# Initial requirements specification

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# Technical References

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|---|---|
| Project Acronym | RECLAIM |
| Project Title | RE-manufaCturing and Refurbishment LArge Industrial equipMent |
| Project Coordinator | HARMS & WENDE GMBH & CO KG |
| Project Duration | 1/10/2019 – 31/03/2023 |

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[1] PU = Public
PP = Restricted to other programme participants (including the Commission Services)
RE = Restricted to a group specified by the consortium (including the Commission Services)
CO = Confidential, only for members of the consortium (including the Commission Services)

# Document history

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# Abbreviations and Acronyms

| Abbreviation | |
|---|---|
| BB | Building Block |
| DoA | Description of Action |
| DSF | Decision Support Framework |
| Dx.y | Number of Deliverable |
| EC | European Commission |
| IoT | Internet of Things |
| KPI | Key Performance Indicator |
| MTBF | Mean Time Between Failure |
| MTTF | Mean Time To Failure |
| OEE | Overall Equipment Effectiveness |
| OEM | Original Equipment Manufacturer |
| pdf | Standard file format of Adobe Acrobat |
| PHM | Prognostics and Health Management |
| ppt | Standard file format of Microsoft PowerPoint |
| RUL | Remaining Useful Life |
| Tx.y | Number of Task |
| WP | Workpackage |
| xls | Standard file format of Microsoft Excel |

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# Summary

The purpose of D2.1 ‘Initial requirements specification’ is to strengthen the common understanding of the project vision and the overall objectives of the project. This document is the guide throughout the project to ensure that the vision of RECLAIM is in line with the objectives of the pilot partners and all members of the consortium. The RECLAIM Description of Action (DOA) forms the basis of this document. Additionally, feedback from pilots within and companies outside the consortium play a crucial role and shape the Vision Consensus. It will help to focus the consortiums’ work, help bring the RECLAIM project outcomes to market and ensure the project creates its intended impact.

The present Deliverable report summarizes the findings of the initial task of WP2 – End-User and System Requirements. In the light of the purpose of this WP to create the overall RECLAIM architecture, one important aspect is the notion and understanding of the current challenges of today’s production environments in order to understand the current demand and how this could be answered by the RECLAIM approach. Therefore task 2.1 intents to gather the requirements on re-use, refurbishment and re-manufacturing from the industry point of view.

The requirement analysis, the prioritisation of the RECLAIM building block and the mapping of the stakeholder’s needs to the objectives and KPI’s provides a profound basis for deriving an initial architecture of the RECLAIM solution. Therefore, this architecture must meet the following requirements:

- fulfil the requirements of the RECLAIM Pilots
- be as specific as possible in order to lower the efforts of individual adoption to the respective Pilot
- the architecture must be open in order to allow for easy adoption to additional needs not know or not in focus at the moment
- fulfil the requirements of stakeholders beyond the consortium

As a consequence, it must contain each RECLAIM building block, allowing to put individual emphasises to the building blocks depending on the individual needs.

Based on requirement analysis, the prioritisation of the RECLAIM building blocks and the mapping of the stakeholder’s needs, an initial architecture has been developed. It defines a two-level model in which the location of each building block is defined. The major contribution of RECLAIM is on the “RECLAIM level” by providing various services and frameworks and the respective interfaces. However, the data required by the RECLAIM level is provided by the Pilot level, in which RECLAIM contributes by providing technology for adding local services to equipment. The present document also outlines, the approach for the individualisation and customisation of the architecture to different industrial needs and setups. Further work will concentrate on the refinement of the architecture and on the iterative refinement of the requirements and subsequent deployment of the technology to the Pilots.

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# 1 Introduction

## 1.1 General aspects

The present Deliverable report summarizes the findings of the initial task of WP2 – End-User and System Requirements. In the light of the purpose of this WP to create the overall RECLAIM architecture, one important aspect is the notion and understanding of the current challenges of today's production environments in order to understand the current demand and how this could be answered by the RECLAIM approach. Therefore task 2.1 intents to gather the requirements on re-use, refurbishment and re-manufacturing from the industry point of view.

Task 2.1 is organized in three blocks of activities (see Figure 1). This report intents to describe the findings of the first block from month 1 to month 5.

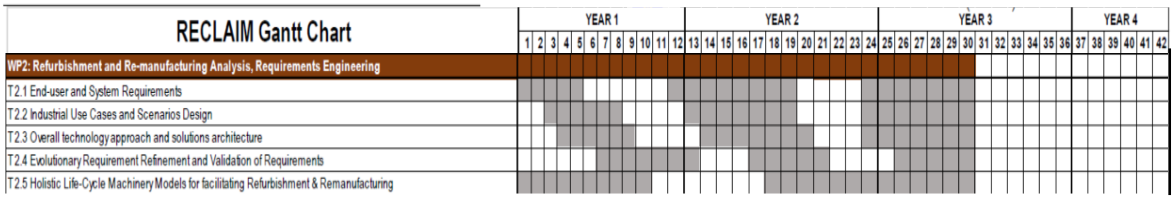


*Figure 1: Gantt Chart for Workpackage 2*

In the light of this target, the requirement gathering obviously targets mainly on the end users. In order to maximize the expressiveness of the study, a wide spectrum of industrial sectors was envisaged. In addition to that, industry-oriented associations and platforms should also be addressed as a target group for the identification of industry needs.

