AI REDGIO 5.0

System Integration and Validation Report – M18

D5.3

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Abbreviations and Acronyms:	
AI	Artificial Intelligence
AIoD	AI on Demand Platofrm
CI	Collaborative Intelligence
DF	Didactic Factory
ESP32	Espressif32
IoT	Internet of Things
ML	Machine Learning
MLOps	Machine Learning Operations
MQTT	Message Queuing Telemetry Transport
SME	Small Medium Enterprises
SotA	State of the Art

Executive Summary

Deliverable D5.3 reports on the first version of the integrated AI REDGIO 5.0 AI Toolkit, which includes the set of components that are tasked to support the different experiments and stakeholders of the domain to design, execute and evaluate AI pipelines that are required to solve their business problems. This deliverable is the direct output of T5.6 which is responsible for the integration of all components developed in WP5.

In order to reach the first integrated prototype version of the AI Toolkit, the different MLOps workflows and practices that have been discussed in the project were considered, and an integration plan was set, which allowed the different partners that work on the development of the WP5 components to progress their individual components, as well as to define the interface points and the required data exchange methods which will allow users of this first prototype version to make use of it as a package that can cover completely their AI needs when it comes to the design, training, and (cloud/edge) AI execution as well as the validation of the AI outputs.

As such, this deliverable discusses the following components that at this point constitute the AI REDGIO 5.0 Toolkit:

- The Collaborative Intelligence Platform, that allow stakeholders to ingest AI results and work on the verification of the algorithms' outputs
- The AI Pipeline Lifecycle Management platform, that allows stakeholders to design, deploy and execute their AI pipelines
- The Open Hardware that supports edge execution of ML pipelines.

During this first phase, apart from the technical verification that has been performed at component level by each stakeholder and the debugging of components with the help of the consortium partners, a small technology acceptance validation round took also place with users that had early access in the different components. These exercises will be intensified during the development of the second version of the AI Toolkit, where verification will be also performed at the integrated toolkit level, while the validation from the end-users (e.g. technology acceptance assessment) will be sought by all engaged end-users, coming whether form the consortium (SMEs/DFs/etc.) as well as from the Open Call winners.

1 Introduction

1.1 Scope of the Deliverable

Deliverable D5.3 reports on the 1st version of the integrated AI Toolkit of the AI REDGIO 5.0 project, which is the direct out of the integration activities of WP5 which aim to bring together the different subcomponents that are delivered by the different WP5 tasks.

In more detail, this deliverable is based on the outcomes of T5.6 of the project, which ingest the results (e.g. the components) that are coming from the following tasks:

- T5.1 which delivers the Collaborative Intelligence platform, a service that can enable human-AI teaming towards improving the results of AI algorithms by involving human operators in the loop
- T5.2 which delivers the Open Hardware platform, that consists of specification on how to construct Edge devices that are capable to execute AI models, as well as the required code and service layer to support those
- T5.3 which provides the AI Pipeline Lifecycle Management platform that allows users to construct, train, deploy and execute their AI models
- T5.5 that delivers the AIoD Interoperability Connector, to allow stakeholders to ingest and utilize of-the-shelf AI models and solutions that are published in the AIoD platform, as well as to publish their own developments back to the platform.

It is noted that work in T5.6 will continue until M33 of the project, to produce the second and final version of the AI Toolkit, that will be based on the revised versions of the sub-components mentioned above.

1.2 Relations to other WPs and Deliverables

The results of this deliverable have been influenced by the requirements gathered in WP2, WP4 and WP6. These WPs and their associated deliverables serve as requirements channels for the integrated AI Toolkit, and in turn also influence the design and development decisions of the different sub-components that are delivered by WP5 and provide needs for integration and interconnections between the different tools at both intra and cross WP level.

1.3 Structure of the Document

Deliverable D5.2 is structured as follows:

- Section 2 discusses the integration plan and provides insights on the methods used to conduct the technical verification and the validation of the components and the integrated toolkit.
- Section 3 provides an overview of the AI Toolkit and a high-level description of its usage. This section then dives into details regarding the different sub-components which altogether compose the AI Toolkit. These are the components that have been already described in deliverables D5.1 and D5.2.
- In Section 4 the technical verification results (in terms of user story completion) and of the validation results from a selected group of end-users is discussed.
- Finally, Section 5 provides an outlook on the future work that will result in the next and final release of the AI Toolkit.

2 Methodology and Planning

This section presents briefly how the different sub-components developed under WP5 have been constructed and later combined to formulate the first version of the AI REDGIO5.0 AI Toolkit

2.1 Integration Planning & Roadmap

The integration plan for the AI Toolkit follows the plan of the project for WP5 as it is set in the DoA. As such, the different sub-components are being delivered based on the timing of the DoA, and then these are integrated into the overall AI Toolkit.

The first sub-components that surfaced from WP5 according to the project's plan, were the Collaborative Intelligence platform and the Open Hardware platform. These components have been delivered as part of D5.1 in M9 of the project and since then they have been refined, tested with end-users (use case partners) and refined.

In M6 of the project, again according to the project's plan, work started for the other two major sub-components of the AI Toolkit, namely the Cloud-to-Edge AI Pipeline Lifecycle Management platform and the AIoD Interoperability connector, initially by extracting the requirements based on the identified requirements elicitation methodology, and then working on the development. It has to be noted, that the implementation of the AIoD Interoperability connector was paused, as the AIoD platform underwent major changes, and as such the ongoing implementation was deemed obsolete. As such, this component had to be re-designed and is not integrated in the 1st version of the toolkit. The expected results have been redefined according to the SoTA analysis of AIoD v2 and the ongoing activities in WP3 and WP5. On the other side, changes have impacted the AIoD and have been shared with WP6 paving the way for the adoption of the platform and support the AI needs of the experiments (if needed).

Once stable versions of the components were ready, in the Q1 of 2024, integration activities have begun, which led to the delivery of the 1st version of the AI Toolkit, that provides a platform that brings together the Collaborative Intelligence Platform, the Open Hardware specifications and the Cloud-to-Edge AI Pipeline Lifecycle Management platform, following a loose integration approach to enable end users to use these components as they see fit, but also enabling to create a pipeline of actions between those.

This overall process is executed twice during the timeframe of the project. The first execution results in the delivery of the 1st version of the AI Toolkit (D5.3 -due to M18) which is described by the document at hand, while the second iteration will deliver the final version of the AI Toolkit in M33. These two phases are presented in the following figure

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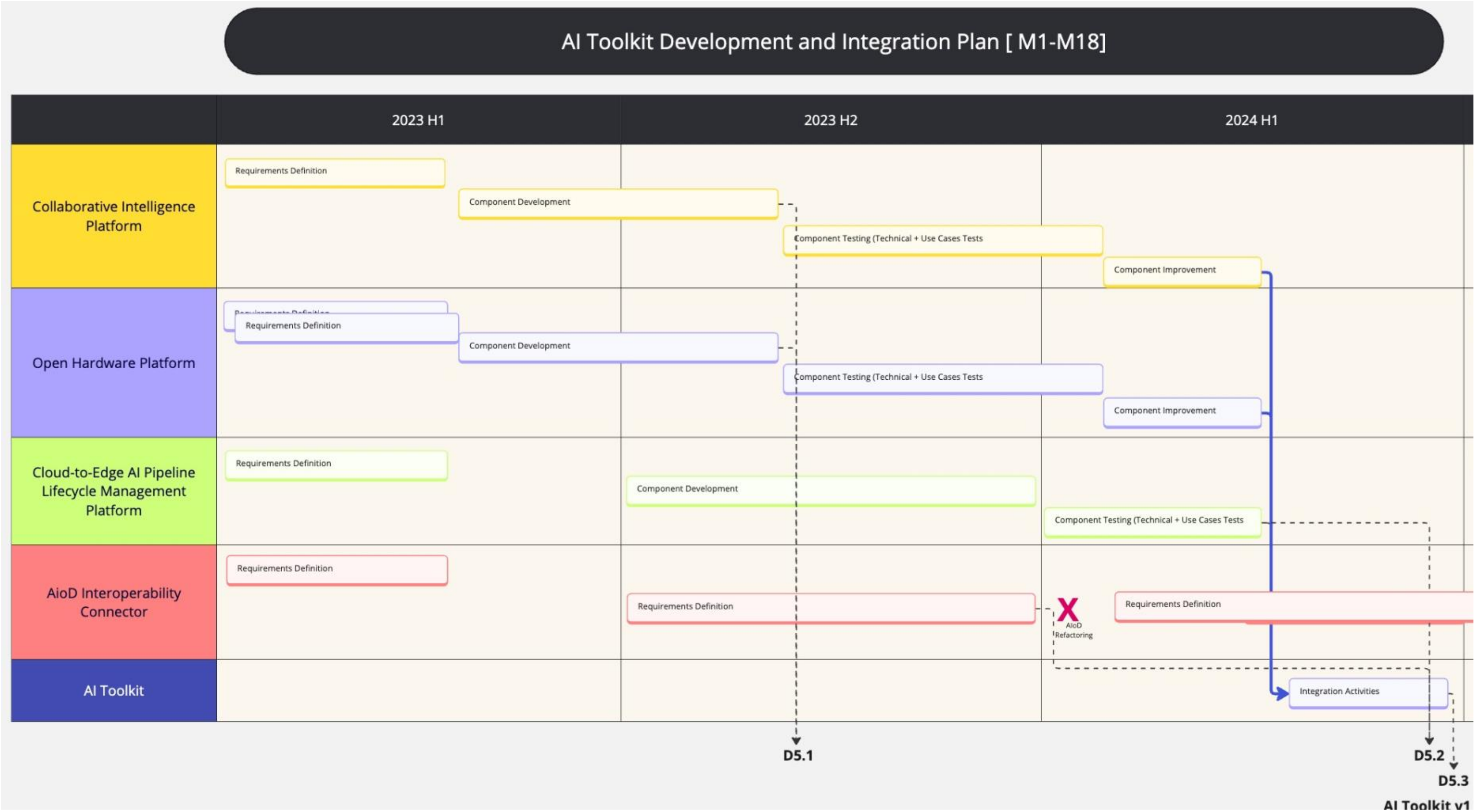


Figure 1 – Integration plan M1-M18

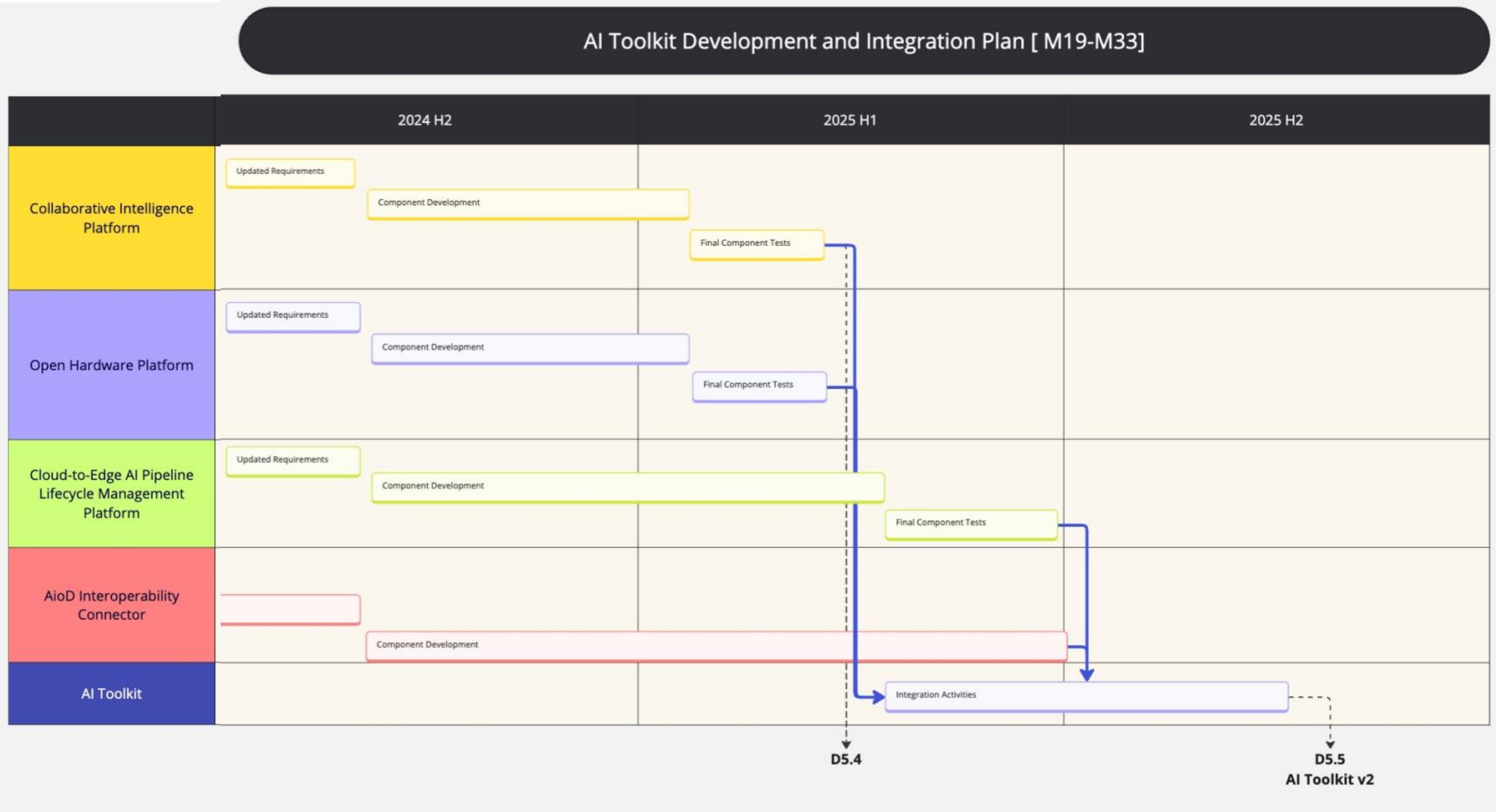


Figure 2 – Integration plan M19-M33

2.2 Quality Assurance, Technical Verification and Validation Methods and Plan

Quality assurance and verification and validation is a crucial step towards the delivery of the integrated AI Toolkit, and as such the partners working on these tasks agreed to follow a unified approach to ensure that certain criteria are met by all developers of the components of the AI Toolkit.

In principle the Verification and Validation approach of followed the known V-Model structure which is shown in the next figure.

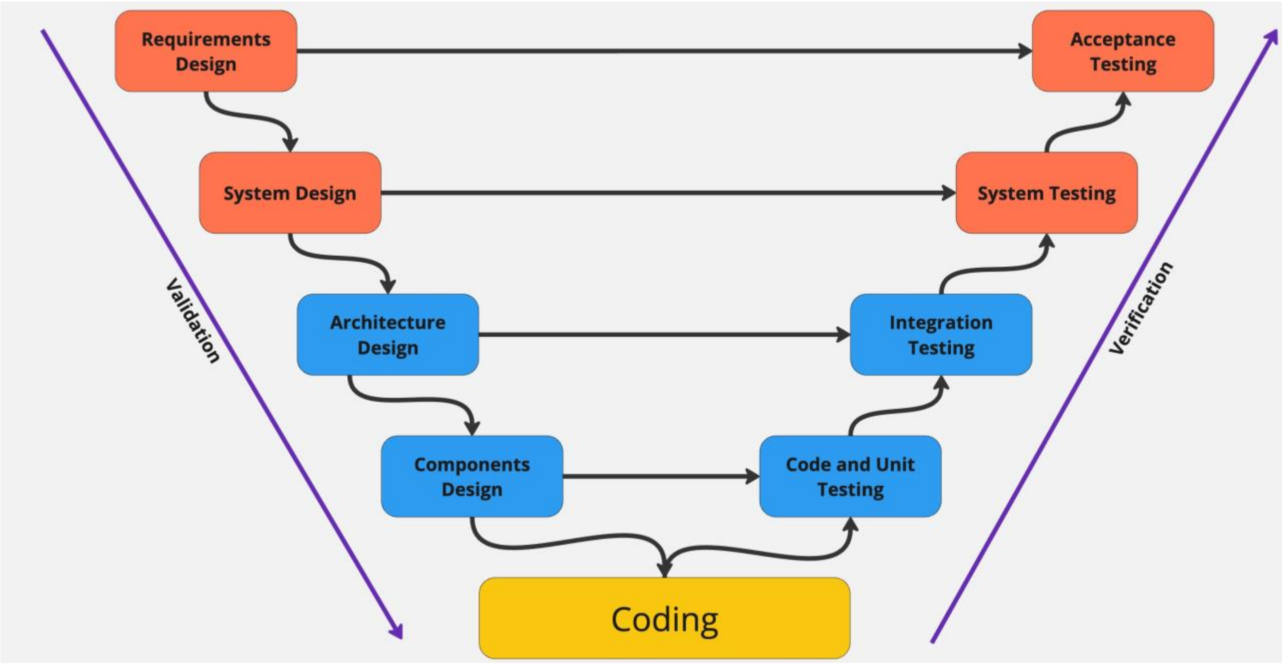


Figure 3 – Validation and Verification V-Model

During the Verification Phases, the following sub-tasks have been executed:

- Requirement Analysis: This was the initial step towards identifying the different requirements. These requirements have been provided to the project's techno-handbook and have been extracted by running a series of interviews with pilot partners, consulting internally with the technical teams and by exploring literature. Moreover, these requirements have been also developed by having in mind the work conducted in the other WPs of the project, and the requests that these had from WP5.
- System Design: This task was performed by consuming the initial requirements and by drawing the actual hardware and software specification of the AI Toolkit, and setting up the different workflows between the sub-components to understand the behaviour of the final integrated solution
- Architectural Design: This step concerned the development of the architecture of the different sub-components, and the overall architecture of the AI-toolkit as the combination of the structural elements that are used in the different sub-components. During this phase, work has been performed in alignment with the overall AI REDGIO 5.0 architecture definition tasks (under WP4) to ensure that the WP5 tools architecture is aligned and compatible with the high-level architecture of the whole AI REDGIO 5.0 platform

- <u>Components Design</u>: This task dealt with the design of the different sub-components of the toolkit, which have been executed by the other WP5 tasks and resulted, after coding, in the different outputs of WP5.

Once the main part of the code was ready, the following tasks have been executed:

- <u>Code and Unit Testing</u>: This task includes test to test simple functionalities of the code delivered in order to verify the correct execution of the different functions. Code testing has been performed at the level of individual components by the different developers
- <u>Integration Testing</u>: This task refers to the software testing of the integrated solution. In the case of the 1st version of the AI Toolkit, due to the strategy of aiming at a loose integration for this version, integration testing has been performed mostly at the level of testing the interfaces between the different components and checking the correct flow of information between those
- <u>System Testing</u>: This task includes the testing of the overall system to judge that the final integrated system performs as expected. In the case of AI REDGIO 5.0 and due to the loose integration of the different sub-components as part of the 1st version of the AI Toolkit, system testing has been performed at UI level, to check that the flow between components is working as expected
- <u>User Acceptance</u>: The user acceptance test plan is prepared during the requirement analysis phase because when the software is ready to be delivered, it is tested against a set of tests that must be met to certify that the product has achieved the target it was intended to. For this phase, and for the 1st prototype of the AI Toolkit, a TAM questionnaire has been set up, and the results of this are presented in section 4.2 below.

