems, creating joint research roadmaps, driving convergence of standards and interoperability and defining policies. We also put them in practice in vertical application domains with societal and economic relevance.

AIOTI is a partner for the European Commission on IoT policies and stimulus programs, helping to identify and remove obstacles and enable fast learning, deployment and replication of IoT Innovation in real scale experimentation across Europe from a global perspective.

AIOTI is a member driven organisation with equal rights for all members, striving for a well-balanced representation from all stakeholders in IoT and recognizing different needs and capabilities. Our members believe that we are the most relevant platform for connecting to the European IoT innovation ecosystem in general and the best platform to find partners for real scale experimentation.