In order to do so, an online survey has been designed and implemented. Besides the technical needs for equipment re-use, also the accompanying business models as well as other relevant boundary conditions were in focus. At the end the survey output shall provide a profound basis for the technology providers of RECLAIM (and beyond) to identify whether:

- Their technological portfolio and research objectives are in line with the existing or upcoming needs of the users
- The current and future business models if their customers fit to the strategies of the technology providers and how the latter need to adopt to potential changes
- Such changes also require changes in the internal organization of the technology providers and their customers and in which areas such changes might be required at most
- Which other influences need to be taken into account in order to be prepared for the future challenges

This report is structured as follows: after this introduction, Chapter 2 describes the RECLAIM overall objectives and the different stakeholders. Chapter 3 explains requirements gathering process in detail. After that, Chapter 4 concentrates on the major part of the activities: the requirement analysis. Finally, in Chapter 5 the conclusions that can be drawn based on the survey results. It looks from an eagle eye perspective on the question's answers and identifies cross-correlations between the different sections.

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## 1.2 Relation with other Tasks

T2.1 plays a crucial role in understanding the interests and requirements of the potential stakeholders of the RECLAIM architecture. Together with T2.2 and-in a second step- with T2.4, the outcome of T2.1 will contribute to the specification of the overall approach for the technology and the RECLAIM solution architecture (T2.3). These relationships are depicted in Figure 2 and explained below.

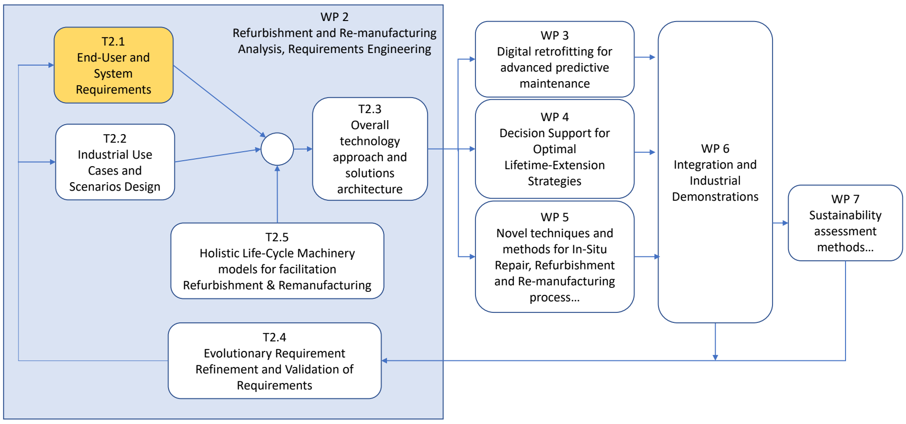


*Figure 2: Visualisation of relation of Task 2.1 within the Workpackage 2*

The interdependencies within WP2 are as follows:

- Task 2.1. This task specifies the general requirements for extending the lifetime of machines. It does not only gather and analyse the requirements of the RECLAIM Pilots, but also includes a requirement analysis on a more general scope.
- Task 2.2. This task aims to identify use-cases for each Pilot and to derive specific requirements. In addition, T2.2 defines KPI's for measuring the success of the approach afterwards
- Task 2.3. In this task, the general approach for the RECLAIM architecture is derived from both, high-level requirements and Use-cases. It intends to identify as much as possible synergies coming from both initial tasks and also intends to identify also gaps which a common architecture cannot fulfil
- Task 2.4. This task will gather the findings of the specification and implementation work of the subsequent tasks – in particular of WP 6 – and will include them in the requirements for the next implementation integration. By this, a continuous refinement of requirements and an improved implementation is guaranteed.
- Task 2.5. This task aims to adapt information coming from the use case scenarios and transform them in reliable data to start understanding behaviour of machine's' and components of the pilots.

It is important to note, that with the first requirements gathering phase of T2.1 plus the findings of T2.2, the first solution architecture will be defined, which serves as a basis for the subsequent technical Workpackages WP 3 – WP 5. For that, the outcomes of both activities within T2.1 and T2.2 are combined in a "melting point" (indicated by the circle between T1.2, T2.2 and T2.3). The combined outcomes are used as the input for T2.3. The first version of the architecture (T2.3) inspires and focusses the technical developments and finally, the integration of the technology in the Pilots. The iteration of three loops of specification, implementation and testing (formally initiated and monitored by T2.4) guarantees a smooth and very early take-up of the technology in the Pilots and a refinement and stabilization of the RECLAIM approach until the end of the project.

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# 2 RECLAIM Goals

## 2.1 RECLAIM overall scope

RECLAIM is an industry-driven project. Its major input for the research and development activities is based on the need of the manufacturing industry. The general approach is to gather the requirements of the RECLAIM Pilot sites and to derive a common-usable and easy to integrate architecture.

For the construction of the architecture, the RECLAIM DoA already defines a set of nine building blocks (see Table 1).