Regarding user acceptance and to measure the quality of the system from a user's perspective (e.g. non-software performance level evaluation) the project makes use of the ISO 25010 Quality in Use Model, that is presenting the quality of the system from a user's perspective.

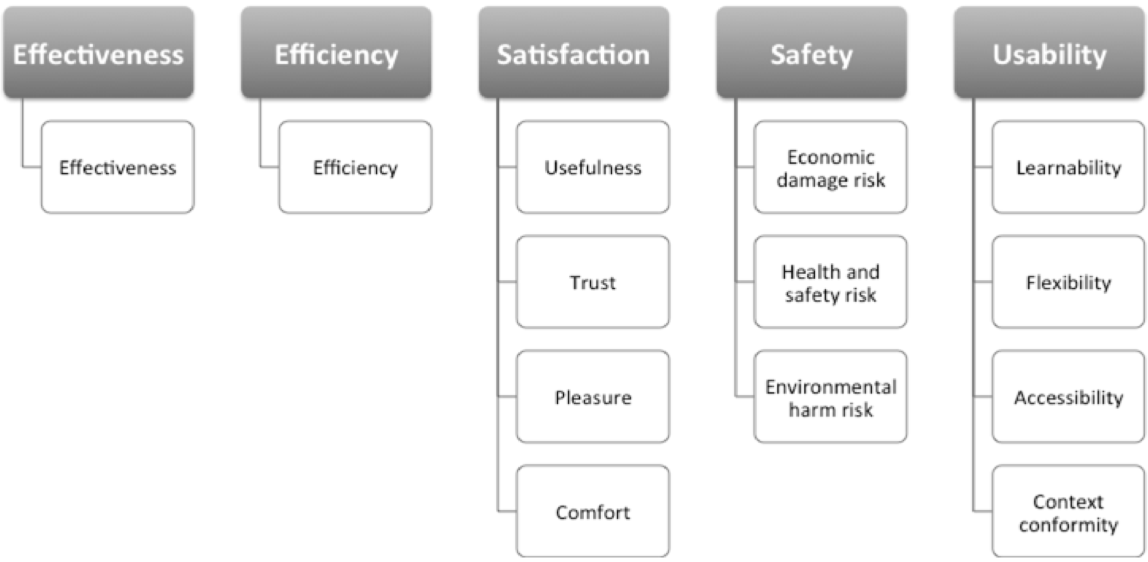


Figure 4 – Quality in use model view based on the ISO/IEC 25010:2011 standard

The Quality in Use Model assesses software quality (from a user point of view) using the following set of characteristics (each of them including other sub-characteristics):

- Effectiveness – Measuring the accuracy and completeness with which users achieve specified goals
- Efficiency – Evaluating the resources expended in relation to the accuracy and completeness with which users achieve goals
- Satisfaction – Aiming to capture the degree to which users are satisfied with the experience of using a product in a specified context of use
- Safety – Providing the degree to which a product or system does not, under specified conditions, lead to a state in which human life, health, property, or the environment is endangered
- Usability – The extent to which a product can be used to achieve specified goals with effectiveness, efficiency and satisfaction in a specified context of use.

The table below provides the qualitative evaluation metrics which correspond to the quality in use model for evaluating the AI Toolkit of the project from an end-user perspective, always based on the promised results of each release round.

It is noted that not all parts of the model are evaluated, as some are not relevant to the AI Toolkit's case. Furthermore, this evaluation concerns only the features and the experience provided by the 1st release of the AI Toolkit, and the same exercise will be performed prior to the final release of the toolkit to improve its quality and functionalities.

Table 1 – Qualitative Evaluation Dimensions

Sub-characteristics	KPIs	Assessment Question
Functional correctness	Level of Correctness	Does the component provide accurate results when it comes to its operations? YES/NO/Partially
Functional appropriateness	Level of Appropriateness	Does the CI platform have attributes that facilitate usability? YES/NO/Partially
Ease of Use	Level of Ease of Use	Do you find the component to be an easy tool to use? Scale 1-5
User interface aesthetics	Aesthetics Level	Do the aesthetics of the component satisfy you as a user? YES/NO/Partially
Effectiveness	Level of Effectiveness	Can you accurately your goals with the component? Scale 1-5
Efficiency	Level of Efficiency	Do you think the component covers the intended purpose of as required in the use cases? Scale 1-5
Usefulness	Usefulness Index	Do you find the component useful? Scale 1-5
Trust	Trust Index	Do you trust the component and its results? Scale 1-5
Pleasure	Pleasure Index	Does the component pleases you when you use it? Scale 1-5
Comfort	Comfort Index	Do you feel that the component provides a comfortable UI and workflow? Scale 1-5
Accessibility	Accessibility Index	Do you believe the platform can be used by disabled users? Scale 1-5

2.3 Integration and Testing Infrastructure

The testing and in sequence integration has been conducted in two different levels.

Initially, testing has been conducted by the partners developing their components on their own testing infrastructures and testbeds. The rationale behind this decision was to accelerate testing and debugging, by refraining to invest time to make the components work on the infrastructure provided for the integrated environment, until a stable version for each component was ready.

Each one of those tools is at the moment using its own code repository, to facilitate the work of its developers, however, in the second version all code repositories will be made available under the same GitHub organisation in order to allow interested stakeholders to have a unique reference point when it comes to the outputs of the project.

Once stable versions were ready, they were integrated using the infrastructure offered for the AI Toolkit, and testing was also conducted over this infrastructure.

3 AI REDGIO 5.0 AI Toolkit

3.1 The AI REDGIO 5.0 AI Toolkit in a Nutshell (SUITE5)

The AI REDGIO 5.0 AI Toolkit is the main infrastructure offered by WP5 that allows end-users to make use of the different elements that are provided by the project to design, execute and evaluate AI models that are used in their use cases.

As such, the AI Toolkit facilitates the following activities through the different sub-components:

1. Design AI pipelines, train them and test them prior to their deployment
2. Deploy the designed pipelines or models, using either edge or cloud infrastructures for the execution, depending on the nature of the problem and the execution resource requirements
3. Evaluate the output of the AI models and of the overall pipelines, using collaborative intelligence and placing human-in-the-loop of the AI process, aiming to optimise models and pipelines.

Aside of the core 3 steps, step 1 is also aided by the ability of the platform to either ingest (import) AI models that are made available over the AIoD platform, or export the models designed during step 1 back to the AIoD platform towards increasing AI model reusability.

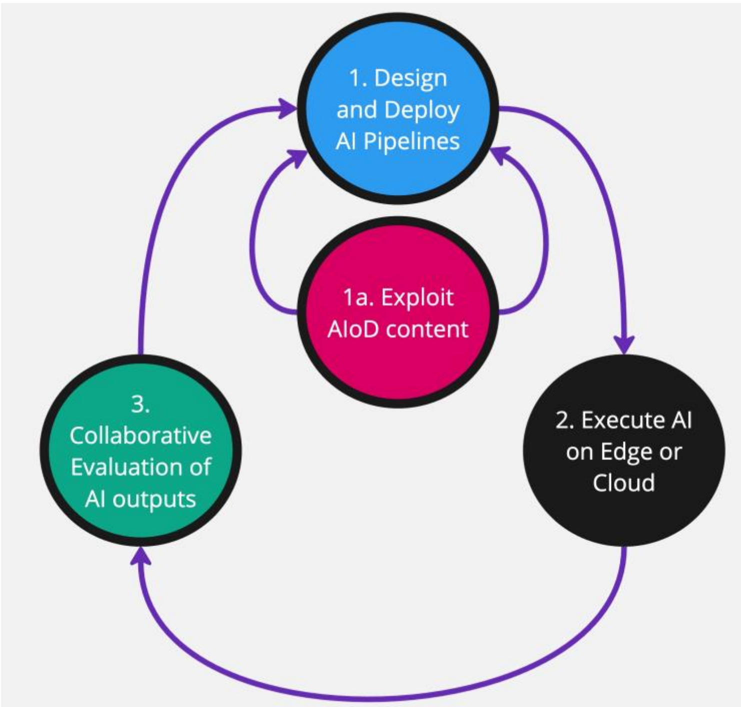


Figure 5 – Cyclic Graph showcasing the use of the WP5 AI Toolkit

The above-mentioned steps are all supported by the different tools (sub-components) developed under WP5, and in more detail:

- The AI Pipeline Lifecycle Management platform is supporting the operations of step #1
- The AIoD Interoperability Connector provides the service to execute step 1.a
- The Open Hardware platform provides the specifications for executing step #2
- The Collaborative Intelligence Platform is used to accommodate the actions of step #3

3.1.1 Current Status

The current version of the AI Toolkit includes stable versions of the following sub-components.

As identified above, the AIoD Connector is not integrated in the present version of the AI Toolkit due to the changes imposed by the AIoD platform.

The following screenshot provides an overview of the main UI that the user is witnessing when logging into the AI Toolkit, where access to the features and functionalities of the different sub-components is provided by clicking the appropriate UI elements (menu selections or tiles).

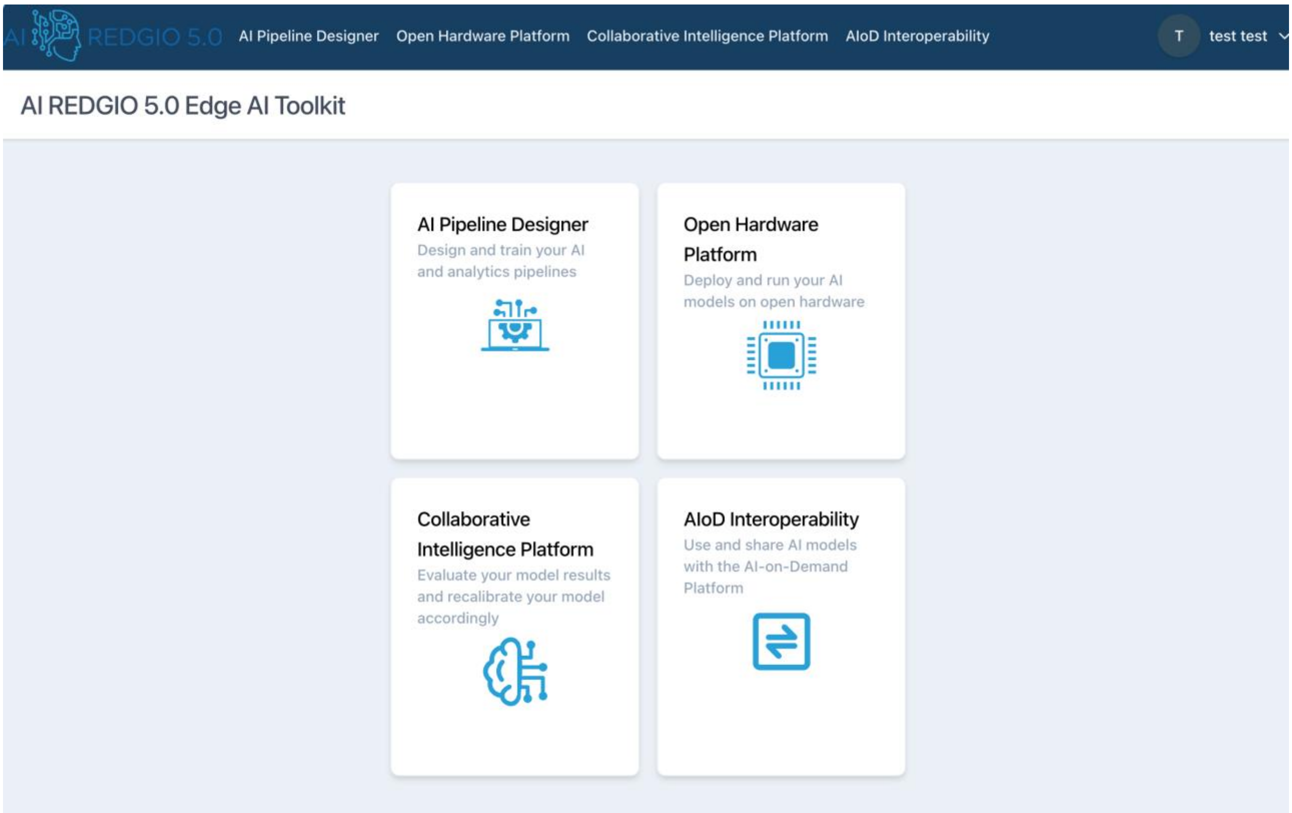


Figure 6 – Main View of the AI Toolkit

3.1.2 Supported Scenarios

The first version of the AI Toolkit covers the main cycle workflow that has to do with the design of AI pipelines and models, their deployment and execution over cloud or edge infrastructures and the evaluation of the outputs via a HITL inclusion methodology that is supported by the Collaborative Intelligence platform. So essentially, steps 1, 2, and 3 are at the moment supported by the AI Toolkit.

3.2 AI Toolkit Components

This section provides a view on the different components of the AI Toolkit, as illustrated above.

3.2.1 Collaborative Intelligence Platform

In the frame of the project, the Collaborative Intelligence (CI) Platform has been developed intended to integrate human expertise with advanced AI technologies. The CI platform facilitates collaboration between human workers and the system, with the aim of improving decision-making and efficiency. It uses real-time data analytics to solve problems and predict maintenance needs. The goal is to help human operators to interact with a more innovative and sustainable industrial environment.

3.2.1.1 Overview and Current Status

The CI platform has three major (sub)components or modules:

- **Process monitoring and validation.** This subcomponent is intended to monitor the outcomes of the industrial process to ensure it meets predefined standards and expectations. Observing process parameters and results can identify deviations and trigger alerts for necessary interventions. This approach helps maintain quality and efficiency, reducing downtime and preventing potential problems.
- **Input Analysis.** This subcomponent is intended to learn a knowledge graph representation of the input data to offer the user several additional advantages, leading to a better understanding of the industrial process. The knowledge graph enables advanced data analytics and insights by organizing and interlinking data points. Users can visualize relationships between different process variables, identify patterns, and make informed decisions based on comprehensive data analysis.
- **Output Analysis.** This subcomponent is designed to evaluate the output of the industrial process. It involves examining the final outcomes against quality standards and performance metrics. It also provides actionable feedback, guiding adjustments to the process parameters for enhanced efficiency and product quality.

The main results achieved for the development of the CI during this period include:

- Improved Quality Control since our platform helps ensure processes meet standards and reduces downtime.
- Extended Data Insights since our platform facilitates better understanding and decision-making through advanced analytics.

Optimized Performance since our platform provides feedback for continual efficiency and product quality improvement. As immediate next steps, towards the finalization of the CI platform, the following tasks have been defined:

- Expand data sources to incorporate additional data inputs to improve the accuracy of insights.
- Extend visualization tools to develop more intuitive and interactive dashboards to visualize data better.

3.2.1.2 User Stories Backlog

Table 2 shows us the different user stories that drove the development of the CI platform.

Table 2 – Collaborative Intelligence Platform – User Stories Backlog

Id	User Story (As an <actor> I want to <action>, so that…<benefit>)	Planned for (v1/v2)
US.CI.01	As a user, I want to monitor a process, so that I detect anomalies	v1
US.CI.02	As a user I want to understand a process, so that I can optimize it	v1
US.CI.03	As a user I want to visualize the outcome of a process, so that I can be sure of its quality	v1
US.CI.04	As a user I want to query a knowledge graph representing the industrial process	v2
US.CI.05	As a user I want to perform reasoning over the relationships discovered	v2

3.2.1.3 Interfaces and Interactions

The next sequence diagrams that reveal the interactions between subcomponents as well as the interactions with other components for each of the user stories.

<u>Flow to realise US.CI.01</u>

The aim of having a system that continuously analyzes critical aspects of the process is to identify deviations from normal behavior in real-time or near real-time. This early detection of anomalies allows us to take corrective actions promptly, preventing potential quality, efficiency, or safety issues from escalating into significant problems. This proactive approach minimizes disruptions and ensures optimal process performance.

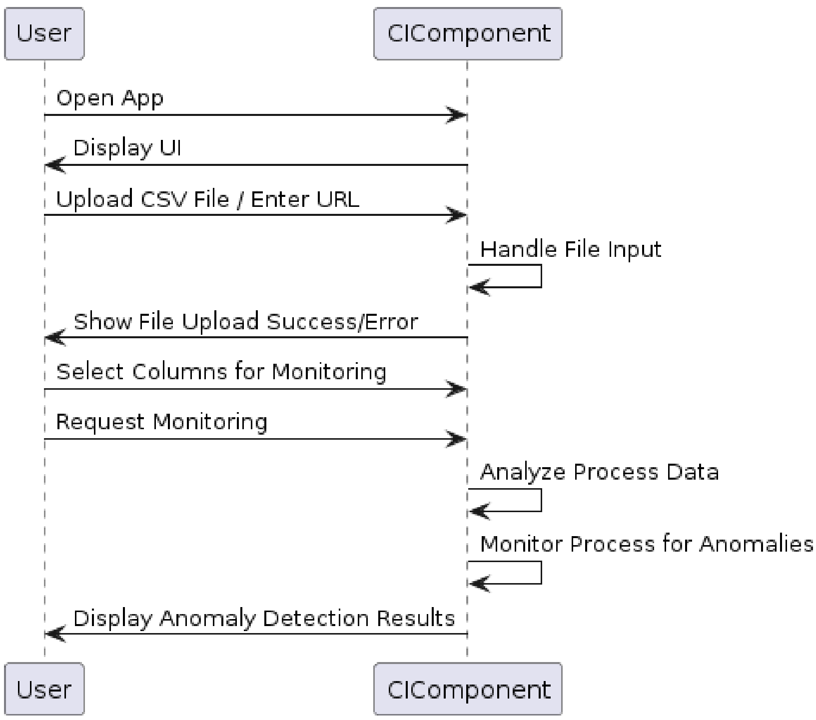


Figure 7 – US.CI.01 Flow diagram

Flow to realise US.CI.02

Understanding the various components and their interrelations within the process allows us to identify inefficiencies and areas for improvement. This understanding enables us to make informed decisions and implement targeted optimizations, improving overall performance, reducing costs, and increasing productivity.