*Table 1 - Overview of the Building Blocks for the RECLAIM architecture*

| | |
|---|---|
| Building Block 1 | **Adaptive Smart Sensorial Network and Digital Retrofitting Infrastructure**<br>A distributed and adaptive smart sensor service to collect and process data for industrial cloud/edge environments and IoT introduction into the manufacture ecosystem, including IoT controllers to be attached at existing devices and machines in order to retrieve data and enabling predictive maintenance tasks. |
| Building Block 2 | **Embedded Cybersecurity for IoT devices**<br>Embed cybersecurity endpoint protection into the design and development processes of Digital Retrofitting Infrastructure but also in the post market phase. |
| Building Block 3 | **Decision Support Framework (DSF) for Optimal Lifetime-Extension Strategies**<br>The DSF component is designed to support and improve the effectiveness of decisions concerning the refurbishment and re-manufacturing of production infrastructure. The DSF will include tools such as the Cost Modelling and Financial Analysis tool, the Adaptive Sensorial Network and Fog computing framework (IoT Platform), the Prognostic and Health Management Toolkit, the Fault Diagnosis and Predictive Maintenance Simulation Engine using Digital Twin, and the Optimisation Toolkit for Refurbishment and Re-manufacturing Planning. |
| Building Block 4 | **Cost Modelling and Financial Analysis Toolkit**<br>The cost modelling will carry out cost estimation and analysis by using the combination of parametric costing and activity-based costing methods. The cost model will take into account all type of life extension strategies and activities for carrying out refurbishment and re-manufacturing of the industrial equipment, as well as the resources needed for each activity. |
| Building Block 5 | **Prognostic and Health Management Toolkit**<br>The prognostics and health management (PHM) provides a peer-to-peer health evaluation as well as component prediction methods to increase equipment (machine) lifetime, productivity and service quality |
| Building Block 6 | **Fault Diagnosis and Predictive Maintenance Simulation Engine using Digital Twin**<br>This building block is to monitor and predict the performance and status of factory assets. This will allow providing to the user all the features needed to schedule the maintenance works on the machines to: avoid failures being predicted by the "Prognostic and Health" algorithms defined in the building block 5; to perform proper maintenance planning, optimizing the production throughput and reducing the production lines stoppages. |
| Building Block 7 | **Optimization Toolkit for Refurbishment & Re-manufacturing Planning**<br>This component aims to support the planning optimization through multi-variable monitoring of the machine's operational parameters where the effects of variable changes will be possible to determine and combine known best practices methodologies for model-based plat-site/shop-floor control. |

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| | |
|---|---|
| Building Block 8 | **In-Situ Repair Data Analytics for Situational Awareness**<br>The techniques of this building block are used to identify and recognize machine operational and behavioural patterns, make fast and accurate predictions and act with confidence at the points of decision. |
| Building Block 9 | **Novel shop floor AR-enabled Multimodal Interaction Mechanisms**<br>This component aims to provide a novel way to visualize and localize information on equipment refurbishment and re-manufacturing operations directly situated on top of the physical equipment. |

The RECLAIM architecture will consist of those building blocks in order to provide a profound basis for equipment refurbishment and remanufacturing. The major scope of the requirements gathering described within this report is a) to elucidate the priority of contribution of each building block to the architecture and b) to identify any technology that is probably not included in a building block, but requires to be include. To do so, a metrics has been developed that weights the importance of each building block. This weighting process has been done one firstly for the RECLAIM Pilots. Secondly, a weighting has also been derived for the general manufacturing industry under consideration based on the results of the survey. More detailed information on the weighting and the results are provided in Section 4.

## 2.2 RECLAIM Stakeholders

### 2.2.1 Stakeholder types

In order to obtain an overview of the relevant stakeholders, a classification of stakeholders has been performed. Taking the RECLAIM goals into account, an organisation is classified as a RECLAIM stakeholder provided that the organisation fulfils at least one of the following criteria:

- The company benefits from the RECLAIM approach in its business activities
- The company contributes to the development of the RECLAIM architecture and the methodologies

Based on this definition, following stakeholders are identified.

*1) End-users / OEM's:*

RECLAIM is a research project strongly related to the needs of the industry. For that, this stakeholder group plays a major and crucial role within the consortium. Their requirements and needs mainly drive the technology to be developed within the project. Those stakeholders consist of Product manufacturers in a wider range of enterprise sizes (i.e. large, medium, small). Following interests make the stakeholders as part of this group:

- End-users are looking for knowhow, technology or methods for extending the lifetime of their equipment already in place.
- End-users are interested in new equipment to be used and integrated in their production facilities that is capable for lifecycle optimisation in terms of investments and resources
- End-users are interested to optimise their production e.g. by increasing the OEE, reducing downtimes, etc.
- End-users that are looking for partners assisting them during the implementation of the latest technology for lifetime extension

*2) Technology providers and service providers:*

The second large group of stakeholders for the RECLAIM project are the providers of technology and services. The following types of technology and service providers are considered within this group:

- *Equipment vendors:* This group supplies the end-users with (physical) equipment and the related services. Within the consortium, equipment vendors of e.g. wood manufacturing machines or welding equipment are present. Some vendors also provide laboratory services (e.g. HWH provides services in their welding labs for testing the weldability of materials) attached to their equipment.

- *IT service providers:* These are the companies that provide IT systems, software, digital services, system integration, and hardware attached to the IT services. Furthermore, services on cybersecurity and safety are in focus.

*3) Knowledge providers:*

The group of knowledge providers consists of universities and research institutes. Their major role is to provide the respective knowledge on the specification and implementation of RECLAIM technology.

*4) Innovation facilitators, Multipliers & Regulators:*

For the wider take-up of RECLAIM technology beyond the project's duration, it is important to disseminate the project's achievements. Thus, the facilitation and promotion of innovation in terms of new products and services, methodologies and approaches for refurbishment and remanufacturing is a significant aspect. For that, the group of the innovation facilitators, multipliers & regulators is crucial for the wider success of the project.

### 2.2.2 Consortium stakeholder classification

The RECLAIM consortium is composed of 22 partners having different profiles:

- 5 end-user representatives (Gorenje, FLUCHOS, Podium, HWH and Zorluteks),
- 7 industrial leading companies and innovative SMEs (ADV, FINT, FCY, SCM, Roboteh, TTS and ICE)
- 7 technical research centres (CERTH, ASTON, LINKS, CTCR, SUPSI, FEUP, TECNALIA)
- 3 non-profit organisations (SEZ, UNI, ESCI)

As a matter of fact, the consortium members take over different roles in terms of their relation to the stakeholder groups identified above. For example, Harms&Wende as a specialist in welding equipment, belongs to the group of end-users as well as to the group of equipment vendors and respective service providers. The relation(s) of each consortium member is illustrated in Table 2.

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*Table 2 - Relation of the consortium members to the stakeholder groups*

| RECLAIM partner | End-users / OEM's | Technology & service providers | Knowledge providers | Innovation facilitators, Multipliers & Regulators |
|---|---|---|---|---|
| HWH | X | X | | |
| CERTH | | | X | |
| CTCR APIDIT | | | X | |
| ASTON U | | | X | |
| LINKS | | X | X | |
| SUPSI | | | X | X |
| UPORTO | | | X | |
| TECNALIA | | | X | |
| SEZ | | | | X |
| UNI | | | | X |
| ESCI | | | | X |
| ADV | | X | | |
| FINT | | X | | |
| Fiercely | | X | | |
| SCM | | X | | |
| ROBOTEH | | X | | |
| TTS | | X | X | |
| ICE | | X | | |
| GORENJE | X | | | |
| Fluchos | X | | | |
| PODIUM | X | | | |
| ZORLUTEKS | X | | | |

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# 3 Requirement gathering process

## 3.1 Methodology of requirements gathering

This section provides a brief explanation of the methodology of the requirement gathering process. The methodology consists of four steps (see Figure 3).

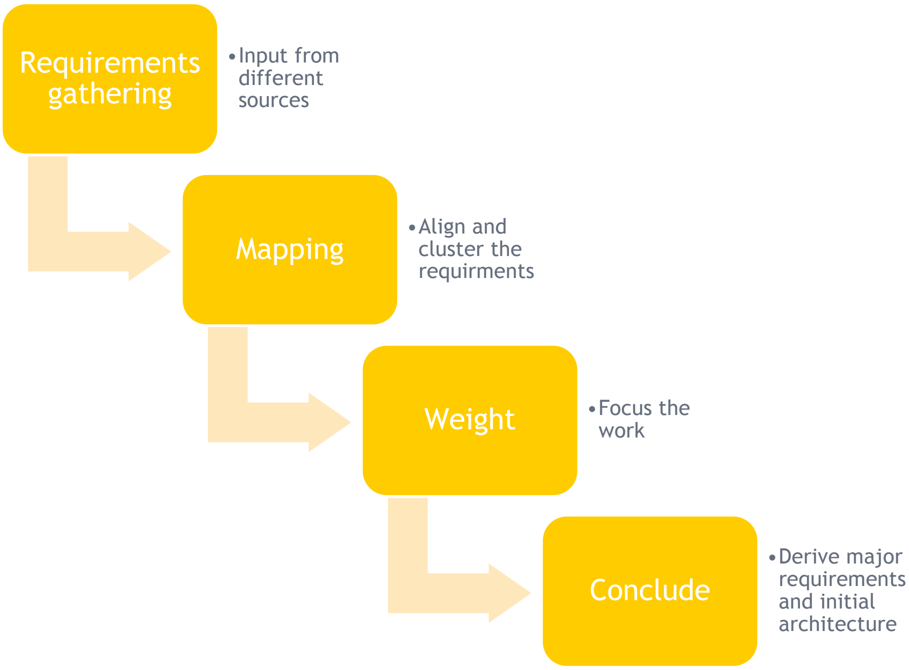


*Figure 3: Four Steps of the RECLAIM Methodology for requirements gathering*

The first step is the requirements gathering process. As this Deliverable report aims to generate a general picture of the requirements on refurbishment and remanufacturing, the requirements gathering process targets on a broad data basis, which goes beyond the scope of the RECLAIM Pilots. For that, the requirements gathered and analysed have been elicited using three different sources (see Figure 4):

1. Requirements gathered by a literature research. An intensive literature research, also considering the DoA, EU projects, etc. has been done.
2. Requirements specifically gathered from the RECLAIM Pilot partners. Those requirements target on very specific challenges which will be tackled within RECLAIM. For that, the major findings of this requirements gathering process are described in D2.2 “RECLAIM Use Cases Definition & Operational Requirements #1”. However, a number of more general requirements have also been identified and will therefore reported in this report.
3. The major input, however, will be the outcome of an online survey that has been developed specifically for providing the input for this report.