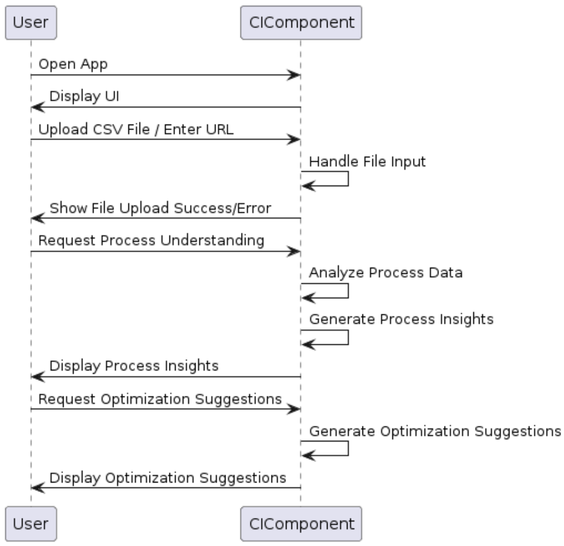


Figure 8 – US.CI.02 Flow diagram

Flow to realise US.CI.03

The key idea behind having a clear and comprehensive visualization of the process results is to assess whether the desired standards and objectives are met efficiently. This visualization lets us identify deviations or issues immediately, facilitating quick and effective quality assurance.

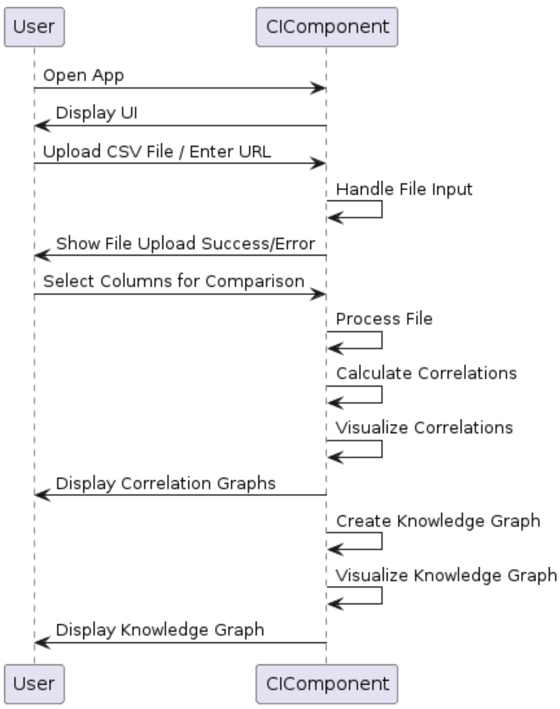


Figure 9 – US.CI.03 Flow diagram

Flow to realise US.CI.04

The key idea behind querying a structured representation of the process is to gain insights into relationships and dependencies between various components, identify patterns, and retrieve detailed data on specific aspects of the process. This capability allows for informed decision-making, troubleshooting, and optimization efforts.

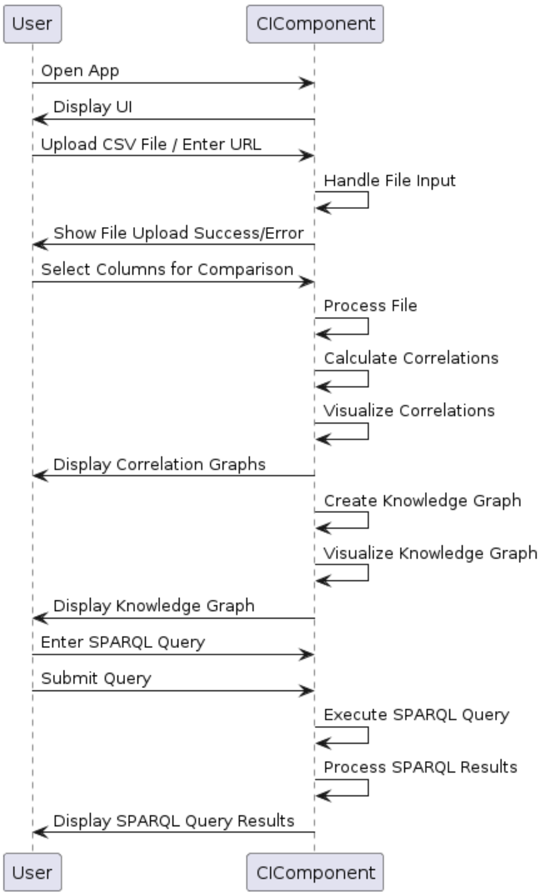


Figure 10 – US.CI.04 Flow diagram

Flow to realise US.CI.05

The rationale behind applying logical reasoning to the identified correlations and dependencies is to uncover underlying patterns, predict future outcomes, and identify potential improvements or issues within the process. This analytical approach improves the user's ability to understand complex interactions and make strategic decisions that optimize performance.

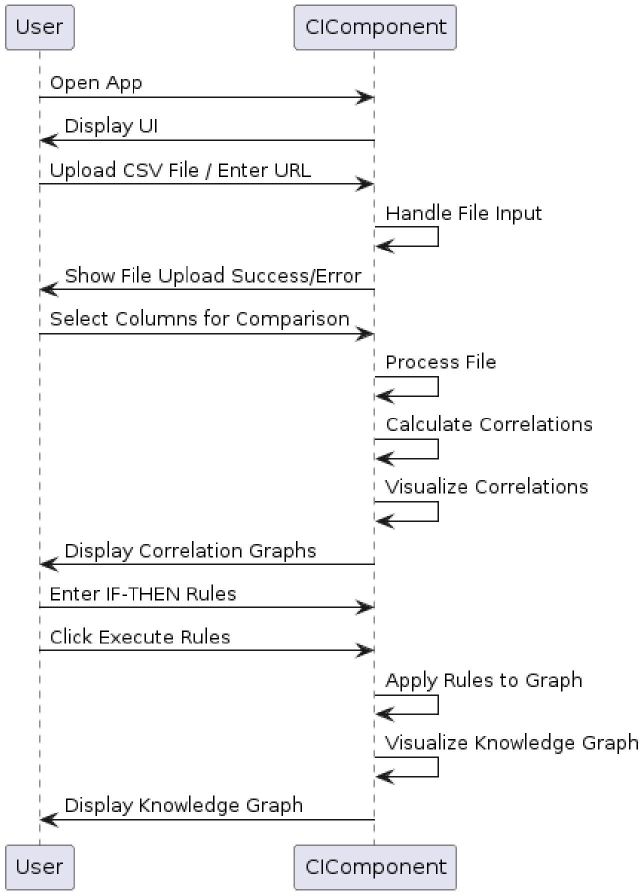


Figure 11 – US.CI.05 Flow diagram

3.2.1.4 Code and Installation / Usage Instructions

The Github repository as well as the relevant instructions for installation and use can be found at the following url: https://github.com/AI-REDGIO-5-0/ci-component

3.2.2 Open Hardware Platform

AI REDGIO 5.0 aims to leverage Open Hardware, specifically the ESP32 microcontroller, to execute AI models with a focus on TinyML applications (Figure 12). The primary objective is to design, develop, deploy, and document an AI model to assess the hardware's performance and compatibility. This project highlights the potential of using cost-effective, accessible hardware to perform complex machine learning tasks at the edge, thus enhancing IoT applications.

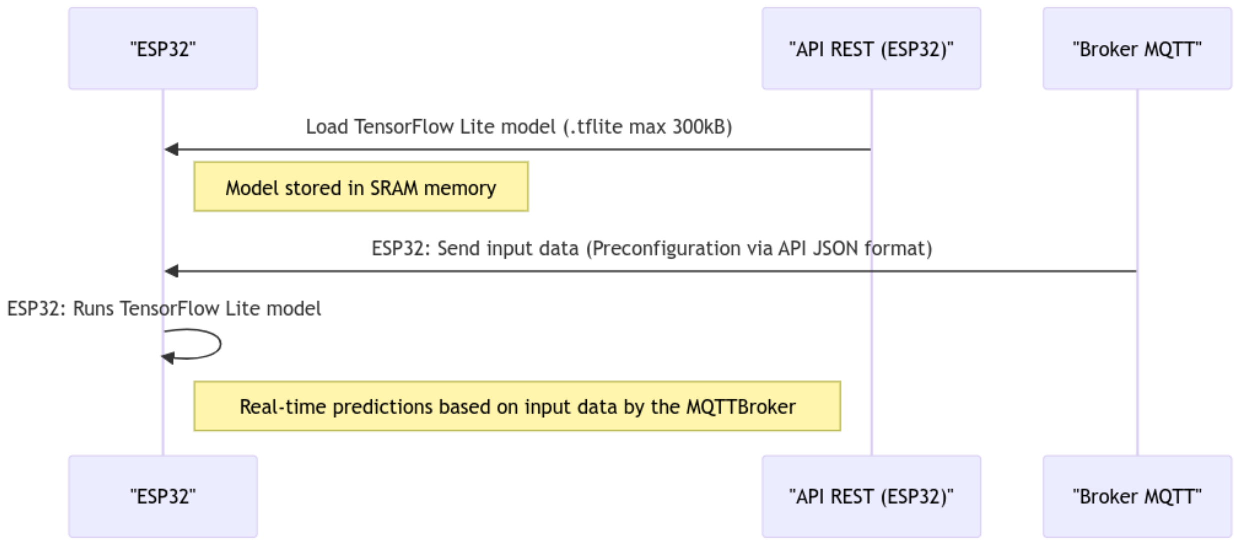


Figure 12 – Open Hardware Platform Schema

3.2.2.1 Overview and Current Status

The objective of this project is to propose an Open Hardware solution using the ESP32 microcontroller and evaluate its capabilities in executing TinyML models. The approach involves designing, developing, deploying, and documenting an AI model to validate the hardware's performance and compatibility with such models.

Design Phase: We have successfully designed an AI model tailored to meet specific example needs. This involved selecting suitable algorithms and structuring the neural network accordingly.

Development Phase: In this phase, the AI model was developed by coding, preprocessing the training data, and training the model using appropriate machine learning techniques. This ensured the model was well-prepared for deployment on the ESP32.

Deployment Phase: The trained model was then converted to a format compatible with the ESP32. Following this, the hardware settings were configured, and the model was successfully loaded onto the ESP32 device.

Documentation: Every step of the process was thoroughly documented, including the challenges encountered and the solutions applied. This documentation provides a valuable resource for future reference and development.

Verification: To verify the hardware's capabilities, real-world data was fed into the model, and the predictions were analyzed against expected outcomes. This process confirmed the reliability and accuracy of the ESP32 in executing the AI model.

The main results achieved during this period are summarized below:

- Delivered the first version of Open Hardware specifications based on ESP32.
- Developed a conceptual framework for AI model design, ready for development and training on the Open Hardware.
- Produced a fully trained and optimized AI model ready for deployment.
- Successfully deployed the exemplary AI model on the Open Hardware.
- Created comprehensive documentation providing insights into model creation and implementation.
- Verified the Open Hardware's ability to execute TinyML models effectively.

Following the current progress with the Open Hardware platform, the immediate next steps for this component of the AI Toolkit include:

- Testing the Open Hardware in industrial environments during the second reporting period.
- Continuing with the integration with other components to ensure robust performance in real-world applications.

3.2.2.2 User Stories Backlog

The following table presents the backlog of the Open Hardware Component.

Table 3 – Open Hardware Platform – User Stories Backlog

Id	User Story (As an <actor> I want to <action>, so that…<benefit>)	Planned for (v1/v2)
US.OH.01	As a data scientist, I want to train a machine learning model suitable for TinyML, so that it can be deployed on resource-constrained devices like the ESP32.	v1
US.OH.02	As a data scientist, I want to convert the trained machine learning model to a TensorFlow Lite format, so that it can be effectively used for edge predictions on the ESP32.	v1
US.OH.03	As a data scientist, I want to upload the machine learning model to the ESP32 using the /upload Model endpoint, so that the model can be deployed and executed on the device.	v1
US.OH.04	As an IoT developer, I want to configure the ESP32 using the /configure endpoint, so that the device can be set up with the necessary parameters for operation.	v1

US.OH.05	As an IoT developer, I want to configure the ESP32 for flexible WiFi settings through a captive portal, so that I can easily set up network connectivity in different environments.	v1
US.OH.06	As an IoT developer, I want to set MQTT broker details and topics on the ESP32 via a web interface, so that it can communicate with other devices and services.	v1
US.OH.07	As a system integrator, I want to monitor the ESP32's predictions by feeding it real-world data, so that I can validate its accuracy and reliability in an industrial setting.	v1

3.2.2.3 Interfaces and Interactions

This project utilizes the ESP32 microcontroller to execute TinyML models, providing an accessible, scalable solution for edge AI in IoT applications.

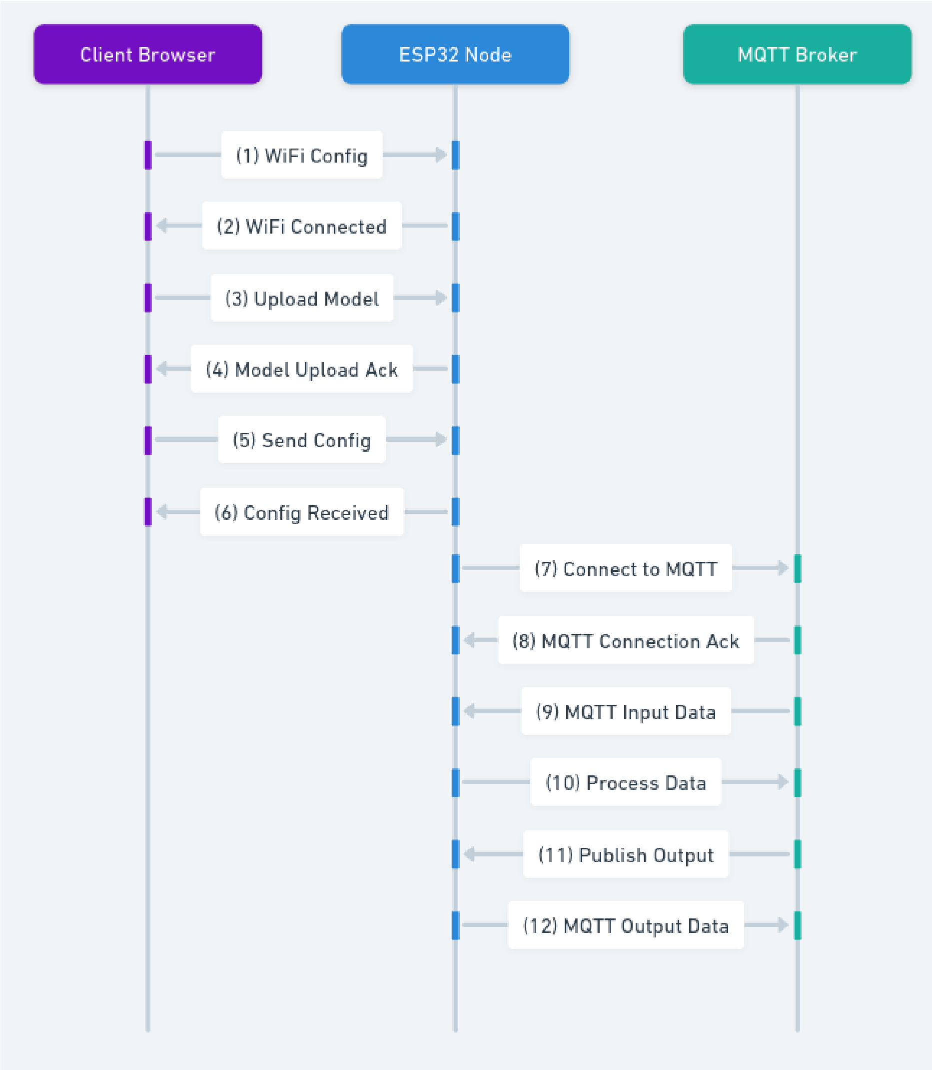


Figure 13 – Execution of TinML over the ESP32

User Interface: The ESP32 features a user-friendly configuration portal, which is a web-based interface designed for setting up network and communication settings. This portal simplifies the initial setup and ongoing management of the device.

Interactions: Users can connect to the ESP32's access point and use a web browser to configure essential settings, such as WiFi and MQTT. This web-based configuration ensures that users can easily adjust the device's settings as needed. The ESP32 utilizes MQTT for real-time data exchange, enabling efficient communication between devices. Additionally, HTTP is used for the initial setup and updates, facilitating a seamless configuration process.

User Roles and Interaction Scenarios:

- Data Scientist: Responsible for uploading and monitoring machine learning models on the ESP32, ensuring the models perform as expected.
- IoT Developer: Tasked with configuring the network and communication settings, ensuring the ESP32 is properly integrated into the network environment.
- System Integrator: Focuses on validating the system's performance in real-world applications, ensuring the ESP32 meets operational requirements.

Scalability and Flexibility: The ESP32 offers modular configuration capabilities through its web portal, allowing for easy updates and adjustments. This flexibility supports various IoT applications by enabling real-time data handling and processing, making the ESP32 a versatile tool for edge computing solutions.

3.2.2.4 Code and Installation / Usage Instructions

The code of the component can be found in the following GitHub repository:

https://github.com/AI-REDGIO-5-0/Open-Hardware

3.2.3 Cloud-to-Edge AI Pipeline Lifecycle Management Platform

The Cloud-to-Edge AI Pipeline Lifecycle management (AIP) platform is the component of the AI Toolkit that enables experiments to design, experiment with, train, execute and deploy AI models that are integral parts of the use cases they are building, either on cloud or on edge infrastructures.

This component addresses the needs of different types of users (i.e. data scientists, technical users, business users) in terms of AI and ML execution, from executing simple data manipulation functions (e.g. filters and aggregations) and applying Artificial Intelligence models for the manufacturing domain analytics, to creating visualizations and reports to highlight insights extracted from datasets and from analytics processes, as well as exporting the outputs of these analyses through interfaces that can be consumed by other systems. Moreover, the platform also allows the deployment of certain models on Edge devices (depending on the complexity of the pipeline and the resources required to effectively execute a model), while it is being prepared to ingest models from the AIoD platform, as well as to export models back to the latter.

3.2.3.1 Overview and Current Status

The platform provides a user-friendly interface that guides the user through the creation of complete pipelines, from selecting and configuring the input data, to the step-by-step processing and exporting the results in the desired form. The internal architecture of the platform is provided in the following figure.

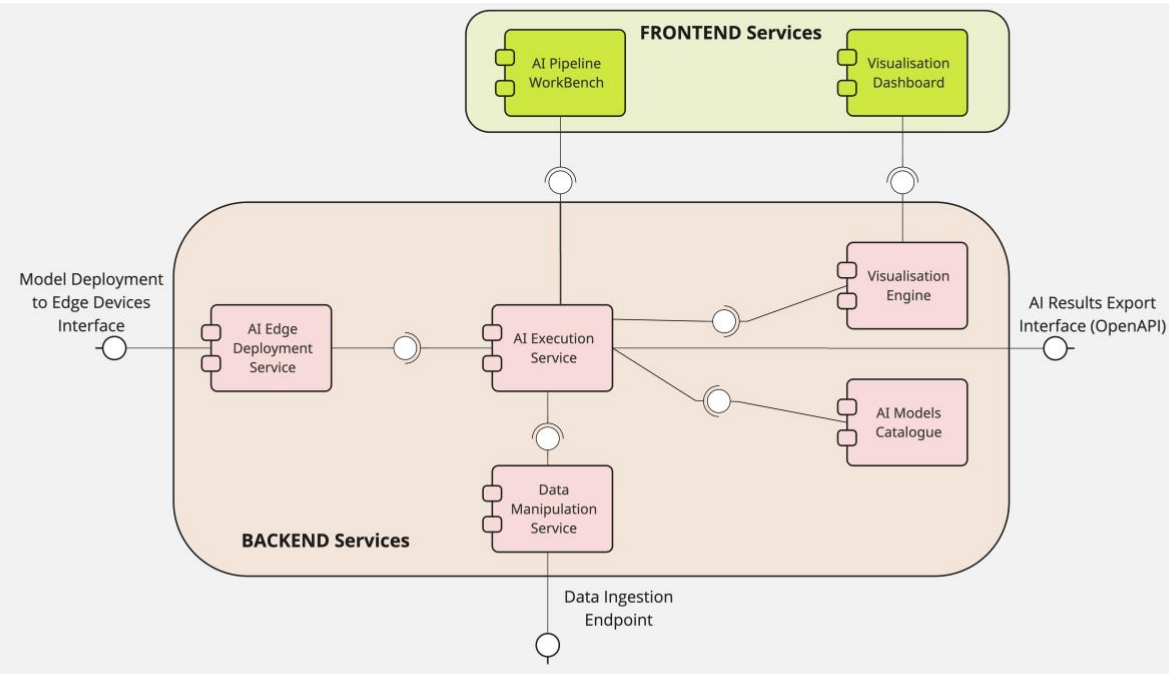


Figure 14 – AI Pipeline Lifecycle Management Platform architecture

In terms of internal components, the platform is composed of the following subcomponents:

- The AI Pipeline Workbench is the responsible for the creation of AI pipelines at "design" time.
- The AI Execution Service is responsible for executing different AI pipelines created in the AI Pipeline Workbench.
- The Visualization Engine is the component that offers functionalities to allow the end users to create custom visualizations of the data/results derived from the data ingestion/analytics

pipeline they want to dive into and to consolidate and manage multiple charts in a user-friendly manner through functions for their dynamic export, etc.

- The Visualisation Workbench that provides to users the interface for designing the visualisations and displaying them to the end user
- The AI Models Catalogue is the component responsible to handle the collection or inventory of various mainstream AI models defined within the context of the AI REDGIO 5.0 project by the AI Pipeline Designer Platform, facilitating analytics using structed data sources.
- The AI Edge Deployment service is responsible for the packaging of AI models and proceeding with their deployment to edge devices that have been registered in the platform, so they can receive this code.

For the 1st version of the platform, stable versions of the above-mentioned components have been developed and integrated in the overall toolkit. In the next figure the view of the AI Pipeline designer is provided, showing the list of AI pipelines developed and the execution of each pipeline

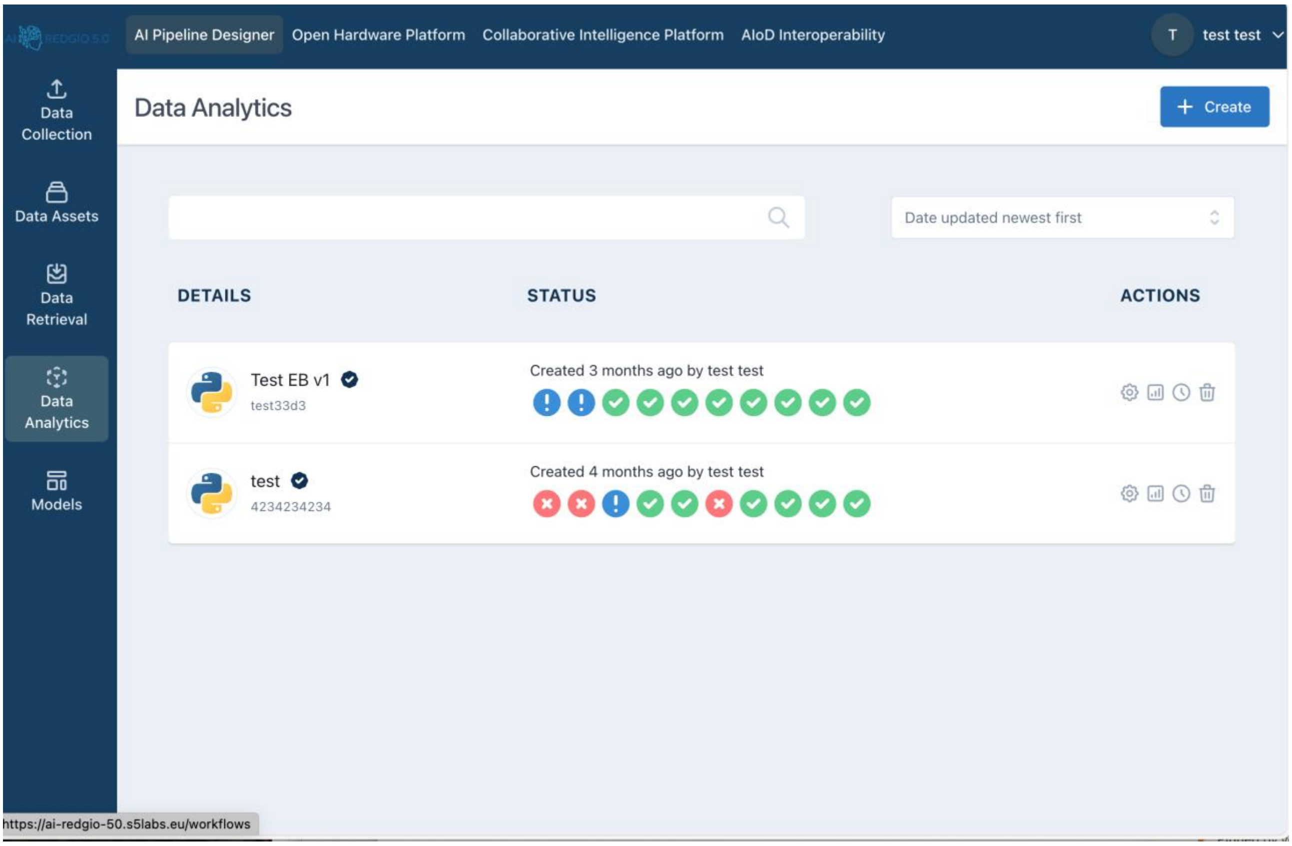


Figure 15 – AI Pipeline Lifecycle Management Platform – List of AI Pipelines & Execution Details

The following figure shows a small example of the graph view of an AI pipeline for training a model and storing the results. As it is shown in the display, options for executing the model over the cloud infrastructure ("Run"), for Downloading the model as well as for deploying and running the model on an edge device "Edge Runner" are available.

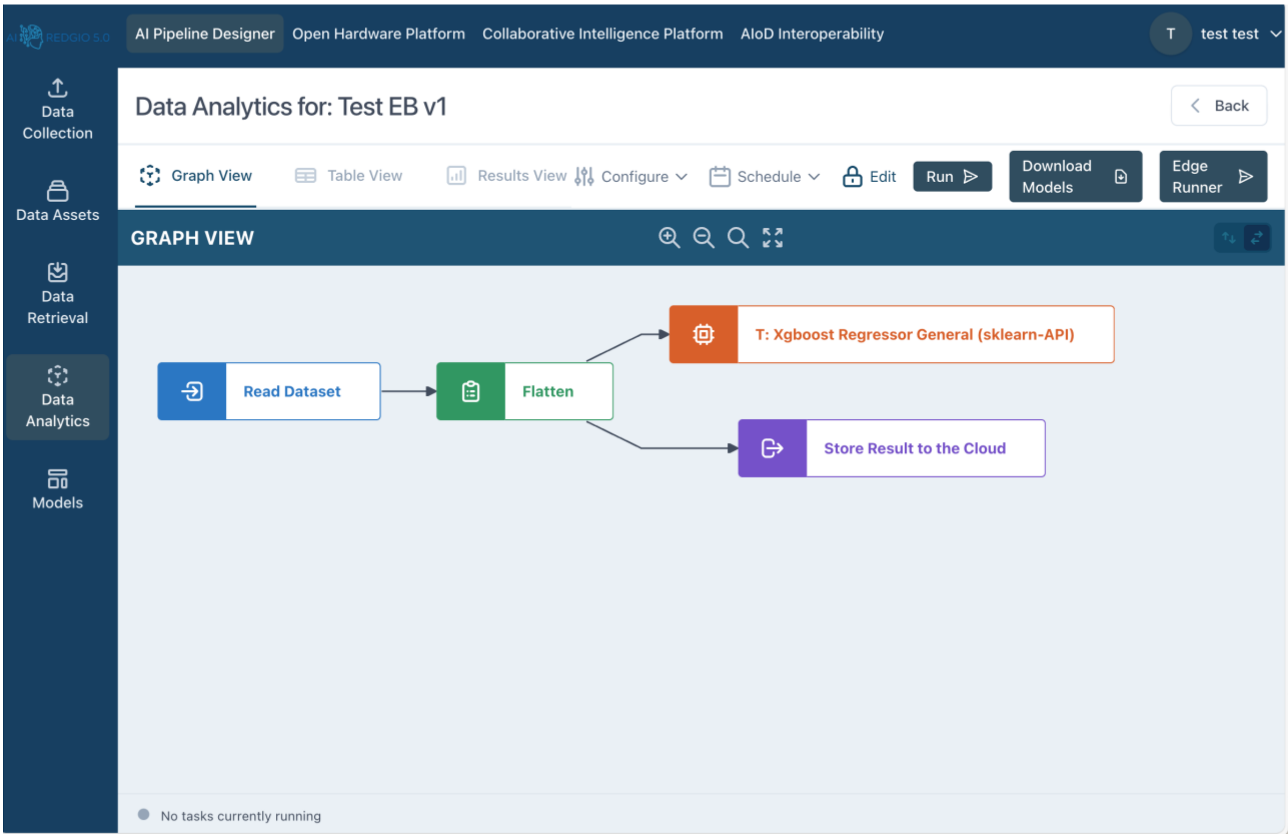


Figure 16 – AI Pipeline Lifecycle Management Platform – AI Pipeline Design Workbench

3.2.3.2 User Stories Backlog

The following table provides the main user stories that have been used to drive the implementation of the platform. These user stories have been generated in such a manner, that the core functionalities have been scheduled for the current delivery of the platform, and more advanced have been developed to be part of the second and final release.

Table 4 – AI Pipeline Lifecycle Management Platform – User Stories Backlog

Id	User Story (As an <actor> I want to <action>, so that…<benefit>)	Planned for (v1/v2)
US.AIP.01	As a data scientist I want to be able to ingest a dataset via an API or via a file to the platform, so I can execute AI analyses on static data	v1
US.AIP.02	As a data scientist I want to be able to ingest a dataset as a stream to the platform, so I can execute AI analyses on streaming data	v1
US.AIP.03	As a data scientist I want to be able to ingest a dataset via the storage of a dataspace to the platform, so I can execute AI analyses on files acquired through a Data Space infrastructure	v2
US.AIP.04	As a data scientist I want to be able to train and execute my AI pipelines over a cloud-based platform, so that I can take advantage of powerful cloud0-resources	v1

US.AIP.05	As a data scientist I want to design an AI pipeline using ready-made components so that I can accelerate the development of my solution	v1
US.AIP.06	As a data scientist I want to be able to share the AI pipelines I create with other users of my organisations, so that I can collaborate with them	v2
US.AIP.07	As a data scientist I want to select to deploy and execute my AI pipeline over cloud-resources, so that I can make use of more execution resources	v1
US.AIP.08	As a data scientist I want to select to deploy and execute my AI pipeline over the open hardware/edge devices, so that I can make use of local execution resources	v1
US.AIP.09	As a data scientist I want to be able to see a snapshot of the results of my AI pipeline, so that I can identify whether I am getting the results I expect	v2
US.AIP.10	As a data scientist I want to be able to export the results of my analyses as a file, so that I can use them later in other tools	v1
US.AIP.11	As a data scientist I want to be able to export the results of my analyses via an API, so that I can set up third party tools to directly ingest them	v2

3.2.3.3 Interfaces and Interactions

The next figure provides an overview of the interactions between the components that constitute the AI Pipeline Lifecycle management platform.

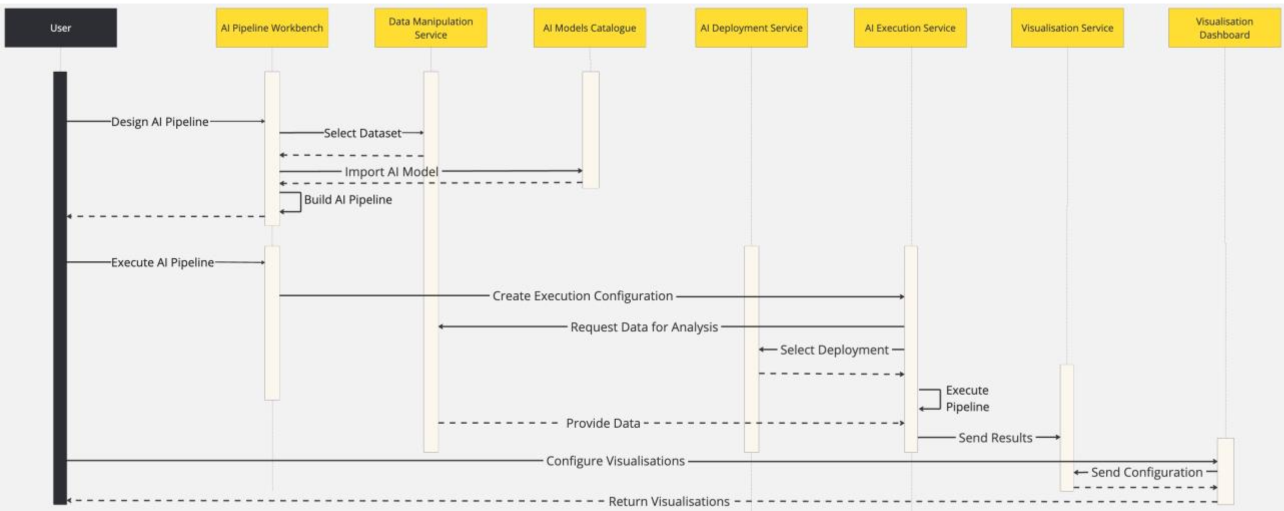


Figure 17 – AI Pipeline Lifecycle Management Platform – Component Interaction Diagram

3.2.3.4 Code and Installation / Usage Instructions

The overall platform infrastructure is offered as a service that is accessible directly through the AI REDGIO AI Toolkit integrated platform, as shown in the previous section. The usage instructions of the platform are embedded into the platform itself, as user documentation as well as via tooltips that guide the users through the whole AI pipeline creation workflow.

3.2.4 Connector with AIoD

Detailed validation procedures and results will be available once the AIoD connector is fully integrated with the AI REDGIO portal. As identified in deliverable D5.2, and due to the recent refactoring of the AIoD platform which raised the need to re-evaluate the development strategy chosen by the project and re-iterate the requirements and development phases, this component is not delivered as part of the toolkit at this point. However, following the initial requirements and designs delivered by this component, AIoD models (in case of pickle files) are able to be onboarded in the AI Toolkit in a manual manner, while the AI Toolkit has the ability to export models, and these can be then published in the AIoD.

The component will be evaluated as part of the portal and its functionality will be tested against the portal requirements.

4 Technical Validation & Acceptance

4.1 Technical Validation

Section 4.1 discusses the technical validation results of the different components, against the user stories provided in the previous sections.

4.1.1 Collaborative Intelligence Platform

One important aspect is to ensure the reliability and functionality of our CI platform. This includes validating data processing methods, verifying the accuracy of algorithms, and confirming the successful integration of various components such as Knowledge Graph creation, visualization, and SPARQL querying. Additionally, we need to be sure that user inputs are handled correctly, that the application performs well under different conditions, and that it is user-friendly. In this context, we wanted to measure if the application meets the requirements for what it was designed, so extensive testing against user stories was performed. The following table shows the user stories that have been completed and are part of the CI component delivered under the 1st version of the AI Toolkit

Table 5 – Collaborative Intelligence Platform – User Stories Completion Status

Id	Acceptance Criteria	Planned for (version)	Implemented in (version)	Comments
US.CI.01	To monitor a process to detect anomalies.	v1	v1	This story was conducted using the validation and monitoring component. We tested it in three different scenarios, and it performed well.
US.CI.02	To understand a process to optimize it.	v1	v1	The output component enabled the visualization of the difference between the expected output value and the value produced by the edge ML model. This allowed users to understand and refine the prediction strategy in three different scenarios.
US.CI.03	To visualize the outcome of a process to be sure of its quality.	v1	v1	The input analysis was used for this purpose, and the visualization succeeded in three different scenarios. However, it is important to note that in some cases, more complete knowledge graphs could be generated compared to other cases where the sensors were only minimally related to each other.

4.1.2 Open Hardware Platform

The following table shows the user stories that have been completed and are part of the Open Hardware component delivered under the 1st version of the AI Toolkit. The technical validation process for the Open Hardware Platform involved the following steps:

1. Initial Setup and Configuration: The ESP32 was configured using the web-based portal to set up network and MQTT settings.
2. Model Deployment: A trained machine learning model was uploaded to the ESP32 and configured to process input data via MQTT.
3. Functionality Testing: Each user story was tested by simulating real-world scenarios to ensure the ESP32 performed as expected.
4. Data Collection: Results were gathered on the system's performance, accuracy of predictions, and overall reliability.

The validation process demonstrated that the ESP32 could effectively handle the deployment and execution of TinyML models. The web-based configuration portal provided a user-friendly interface for setup, and the system successfully processed and responded to real-time data inputs. The results indicated strong performance in terms of prediction accuracy and reliability, confirming the platform's suitability for edge AI applications in IoT environments.

Table 6 – Open Hardware Platform – User Stories Completion Status

Id	Acceptance Criteria	Planned for (version)	Implemented in (version)	Comments
US.OH.01	The trained machine learning model is optimized for TinyML. The model can be successfully deployed on the ESP32.	v1	v1	The TinyML model was successfully trained and optimized. Performance tests confirmed the model's efficiency and suitability for deployment on the ESP32.
US.OH.02	The machine learning model is successfully converted to TensorFlow Lite format. The converted model retains its integrity and functionality.	v1	v1	The model was converted to TensorFlow Lite format without issues. Tests verified that the model maintained its performance and accuracy post-conversion.
US.OH.03	TThe machine learning model is successfully converted to TensorFlow Lite format. The converted model retains its integrity and functionality.	v1	v1	The model was uploaded to the ESP32 using the /uploadModel endpoint. Deployment was successful, and the model was able to run on the device.
US.OH.04	The ESP32 can be configured using the /configure endpoint. The JSON configuration is applied correctly, and the device operates with the provided parameters.	v1	v1	Configuration via the /configure endpoint was successful. The ESP32 operated correctly with the configured parameters.