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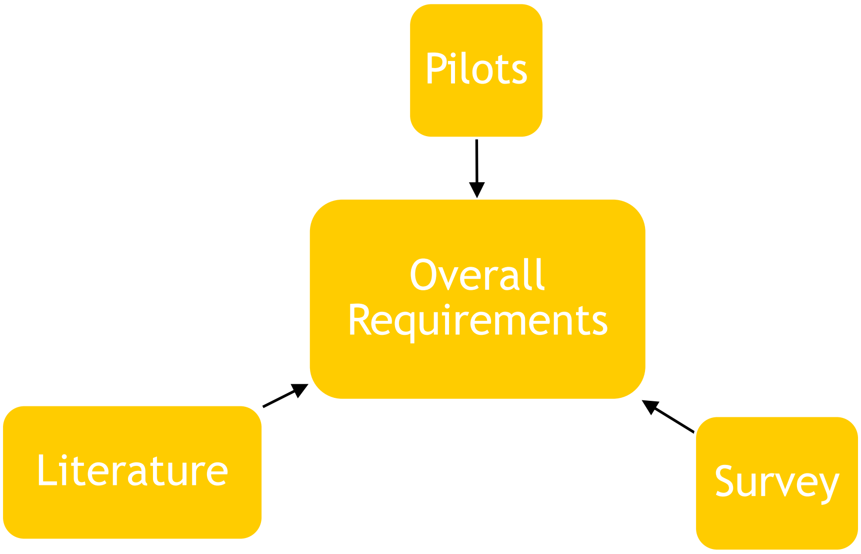


*Figure 4: Sources of the Requirements gathering process*

Once the requirements from these three sources were available, the second step in the methodology is a mapping process. Within this process, the requirements coming from the various sources will be aligned in order to identify common clusters of requirements. The initial clusters will be based on the RECLAIM Objectives as described in the DoA.

In order to focus the research and development activities of RECLAIM and also to obtain a picture of the "importance" of the clusters identified in the step before, the third step is a weighting process. Clusters of high relevance will be more in focus within RECLAIM than clusters with low relevance.

The final step within the methodology of requirements finding is to derive the overall requirements for refurbishment and remanufacturing in the given scope. This final step will serve as the major path for the research and development activities. From that, the general architecture will be derived (see section 6.2), the implementation of the various technologies will be initiated and the overall success of the project will be measured based on a set of relevant KPI's (see section 4.4).

As an outlook and in order to guideline the activities within Task 2.3 "Overall technology approach and solutions architecture", an initial architecture for the RECLAIM approach will be derived from the requirements identified. This step concludes the work of Task 2.1 within the first block of activities from M1 to (initially) M5.

## 3.2 KPI gathering process - online survey

This section describes in detail the conception of the online survey. First it will provide an overview of the expected outcomes and the target groups. The main focus in on the illustration of the structure of the survey.

### 3.2.1 Focus and expected outcome

The focus of the survey is to reveal the specific challenges and opportunities in current and future manufacturing systems with regard to re-use, refurbish and re-manufacturing of equipment. The new opportunities promised by the substantial changes of production

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digitalization known as Internet of Things (IoT), Industrie 4.0 or cyber-physical systems have triggered discussions about potential benefits these technologies could bring. Among others, these are:

- More sustainable production processes and equipment performance
- Life-cycle assessment of production equipment
- Proactive and predictive maintenance in order to increase the OEE
- Keeping the human in the loop for production monitoring optimization and maintenance
- More transparent production processes and equipment performance

The expected outcome of the survey is to identify the most prevalent demand for solutions, the priority challenges and also to open towards the prospected opportunities coming along with the digitally enabled smart production of the future.

With the above-mentioned scope in mind the rationale for the conception is the following:

The survey shall – at this point – be fully unbiased and concentrate on the challenges without implying potential, real solutions already existing through the work of the Pilots. It does therefore neither refer to specific results nor to technology, but rather highlight the concept of “solutions”.

The survey intents to consider all aspects of origin of potential challenges and opportunities including product-, process-, technology-, organization-, business strategy- and marketing-based factors.

A further step following the survey analysis and technology pull review would be to match the demand of the respondents with the technical solutions for this challenges and opportunities out of RECLAIM.

### 3.2.2 Target group of the questionnaire

The target group of respondents is composed of end-users in the manufacturing industry, the processing industry or other industry branches. The background and the job positions of the respondents differ. Included are CEOs, CTOs, R&D, team and project managers and developers. Furthermore, the target group covers different industrial sectors, associations and platforms such as:

- White and brown goods, automotive, Aerospace, textile, furniture, corresponding but not limited to the RECLAIM pilot companies
- VDMA, VDE
- Manufuture, ICT, etc.

The questionnaire can be answered anonymized or by also providing contact data.

### 3.2.3 Survey format, access and promotion

In order to provide an easy access to the survey, an online questionnaire was created. To do so, the questionnaire has been developed using the SurveyMonkey online platform (www.Surveymonkey.com). An easy to understand structure (see next section) including 8 main chapters has been developed in order to guide the user through the questionnaire. Besides the questionnaire itself the platform also provides tools for the analysis of the results. The analysis data is available as ppt, pdf or xls format, aggregated and per respondent. The questionnaire was open in the period from February 2020 to May 2020.

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The questionnaire has been promoted using several measures:

- Intensive mailings have been performed by the RECLAM partners via their network. The emails also included a weblink to the online questionnaire. The mailings addressed more than 100 potential questionnaire users.
- Professional social platforms for business contact exchange have been used to issue postings on the questionnaire. In particular postings at LinkedIn have been issued. To do so, the project profile of RECLAIM and the personal profiles of several members for issuing postings have been used.
- The questionnaire has also been promoted using several websites. For instance, the RECLAIM webpage well as some webpages of the involved organizations (e.g. the Harms & Wende research webpage) included short articles on the questionnaire and provided the link to it.
- Personal talks for questionnaire promotion or even personal interviews for filling out the questionnaire have been taken place. Several phone interviews have also been performed.