US.OH.05	The ESP32 provides a captive portal for WiFi configuration. Users can easily set up and change WiFi settings through the portal.	v1	v1	The captive portal for WiFi configuration was user-friendly and efficient. Users were able to set up and modify network settings without difficulty.
US.OH.06	The ESP32 can be configured with MQTT broker details and topics through a web interface. The device successfully communicates with other devices and services using the configured settings.	v1	v1	MQTT configuration via the web interface was straightforward. The ESP32 successfully communicated with other devices and services using the specified MQTT settings.
US.OH.07	The ESP32 processes real-world data inputs and provides accurate predictions. The predictions are validated against expected outcomes.	v1	v1	Real-world data was successfully fed into the ESP32. The device provided accurate predictions, validating its performance and reliability in an industrial setting.

4.1.3 Cloud-to-Edge AI Pipeline Lifecycle Management Platform

The following table shows the user stories that have been completed and are part of the AIP component delivered under the 1st version of the AI Toolkit.

The different tests have been primarily performed internally, engaging both developers and data scientists from the company in order to verify the correct execution of the different functions of the platform, while also end-users have been consulted to define the UI/UX experience that has been designed to match the needs of the project.

Extensive tests have been performed using sample data acquired either from open-source datasets as well as from selected partners of the project, to verify the data ingestion and the AI execution processes of the platform.

Table 7 – AI Pipeline Lifecycle Management Platform – User Stories Completion Status

Id	Acceptance Criteria	Planned for (version)	Implemented in (version)	Comments
US.AP_01	User Story Acceptance criteria	v1	v1	
US.AIP.01	Access over the AIP platform data that is collected via an API Access over the AIP platform the same dataset file that is pushed via an API	v1	v1	Ability to upload data via APIs or direct file uploads exists 100% of data pushed to the platform is accessible
US.AIP.02	Data Stream Data can be accessed through the AIP platform	v1	v1	Ability to ingest data streams exists Data stream content available in the data storage of the AIP platform

US.AIP.04	Trained Models are made available after applying a train block	v1	v1	Trained Models have been created and also tested offline
US.AIP.05	Combining AI blocks to finalise an AI pipeline	v1	v1	The execution of the AI pipeline ran without problems
US.AIP.07	Delivery of deployable AI model package Execution of model container on Edge hardware	v1	v1	Sending the AI model and AI Execution over Edge infrastructure has been tested
US.AIP.08	Execution of AI model over cloud delivers results	v1	v1	AI Execution over Cloud has been tested
US.AIP.10	AI results file can be downloaded	v1	v1	Results from the platform are made available as JSON downloads

4.2 User Technology Acceptance

User technology acceptance was based on qualitative evaluation from end users using a structured questionnaire (as discussed in section 2 and presented in Annex A) to measure the Technology Acceptance of the different components. Answers to the questionnaire were anonymous during this round, while in the following rounds the questionnaire will require named responses, in order to allow the developers to come in direct contact with the respondents to better understand their needs.

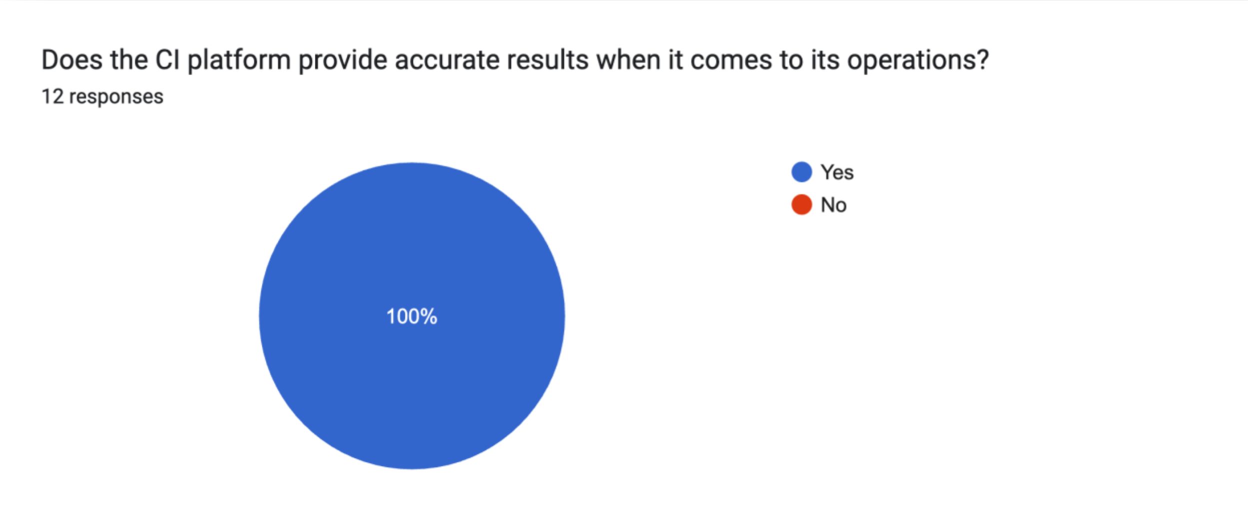
During this round, and only for the 1st prototype of the AI Toolkit and its subcomponents, this evaluation has been performed by engaging with a closed group of persons coming from both the technical partners which developed the different tools, as well as from stakeholders that will execute pilot use cases under the AI REDGIO 5.0 project and who have been approached to test initial designs and functionalities of the tools.

During the second period, and towards the final release of the AI Toolkit, this group will be enlarged and will consider all pilot partners as well as the Open Call winner stakeholders.

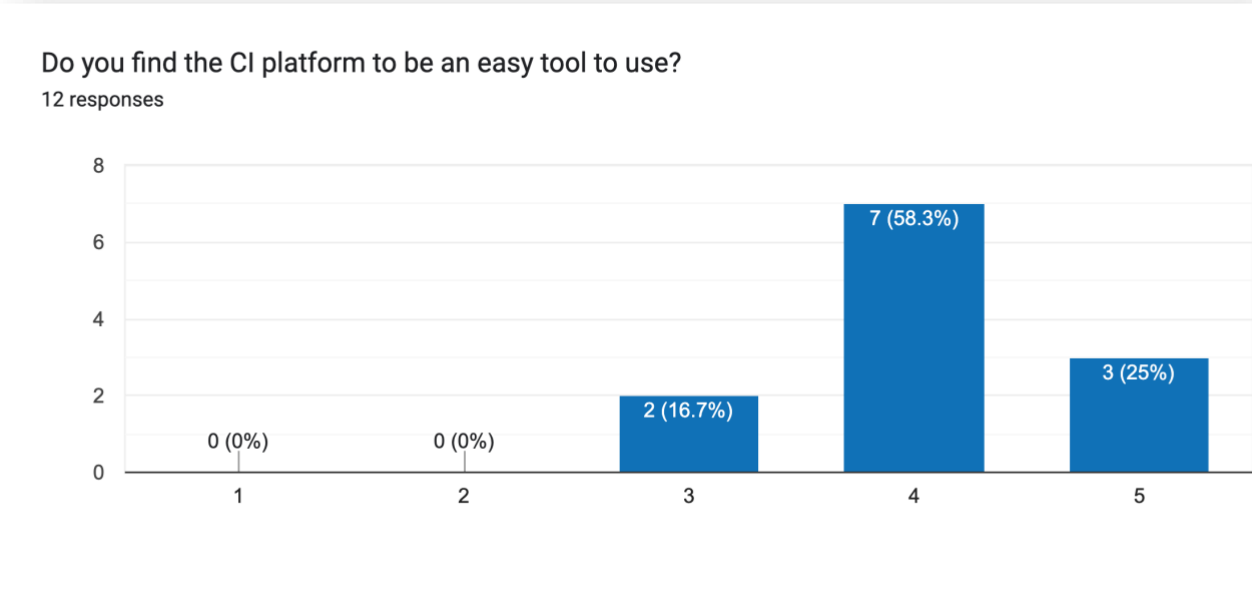
4.2.1 Collaborative Intelligence Platform

The validation of the CI platform was performed using a questionnaire. The questionnaire aimed at evaluating the CI platform's performance and user experience. It asked if the platform provides accurate results, is easy to use, and helps users achieve their goals. It also inquires whether the platform integrates human input effectively for specific use cases, and whether users find it useful and trustworthy. The questionnaire assessed the platform's usability features, its accessibility for disabled users, and the satisfaction derived from its aesthetics and overall user experience. Additionally, feedback on whether the platform offers a comfortable user interface and workflow has been requested.

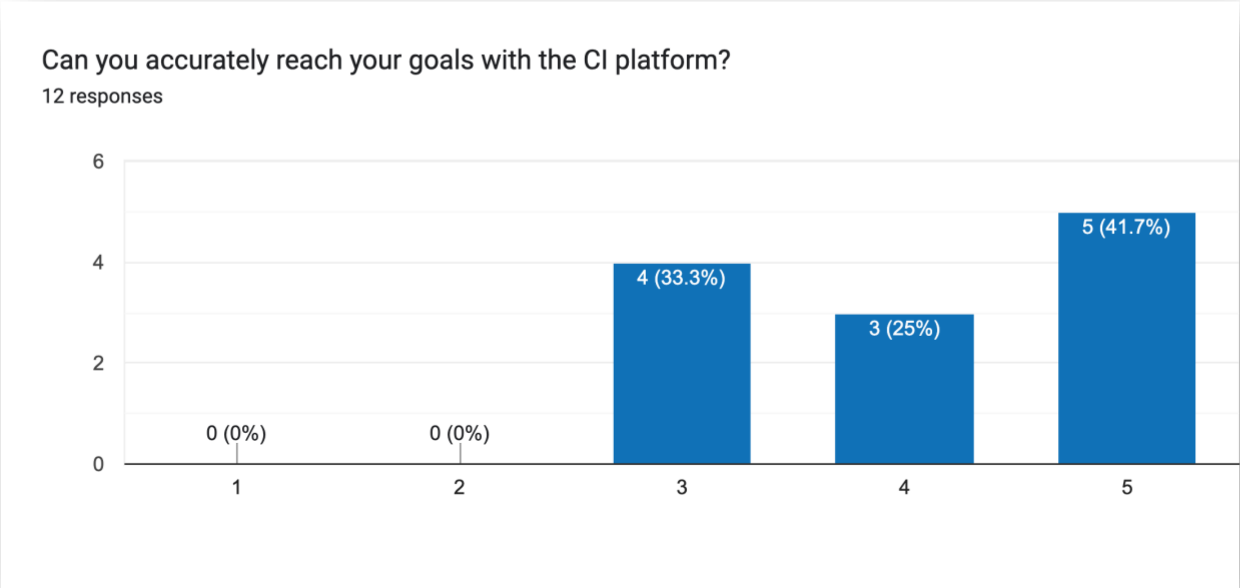
The results show that the CI platform generally provides accurate results, with most respondents indicating high trust in its operations and outcomes. Users find it easy to use and effective in helping them achieve their goals, particularly appreciating its ability to meet the intended purpose of integrating human input as needed. The platform is considered useful, with many users finding it trustworthy and equipped with enhanced usability features. While opinions vary, many users believe disabled individuals can use it. The aesthetics of the UI are generally satisfying, contributing to a pleasing and comfortable user experience.



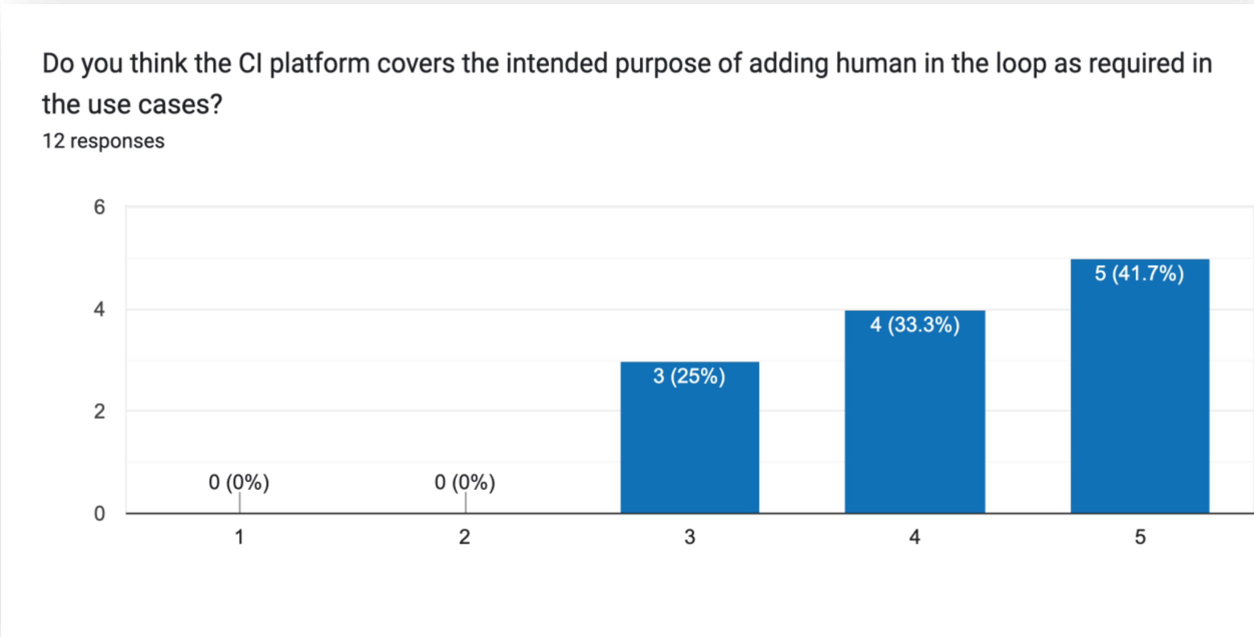
The Figure shows us that the users have agreed (100%) that the CI platform provide accurate results when it comes to this operation.



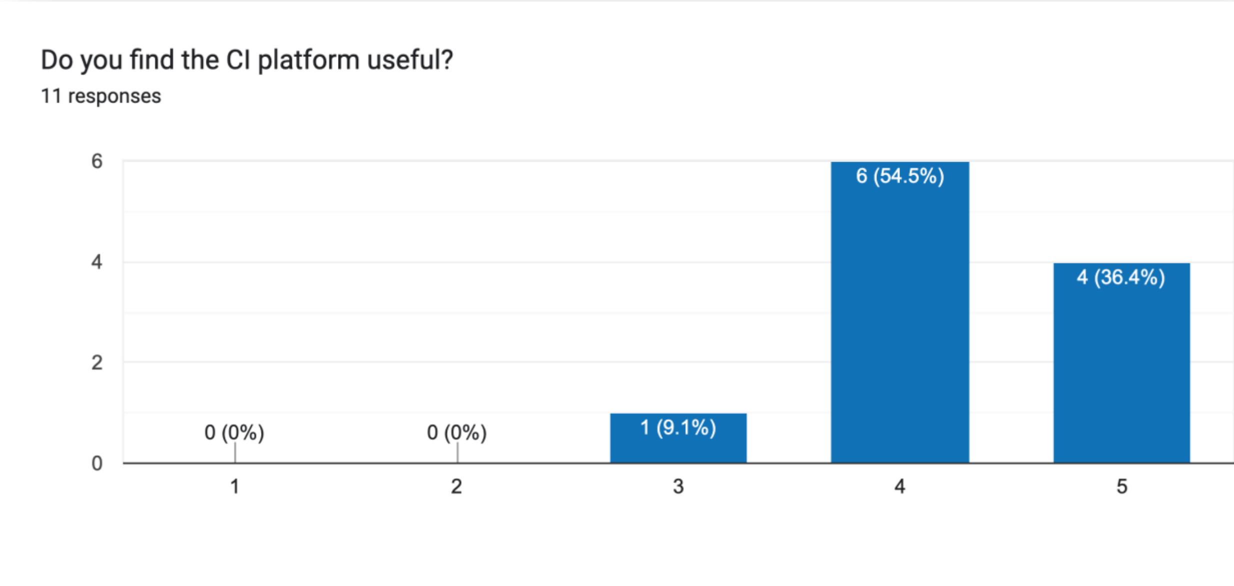
Most users find the CI platform easy to use, although most of them give a 4 in this aspect.



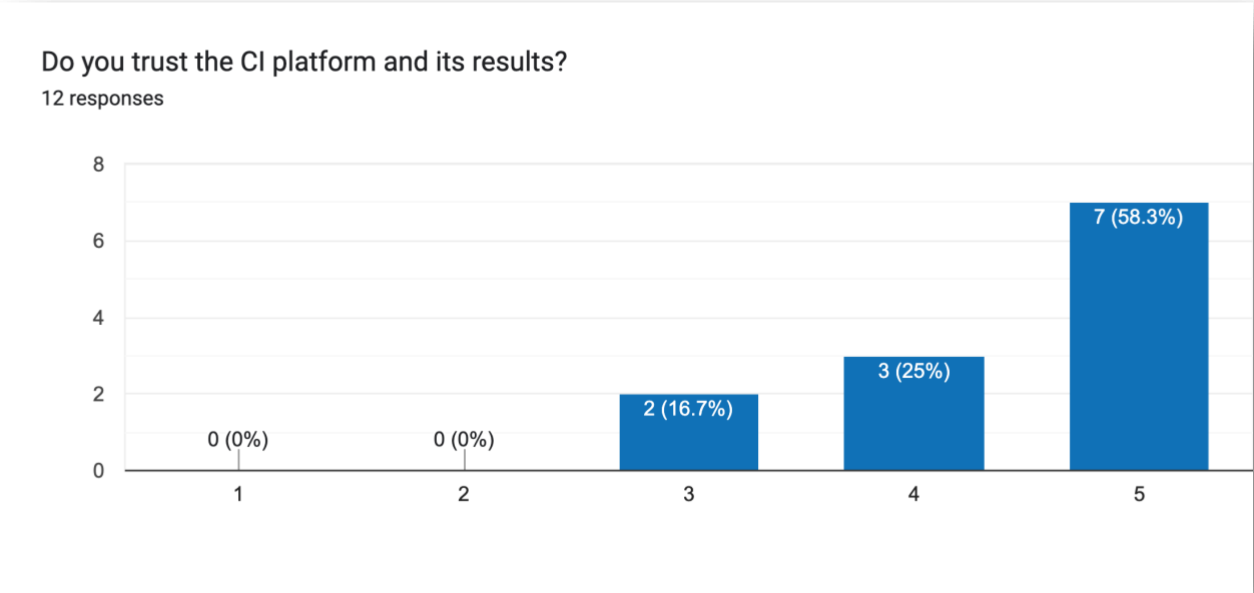
Most users find the CI platform generally effective in helping them reach this goal, with ratings ranging from 3 to 5.



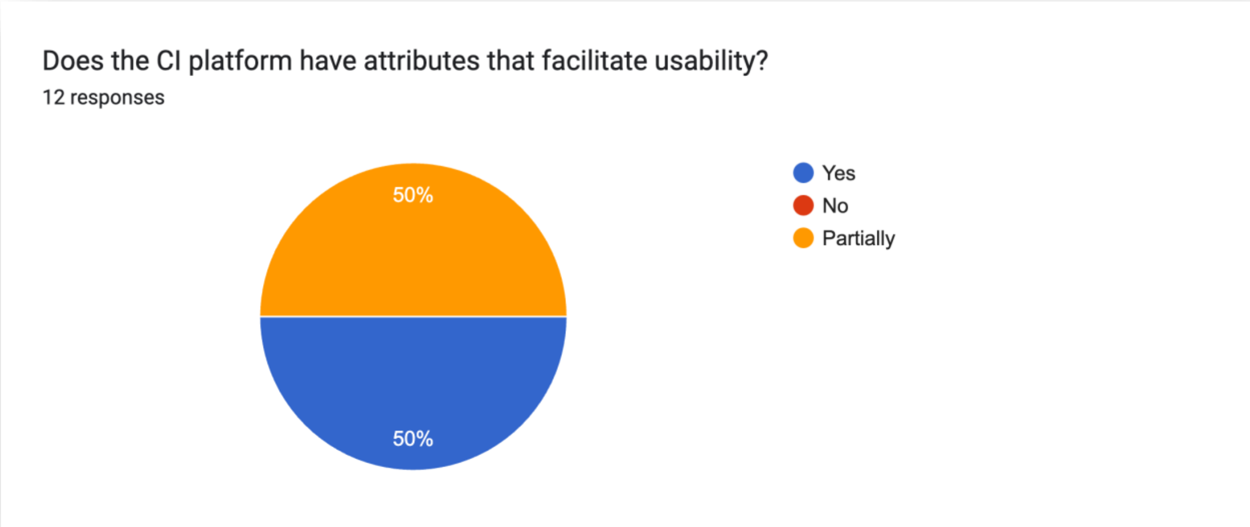
Most users think that the platform integrates human in the loop, although it is true that not all agree on the degree of success in this aspect.



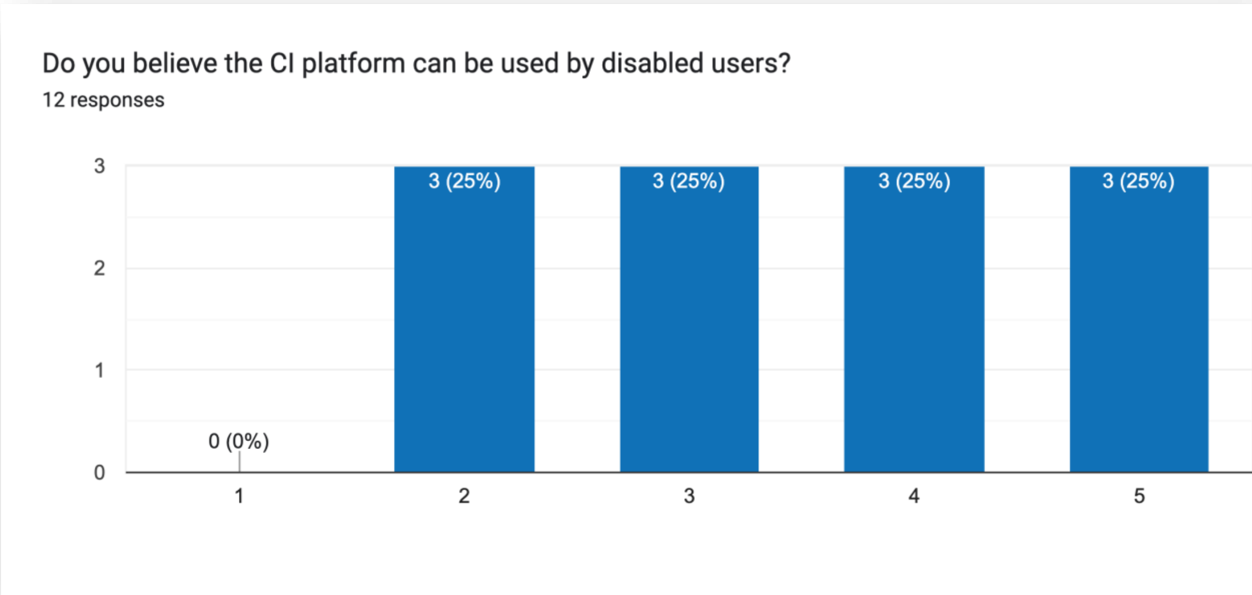
Most users find the CI platform useful in this regard, with ratings predominantly at 4 or 5.



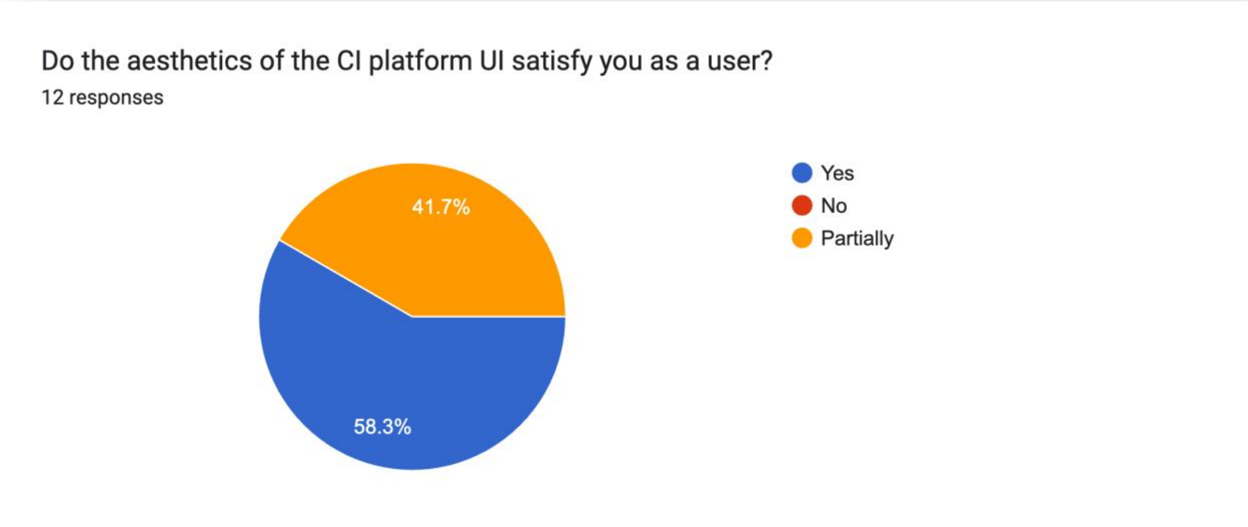
Most people consulted are confident in the results of the CI platform, although some are aware that it is still a test solution and should move towards higher TRLs in the coming months.



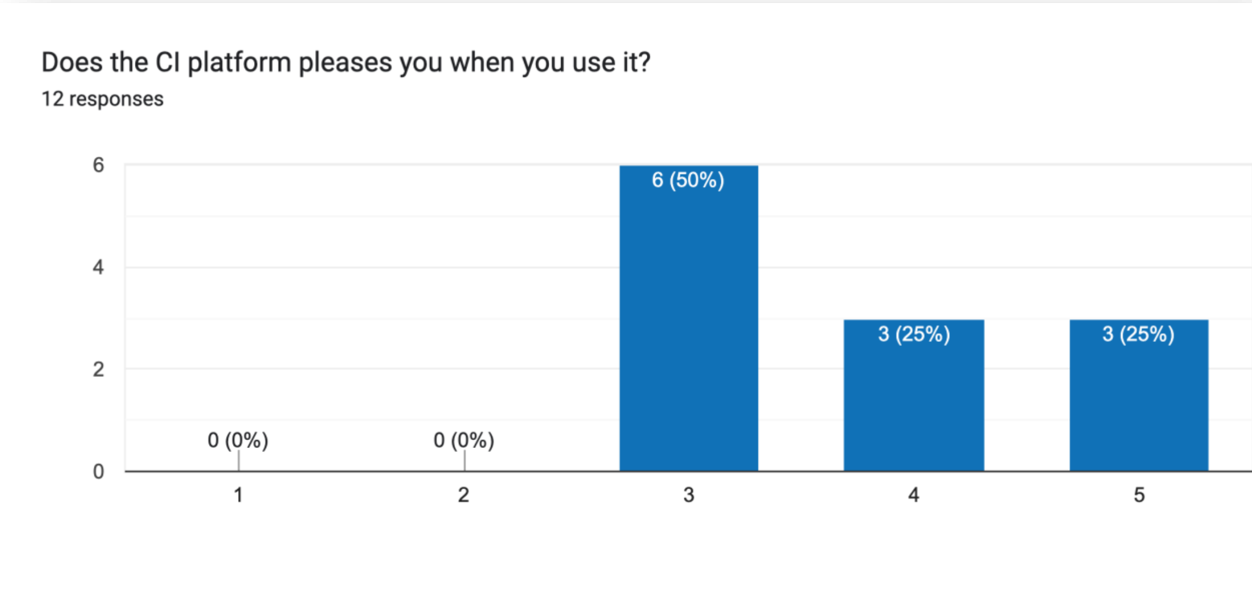
No one thinks that the usability of the platform is bad, but half of the respondents think that there are aspects that can be improved in relation to usability.



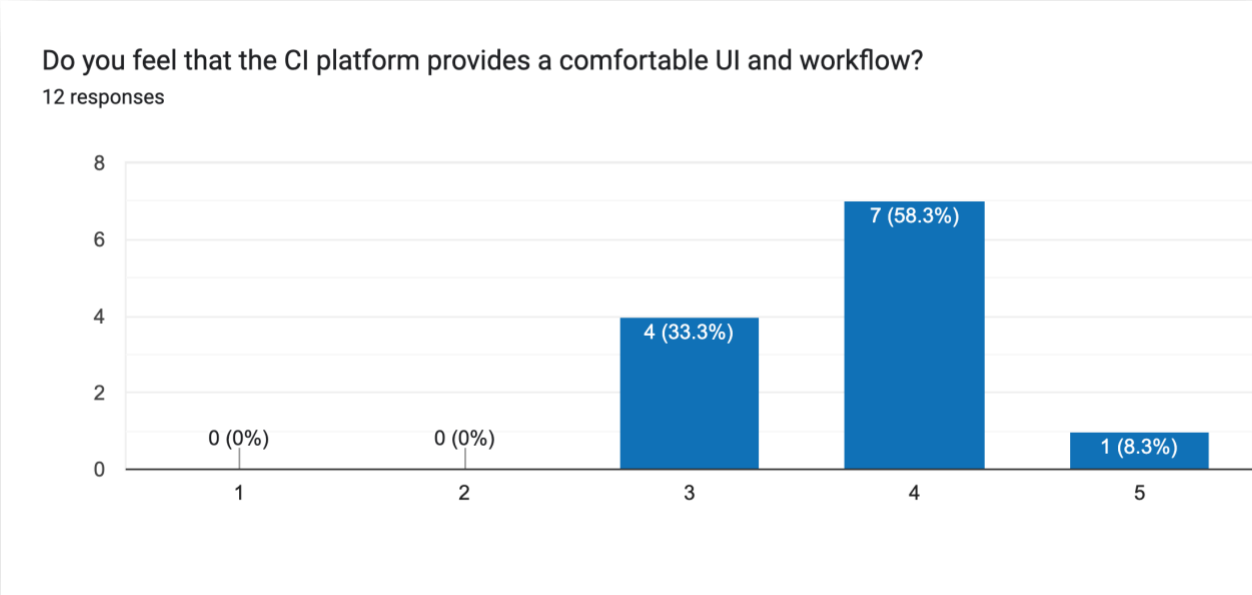
The aspect that has generated the most divergence has been the question of whether they believe that disabled people could use the solution. As can be seen there is a great disparity of opinions ranging from 2 to 5.



A significant percentage of the people consulted think that more can be done to improve the aesthetics of the front of the CI platform.



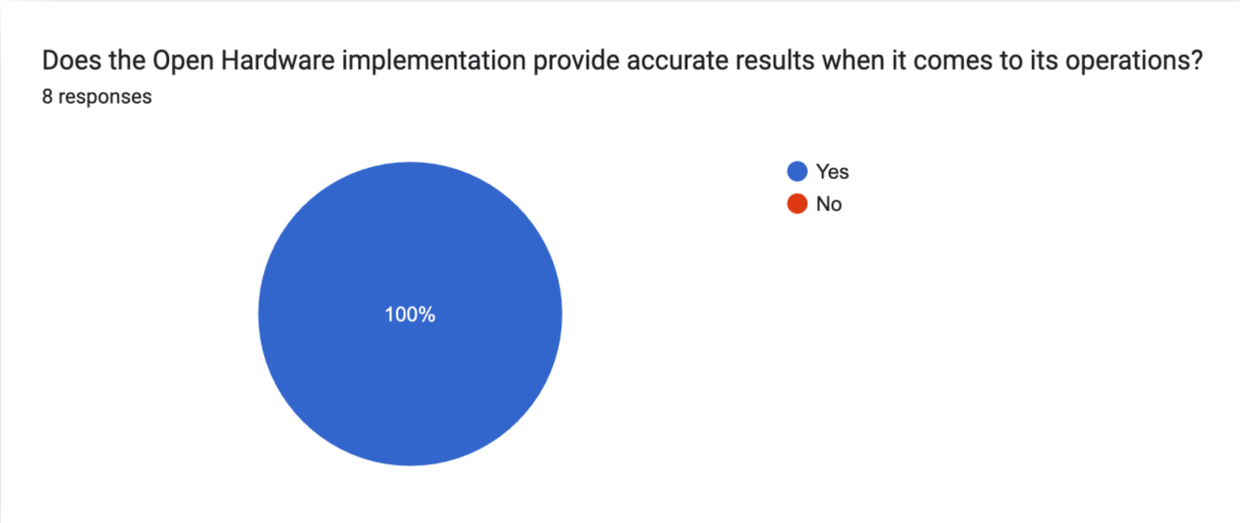
Perhaps the unfinished business of the CI platform is to provide a higher level of comfort to the user, since a majority gives a 3 in this aspect.



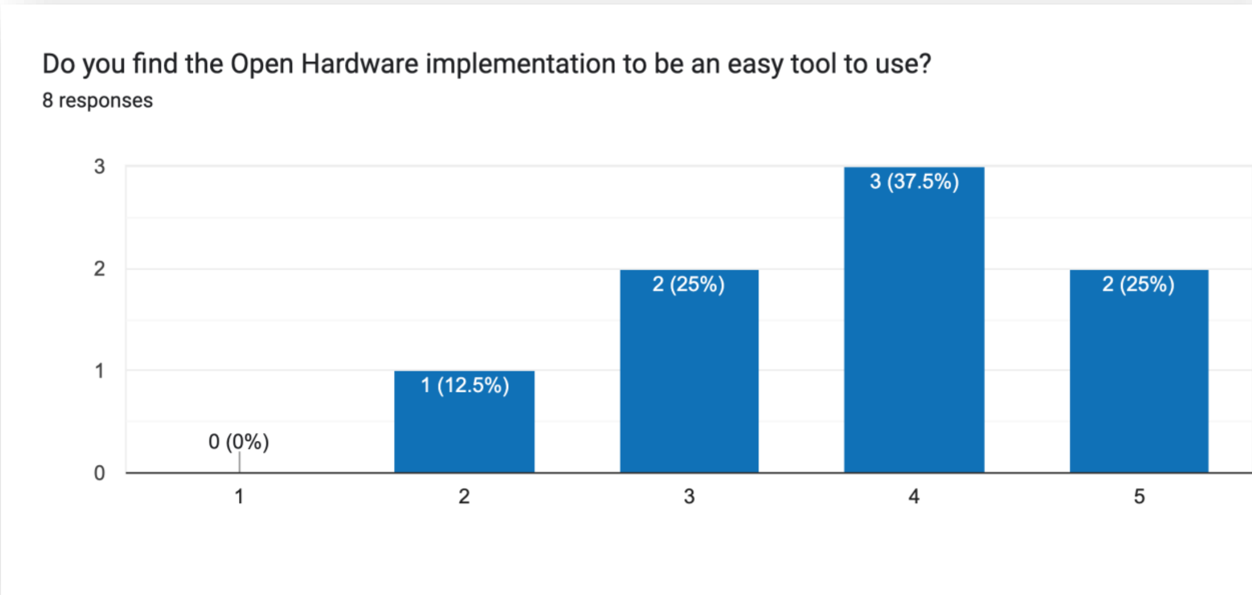
A significant percentage of the people consulted think that more can be done to improve the external appearance of the CI platform. Keep in mind that the first versions have been developed in HMTL, which is a language that can be used to build prototypes very quickly, but we will enrich it with CSS and JavaScript as the project progresses.

4.2.2 Open Hardware Platform

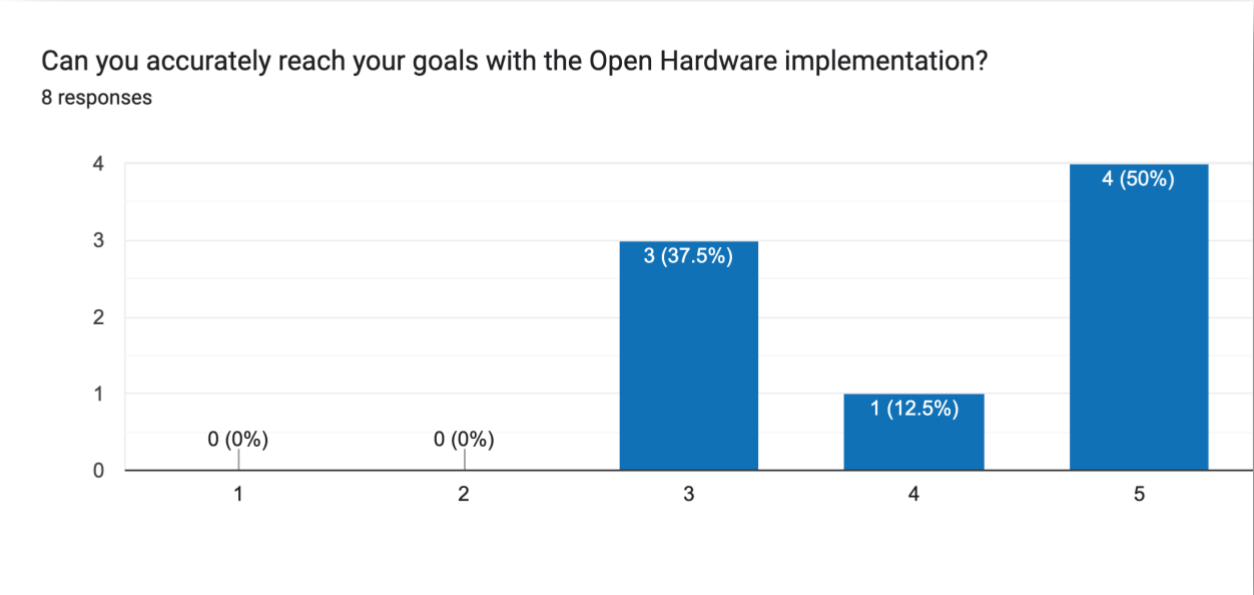
The U.A verification process involved distributing a detailed questionnaire to users who interacted with the Open Hardware system. Their feedback on the system's accuracy, usability, and performance was collected and analysed to assess overall reliability and identify areas for improvement, ensuring comprehensive user acceptance evaluation.