### 3.2.4 Survey structure

The RECLAIM survey on end-user requirements is composed of eight chapters.

#### 1 Introduction

In Chapter 1 a general introduction is provided. It describes the RECLAIM project, its goals and content and provides information on the purpose of the survey. In addition, information on data protection is provided. Furthermore, a checkbox is included that -if checked- personal data of the participant (name and surname, name of organisation, email and website) can be used and published if provided.

#### 2 General company data

Chapter 2 gathers some general data of the participant's company. Questions such as the following were asked. All that information is used to obtain an impression on the distribution of the stakeholders of the survey.

- Q2 The foundation year
- Q3 The organisation type
- Q4 The companies turnover last year
- Q5 The number of employees
- Q6 major products the company produces or sales
- Q7-10 information on the organisation name, website, etc. (optional)

#### 3 Existing equipment

The purpose of Chapter 3 is on the elicitation of the existing equipment the company uses. The following questions were asked:

- Q11 Which types of machines do you use for production?
- Q12 Which are the most relevant/critical machines, equipment and tools in your production system?
- Q13 How old are these machines in average?
- Q14 How old is your oldest machine that is still used for production?

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- Q15 Do you intent to replace old machines within the next months?
- Q16 I replace old machines usually when ...
  - The machine is defect and it does not make sense to repair it
  - The machine's costs are depreciated
  - The machine's productivity is not sufficient anymore
  - The machine is not capable to produce new products
  - Other (please specify)

# 4 Refurbishment of existing equipment

One other interesting aspect is to identify, how the various companies are managing existing equipment in terms of refurbishment and remanufacturing. For that reason, Chapter 4 is dedicated to the identification of the strategies and aims for equipment refurbishment.

- Q17 Do you already have strategies in place to refurbish old machines
- Q18 Refurbishment targets or will target on the following technical issues
  - Replace worn out parts/components of machines
  - Include the newest safety technology
  - Include I4.0 technology e.g. for data communication or predictive maintenance technology
  - Higher automation level
  - Other (please specify)
- Q19 Refurbishment is done by
  - Our own company
  - Machine/component supplier
  - Company specialised in refurbishment
  - Other company (please specify)

# 5 Use of refurbished equipment

After the study of potential refurbishment of already existing equipment in Chapter 4, Chapter 5 is targeting on buying and using of refurbished equipment for existing machine parks. In order to elucidate potential issues and opportunities, Chapter 5 consists of the following questions:

- Q20 Have you ever bought refurbished equipment?
- Q21 Would you buy refurbished equipment in future?
- Q22 If "yes": Why would you use refurbished equipment instead of new equipment?
- Q23 Which requirements do you have for buying refurbished equipment?
- Q24 Cost savings in buying refurbished equipment are expects to be x% of new equipment
- Q25 Are you open to new business models for equipment purchasing?

# 6 Technology for life cycle management

Life-cycle management is an important aspect in the frame of equipment re-use. In the survey we wanted to identify if technology for life cycle management is already in place and if, which technology is currently used. Therefore, Chapter 6 of the survey consists of the following questions:

- Q26 Do you have any measures for calculating the life time of your

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- equipment?
- Q27 Do you already have advances technology in place for extending
- the lifetime of your equipment?

# 7 Refurbishment and maintenance approaches

Chapter 7 is directly related to the existing approaches for refurbishment and maintenance. The general purpose is to elucidate the current technologies and methods implemented in factory environments. To do so, the following questions have been asked:

- Q28 How reliable do your assets are and need to be?
- Q29 Which of the following activities do you currently perform in your daily operations?
    - Analyse and classify assets (equipment, machines and tools) and their components criticalities
    - Calculate/estimate the breaking points and wear of the equipment, machines, tools and components according to the future production rate
    - Collect data from sensors & PLCs
    - Visualise and Analyse data to predict impending failures
    - Create and optimize maintenance, refurbishment and replacement programs
    - Other (please specify)
- Q30 Which of the following approaches does mostly fit with the current
- maintenance approach of your company?
    - Reactive Maintenance
    - Corrective Maintenance
    - Preventive maintenance
    - Predictive maintenance
    - Prescriptive maintenance
- Q31 Which prognostics and health management (PHM) indicators and data do you currently monitor/collect?
- Q32 Which prognostics and health management (PHM) KPIs do you currently use to plan and make equipment/machines maintenance, refurbishment and replacement activities? E.g. KPIs (OEE, MTTF, RUL)
- Q33 Which are the most relevant barriers you faced trying to achieve an advanced asset management approach? Please add any relevant detail.
- Q34 Which of the following activities do you expect to integrate into your daily operations by the next 5 years? Please add any relevant detail.
- Q35 How much do you plan to spend in maintenance over the next five years?
- Q36 How much do you plan to spend in refurbishment and/or replacement of current assets over the next five years?
- Q37 How much do you plan to spend to improve existent assets' health management system over the next five years?
- Q38 Rate from 1 (very important) to 5 (not important) the following benefits you would achieve through maintenance, refurbishment and/or replacement of machinery based on your priorities

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# 8 Implemented Standards

Standards are a major requirement for the successful implementation and integration of technology in existing factories. In order to address this issue properly, the last chapter of the survey on requirements was dedicated to the existing and implemented standards of the users. Therefore, the following questions needed to be answered:

- Q39 Table 1: please indicate standards implemented in your organization covering the whole internal value chain
- Q40 Which are the main problems encountered in implement the Standards
- Q41 What are main areas of improvement for the above mentioned standards?
- Q42 Why are you implementing those standards?
- Q43 What type of competitive advantage, if any, does it provide?
- Q44 Are there any other standards you're going/willing to implement? What type of benefit are you expecting?
- Q45 Are there any issue within maintenance, refurbishment and/or replacement of machinery not covered by standards?