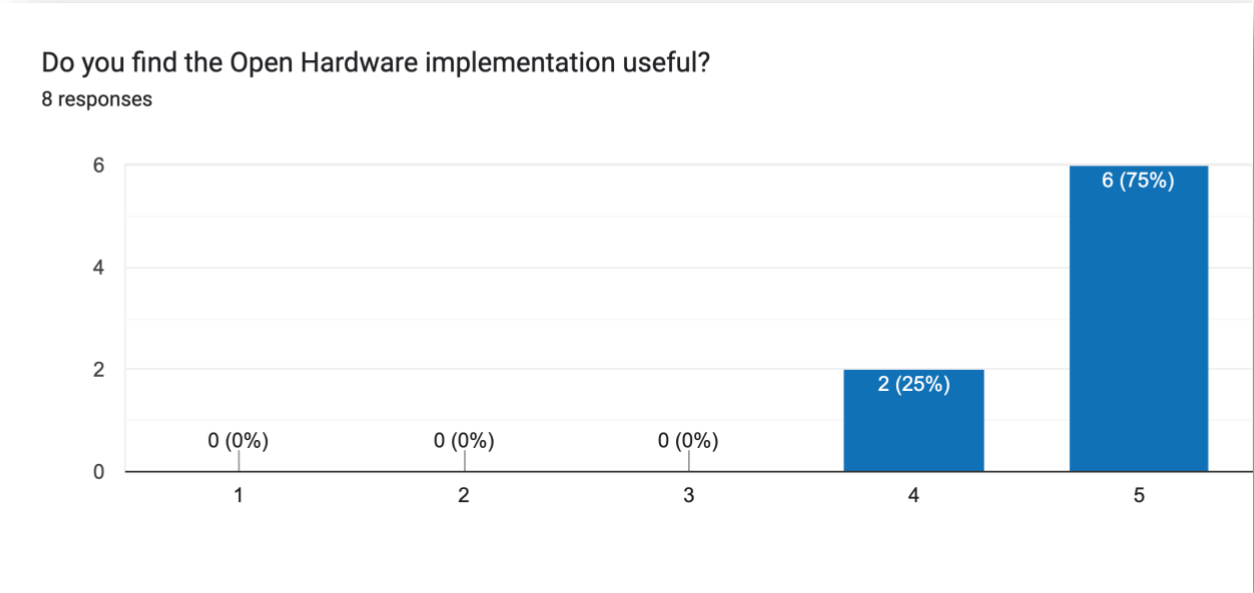
The unanimous positive feedback indicates that the Open Hardware implementation is performing well in terms of operational accuracy. This is a strong validation of the system's reliability and effectiveness. It suggests that the TinyML models and the overall setup are correctly configured and are delivering the expected performance. Moving forward, maintaining this level of accuracy will be crucial as the project scales and integrates with more complex industrial environments.



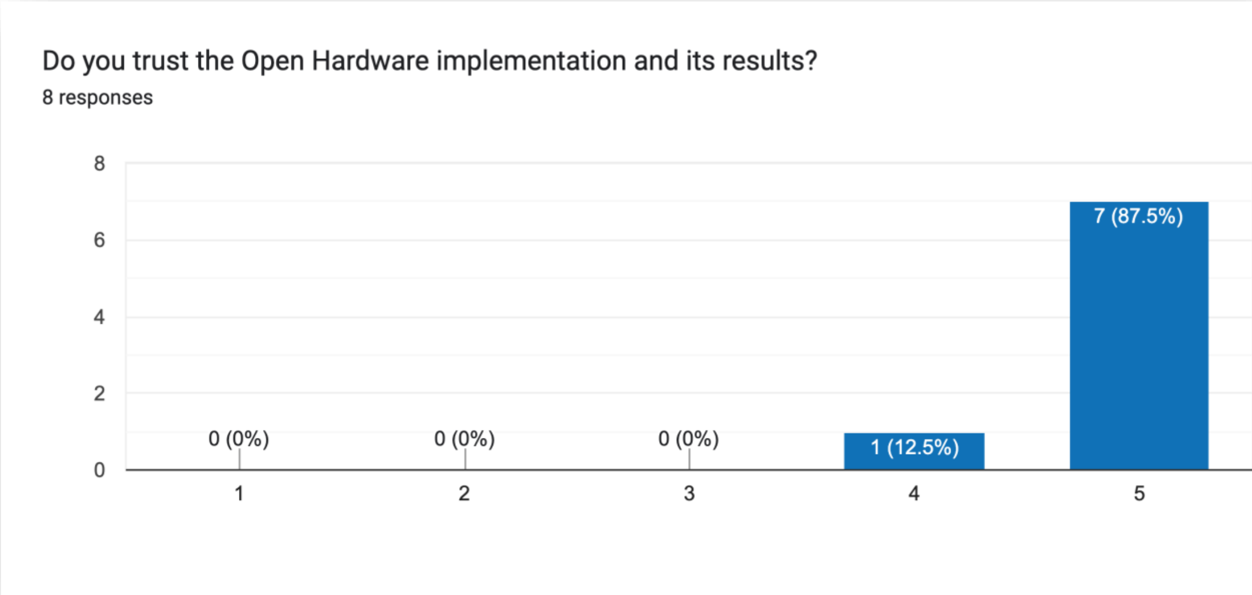
The majority of respondents (5 out of 8) rated the Open Hardware implementation as 4 or 5 stars, indicating that it is generally perceived as easy to use. However, the lower ratings from 3 respondents (3 and 2 stars) suggest that there may be aspects of the user interface or overall usability that could be improved. This feedback highlights the need for a more intuitive design or additional user training to enhance ease of use and ensure a smoother user experience for all users.



Most respondents (5 out of 8) gave high ratings (4 or 5 stars), indicating that the Open Hardware implementation effectively helps users achieve their goals. However, with 3 respondents rating it 3 stars, there is a noticeable segment of users who find it moderately effective. This suggests that while the implementation is generally successful, there may be specific areas or functionalities that could be enhanced to improve goal achievement for all users. Further investigation into the lower ratings could provide insights into specific challenges or limitations faced by these users.

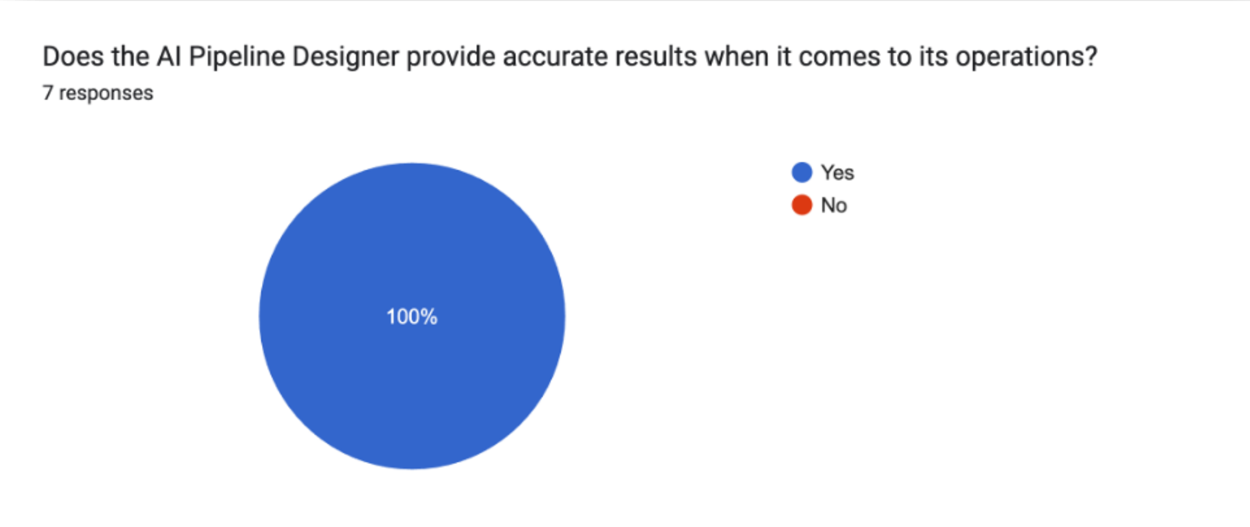


The positive responses, with all 8 respondents rating the implementation 4 or 5 stars, indicate that the Open Hardware implementation is highly valued and considered useful by users. This strong endorsement underscores the system's relevance and effectiveness in meeting user needs. While the feedback is very positive, continuous improvements and updates will help maintain and potentially enhance this high level of user satisfaction.

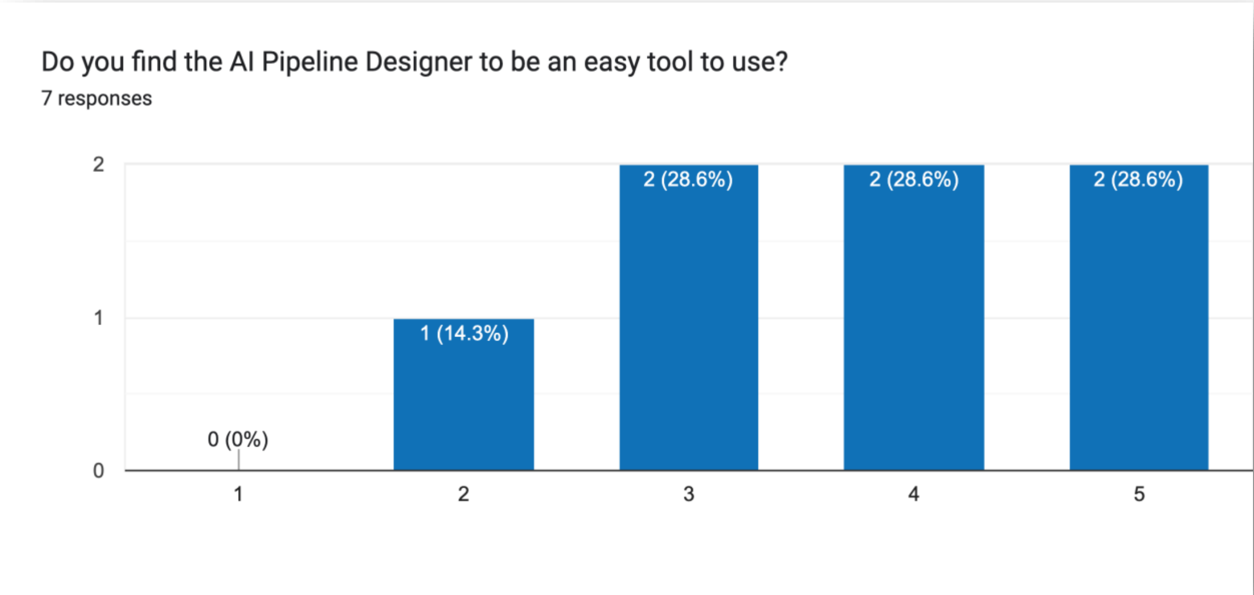


The responses reflect a high level of trust in the Open Hardware implementation and its results, with 7 out of 8 respondents giving it the highest rating of 5 stars and 1 respondent giving it 4 stars. This indicates strong confidence among users regarding the accuracy and reliability of the system. Such positive feedback highlights the robustness and dependability of the implementation, affirming its credibility in practical applications.

4.2.3 Cloud-to-Edge AI Pipeline Lifecycle Management Platform



As identified by the different responders, the AI pipeline component is in principle delivering results that are highly accurate, when also compared with other AI solutions following the same model configuration and data inputs. This is one of the most important aspects for this component, as the accuracy of the AI operations is highly required.



In terms of easy of use, the AI Pipeline platform received mostly positive remarks. This is due to the core design decision behind the platform, where many of the AI design functions are performed through a user interface, that makes it easy for users to develop their AI pipelines.

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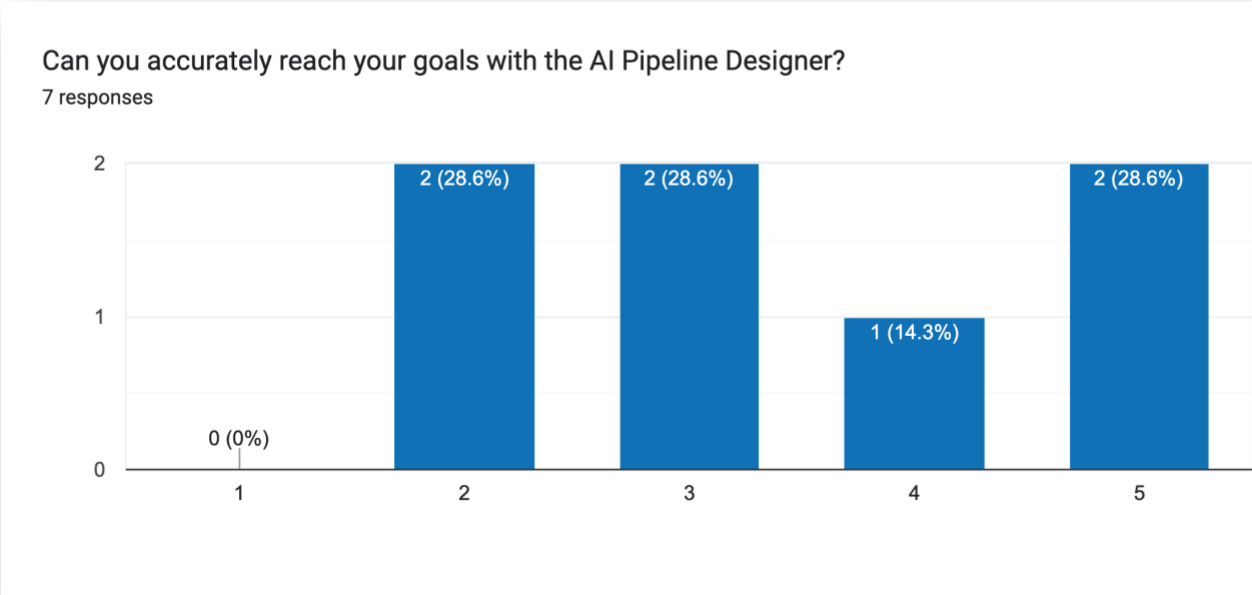
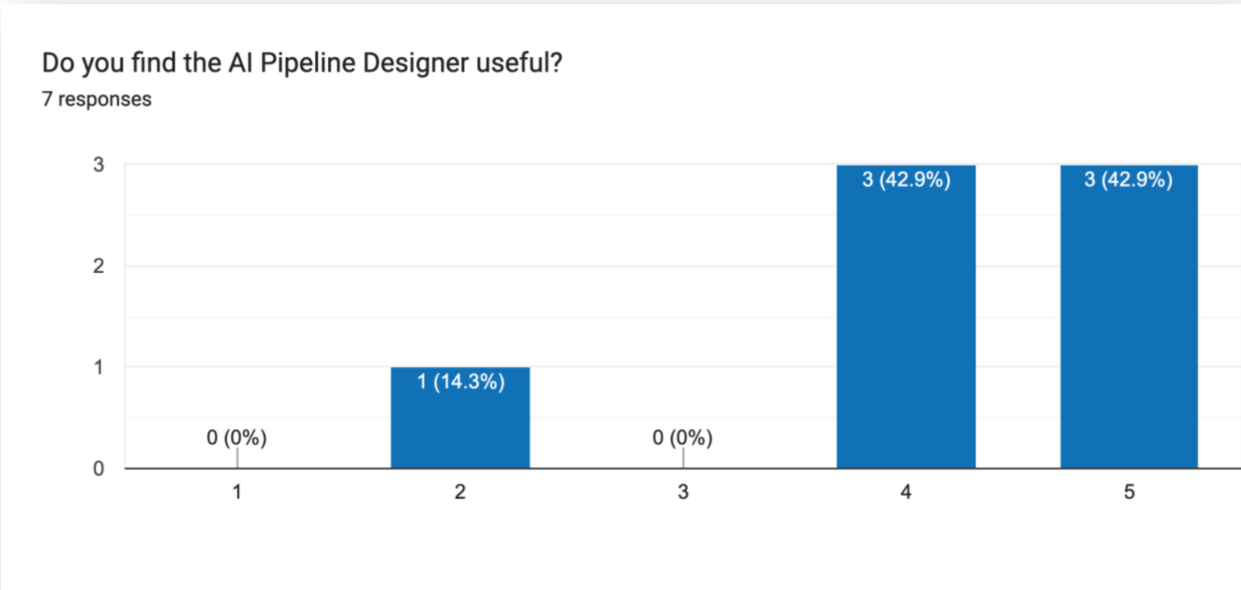
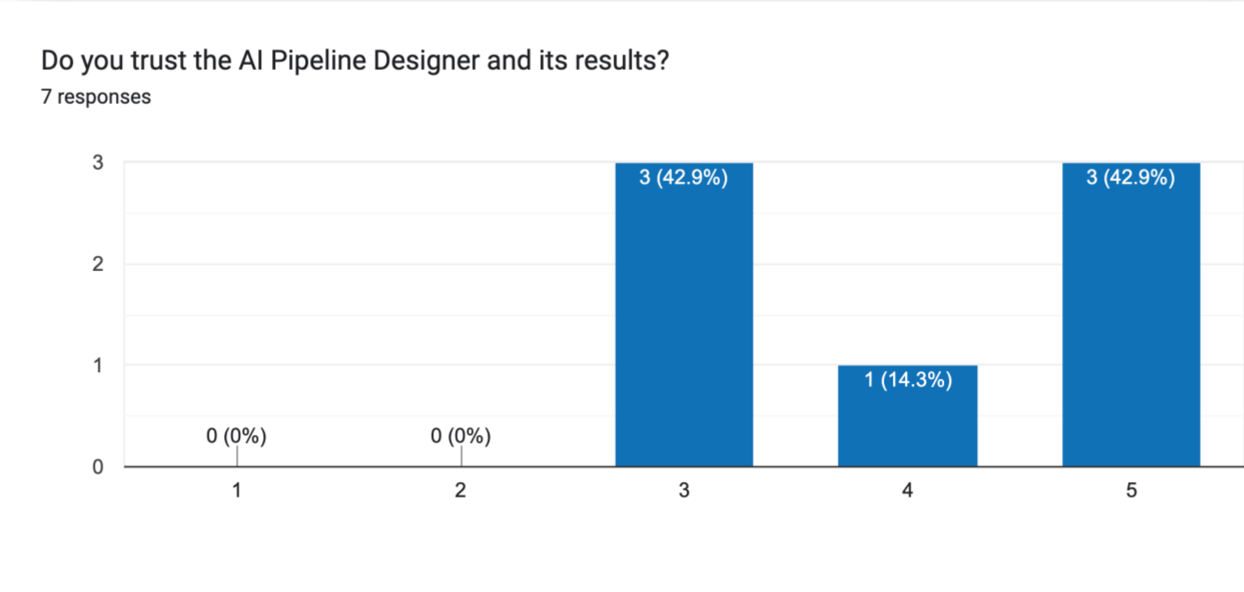


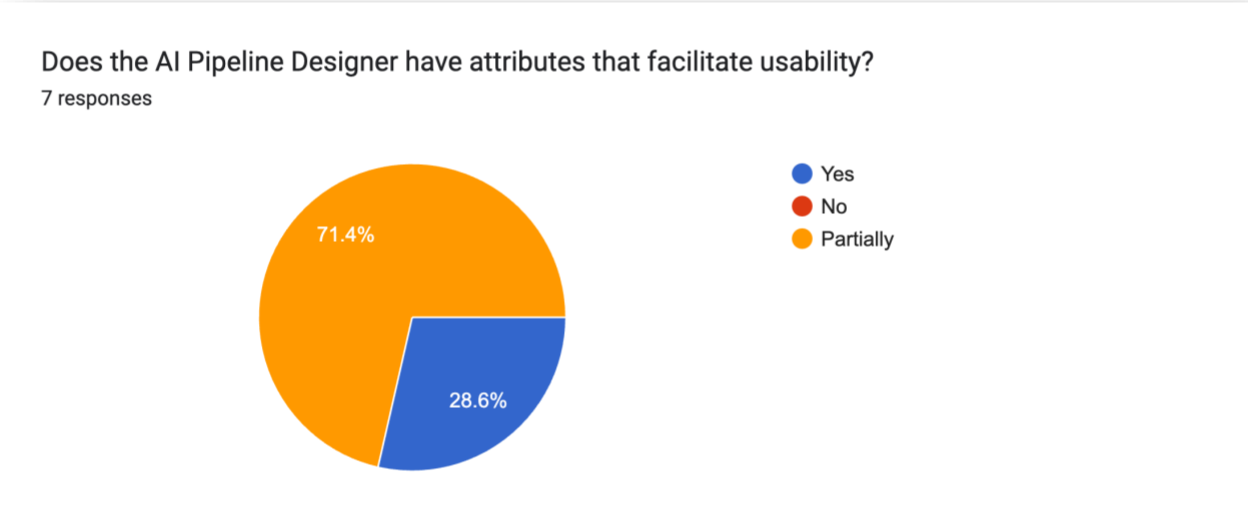
Reaching the goal of designing AI pipelines and executing them also has received positive remarks. However, some slightly negative answers were also recorded, but those came from people with not adequate data science background knowledge, thus more explanations and tooltips will be added to the platform to guide users through the process of designing an AI pipeline end to end.



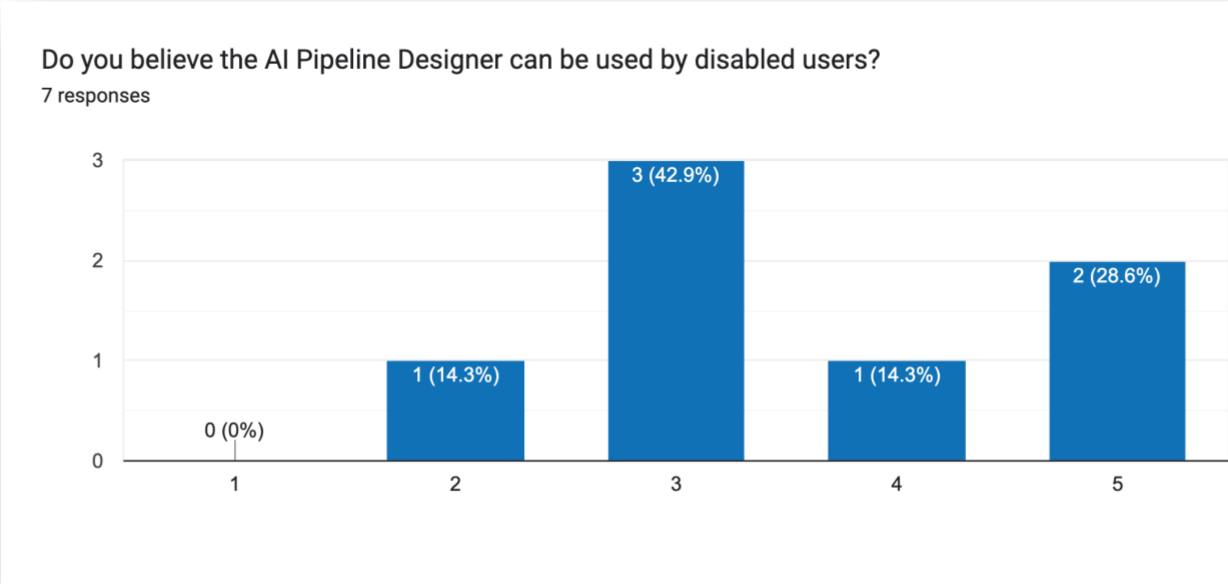
In terms of usefulness, the majority of respondents claim that the platform useful as a tool to deliver production-grade AI pipelines. The negative answer came with the comment that the AI pipeline desinger can be replaced by other AI/ML model development tools, such as notebooks, which however are not considered equally robust for production grade applications.



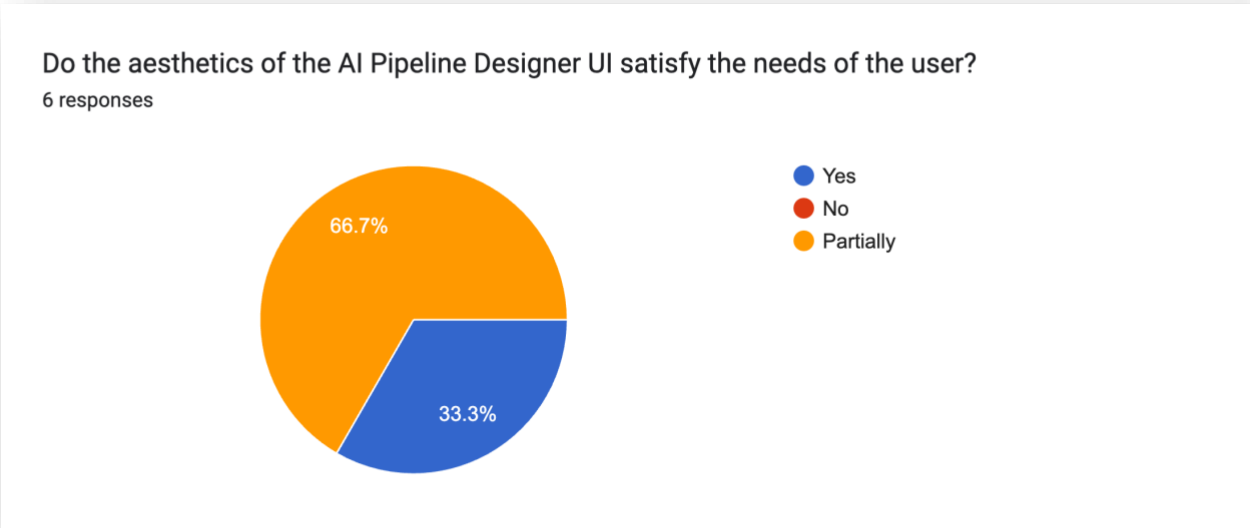
Trust in the results of the AI pipeline platform are in general positive, as coming out of the questionnaire.



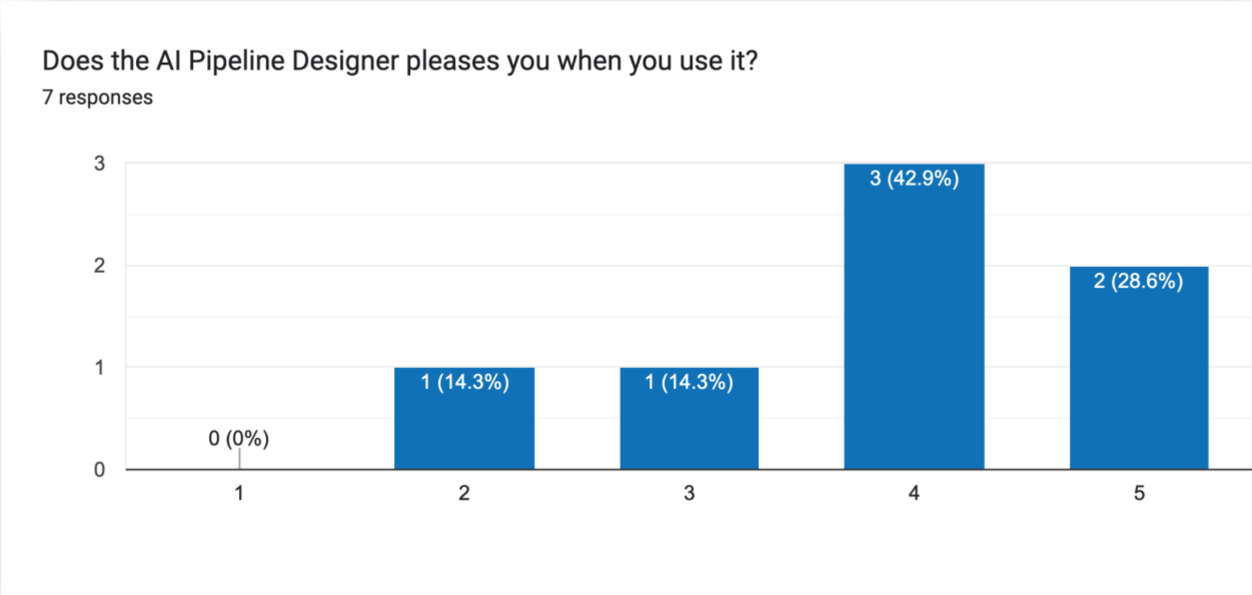
In terms of usability, the majority of respondents answered that the platform provided partially usability, and this is interpreted due to lose integration approach chosen for this 1st version of the platform.



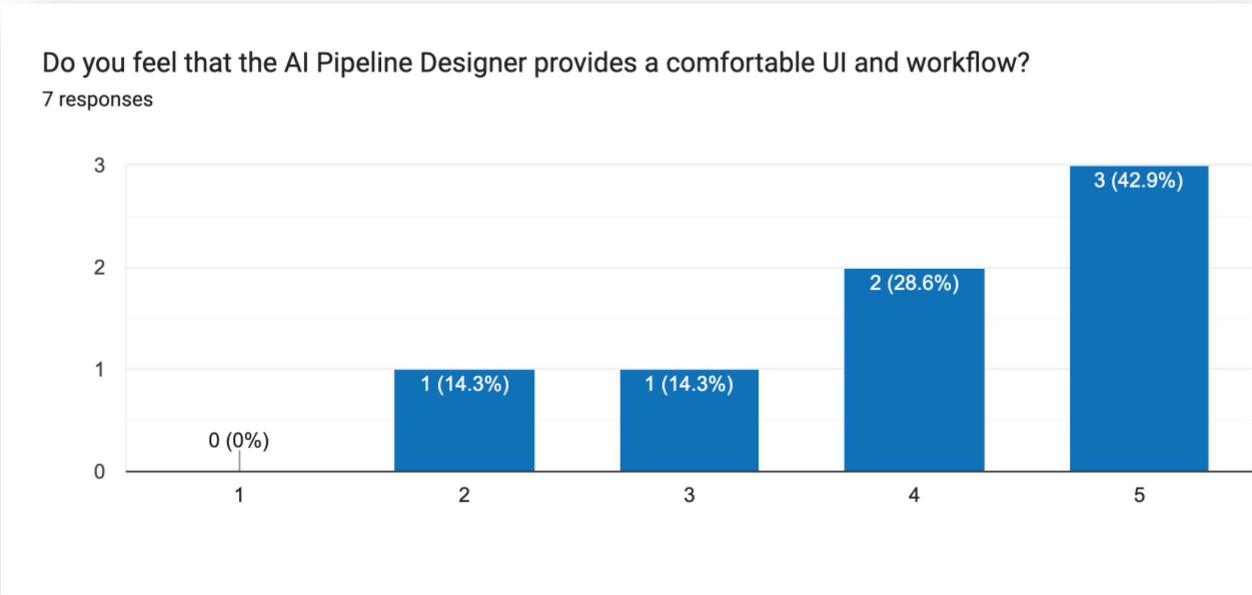
In terms of utilisation by disabled users high scores were obtained. However, it is noted that due to the platform being based highly on visual elements that represent functions, these scores are not expected to raise in the near future, as the different frameworks that allow the exploitation of visual artefacts for generating dashboards and to be placed over workbenches, are not fully supporting accessibility functionalities.



In principle, the majority of respondent answered that the aesthetics of the component partially satisfy the users. This resolution is logical, as during the 1st version of the component limited focus was placed on the aesthetics of the platform, which is a task to be performed prior to the release of the final version of the component.



In terms of feeling comfortable with the AI Pipeline designer, most of the respondents provided positive feedback.



Similar to the previous question, most respondents provided positive feedback about the current UI/UX of the platform, which is expected to be further improved in the next version.

5 Next Steps

The deliverable at hand reports on the first version of the integrated AI REDGIO 5.0 AI Toolkit, which includes the set of components that are tasked to support the different experiments and stakeholders of the domain to design, execute and evaluate AI pipelines that are required to solve their business problems.

The next steps towards the finalization of the AI Toolkit, the following have been identified:

- Technical Support to the SMEs, DFs and the Open Call winners, through direct mentorship of those stakeholders, and bi-weekly meetings to accommodate any discussions that are relevant to the WP5 outputs
- Further development, feature enhancement and improvement of the different sub-components of the AI Toolkit, as new versions of those components are expected in the second period of the project, and those will be then forwarded for integration
- Tighter integration of the AI Toolkit components with each other, to allow the seamless flow of information and control from one component to the other
- Continuous debugging and code improvements of the integrated prototype and its sub-components, following the code quality assurance practices followed by the different partners.
- Integration with data components from WP4, to allow WP5 tools to directly ingest data from the tools developed under WP4 and to have the AI tools ingest data of higher quality
- Wider validation, feedback acquisition and improvement. The activities of the verification and validation will be intensified during the development of the second version of the AI Toolkit, where verification will be also performed at the integrated toolkit level, while the validation from the end-users (e.g. technology acceptance assessment) will be sought by all engaged end-users, coming whether form the consortium (SMEs/DFs/etc) as well as from the Open Call winners
- Delivery of the final version of the AI Toolkit in M33, to facilitate the different use cases of the project and to allow domain stakeholders to access it and perform their AI operations.

6 References

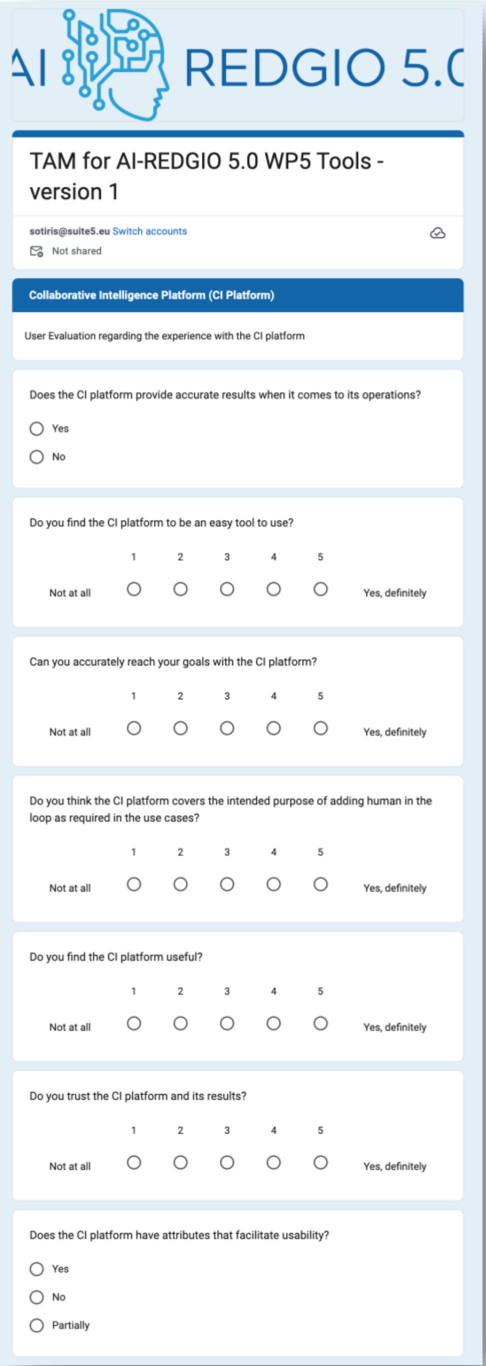
[1] Buchgeher, G., Gabauer, D., Martinez-Gil, J., & Ehrlinger, L. (2021). Knowledge graphs in manufacturing and production: A systematic literature review. IEEE Access, 9, 55537-55554.

[2] Martinez-Gil, J., Hoch, T., Pichler, M., Heinzl, B., Moser, B., Kurniawan, K., ... & Krause, F. (2024). Examining the Adoption of Knowledge Graphs in the Manufacturing Industry: A Comprehensive Review. Artificial Intelligence in Manufacturing: Enabling Intelligent, Flexible and Cost-Effective Production Through AI, 55-7.

ANNEX

User Technology Acceptance Questionnaire

The following screenshot provides a part of the TAM questionnaire used for evaluating the different components from the user side.



AI REDGIO 5.0

TAM for AI-REDGIO 5.0 WP5 Tools - version 1

sotiris@suite5.eu Switch accounts

Not shared

Collaborative Intelligence Platform (CI Platform)

User Evaluation regarding the experience with the CI platform

Does the CI platform provide accurate results when it comes to its operations?

- Yes
- No

Do you find the CI platform to be an easy tool to use?

Not at all 1 2 3 4 5 Yes, definitely

Can you accurately reach your goals with the CI platform?

Not at all 1 2 3 4 5 Yes, definitely

Do you think the CI platform covers the intended purpose of adding human in the loop as required in the use cases?

Not at all 1 2 3 4 5 Yes, definitely

Do you find the CI platform useful?

Not at all 1 2 3 4 5 Yes, definitely

Do you trust the CI platform and its results?

Not at all 1 2 3 4 5 Yes, definitely

Does the CI platform have attributes that facilitate usability?

- Yes
- No
- Partially

Figure 18 – Online TAM Questionnaire Screenshot