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# 4 Requirement analysis

## 4.1 Survey responses

In total, 86 persons participated in the questionnaire on End-User and System Requirements. 36 respondents have fully completed the questionnaire and 52 respondents only partially omitting one or several questions. This results in a completion ratio of 42%.

The survey has been launched in February 2020, accompanied with respective promotional activities. By March 2020, 55 responses had been received and a further 29 responses were recorded in April. Unfortunately, after that only 2 further responses have been received in May 2020. After that, the survey has been closed.

### 4.1.1 Stakeholder representation of the survey

In order to obtain a more common basis of the requirements on refurbishment and remanufacturing, the online survey has been spread to stakeholders coming from different industries. The distribution in terms of the stakeholder groups (see Figure 5) show a significant proportion of OEM's/end-users (37%) and Technology & service providers (33%). Furthermore, system integrators are also well presented (18%). Other organisations such as knowledge providers (2%), consultancies (6%) or associations (4%) are in the minority. The distribution perfectly reflects the envisaged target group for the survey as the majority of participants is related to industrial organisations. Thus, their opinion about the requirements of the RECLAIM solutions provides an excellent basis for the further specification and development. Furthermore, end users, system integrators and technology providers spread a wider bandwidth of technology use and technology development. For that, the approaches for re-use and refurbishment are reflected from very different perspectives.

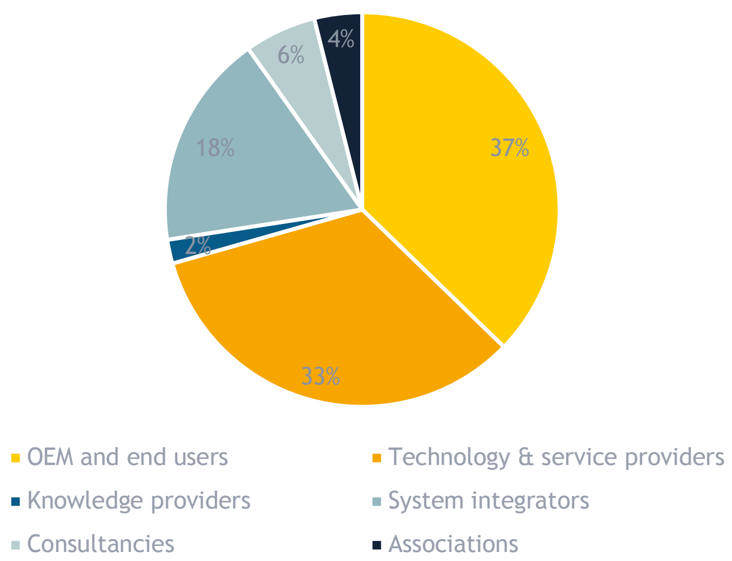


*Figure 5: Share and distribution of stakeholders who participated in the survey*

When looking at the distribution with respect to the turnover of the organisations it is noticeable that more than 60% of them has a turnover either more than 50 Mio. Euro or less than 2 Mio. Euro. This also corresponds to the number of employees (see Figure 6).

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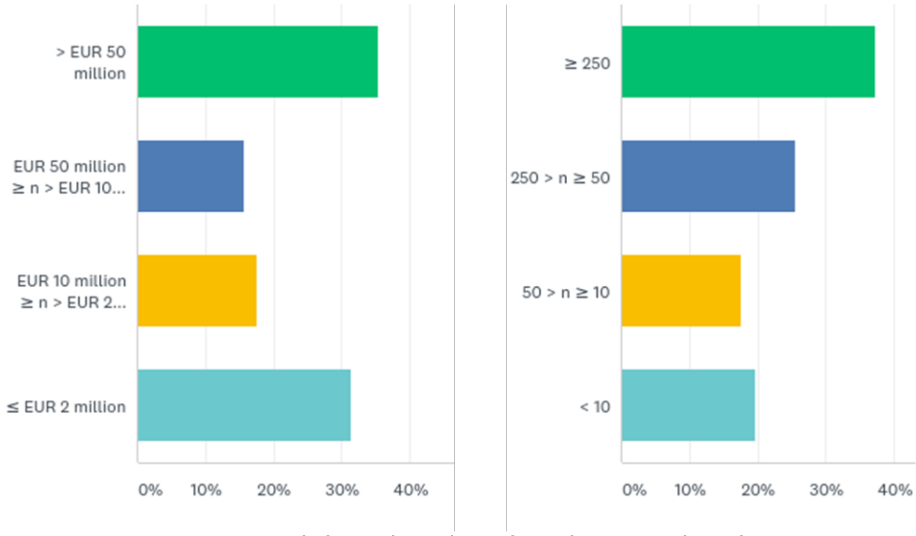


*Figure 6: Turnover (left) and number of employees (right) of organisations involved in the survey*

It is supposed that mainly the OEM's and end-users can be related to those companies having a high turnover while the others fall in the other categories. In general, a good distribution of small companies, midcaps and large companies can be identified.

### 4.1.2 Stakeholder products and machines

The five Pilots of the RECLAIM project concentrate on very different manufacturing processes and products. The product range consists of white goods such as washing machines to footwear, textiles for tablecloths or wooden kitchens. For the manufacturing of those goods, different processes and equipment such as robots, welding machines, saws, etc. are used. In order to get an even broader scope of requirements for remanufacturing, the target of the survey was to get a high bandwidth of different machines, components and final products. The following figure illustrates the machine types indicated in the survey responses. (see Figure 7)

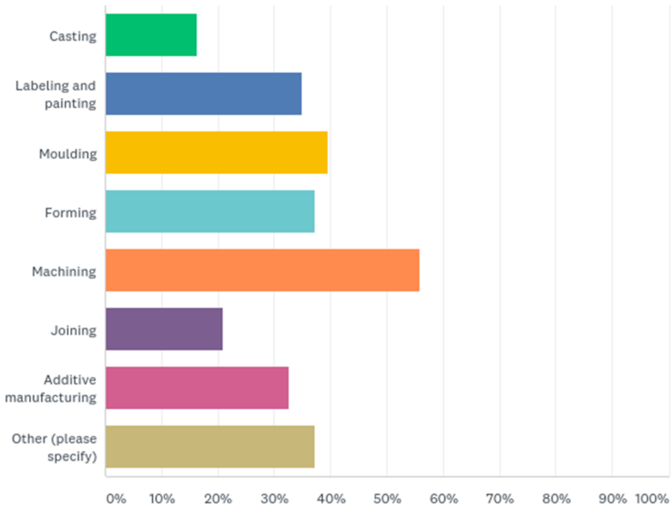


*Figure 7: Machine types indicated in the survey responses*

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It can be seen that the organisations responded to the survey are using very different machines, which are not reflected by the machine park of the RECLAIM Pilots. More in detail, the following machines and components have been mentioned (examples):

- Pneumatic components
- Hydraulic filter elements
- packaging machines
- AGV Automated Guided Vehicles
- Vehicles lifts
- Mag & Laser welding machines
- Resistance welding machines
- High Speed winders for paperboard based webs
- Workplace occupancy sensors
- Palletizing systems
- Automatic assembly systems
- Robotic cells for assembling & testing discrete manufacturing
- Electric motors

In additions, also the products differ (examples):

- Industrial trucks
- Textiles
- Hoses
- Footwear
- Passenger vehicles
- Steel products
- Aerospace test stand
- Powertrains
- Medical devices
- Electronics

By this, the target of the survey to widen the scope of requirements gathering beyond the consortium Pilots need is fulfilled.

A closer look to the machines used for the production process reveals the potential for refurbishment and remanufacturing. A significant share of the machines of the stakeholders are older than eight years (Figure 8, left). Even more impressive is that more than 60% of the manufacturers do use machines that are 12 years or even older (Figure 8, right).

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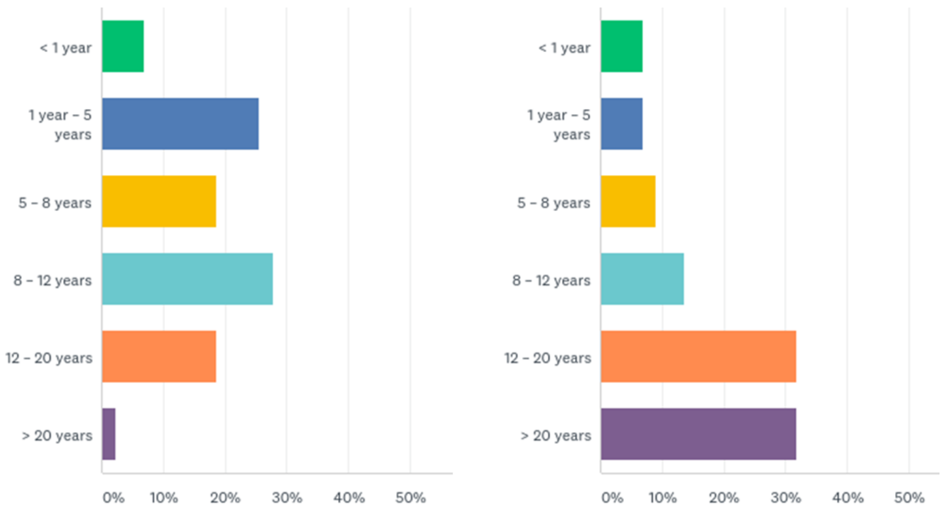


*Figure 8: Overview of the average age of the producing machines (left) and the oldest still running production system (right)*

In addition to those numbers, about 20% of the manufacturers stated, that they are intending to replace old machines by new ones within the next months. As a consequence, the old, worn-out machines will not be used anymore.

In the next sections, an analysis of the survey is made. The responses of the survey are put in relation to the RECLAIM overall Objectives. The survey was then evaluated in relation to the KPI's of each objective in order to see to what extent these KPI's are still correct and to determine a possible weighting of these KPI's. Subsequently, the nine building blocks are then evaluated using the survey response. Furthermore, the RECLAIM pilots were asked to rate the nine Building Blocks to their respective needs. The resulting weighting from 1 – Low priority to 5 – high priority is based on the analysis of the questionnaire. At the end of this section, a comparison of both ratings is done.

### 4.1.3 Analysis related to RECLAIM overall Objectives

One of the RECLAIM overall objectives is to maintain the competitiveness of manufacturing companies. To achieve this, it is important to continuously increase the effectiveness and efficiency of production processes and facilities. From this point of view, maintenance activities have become even more crucial for business success. The objective formulated at the beginning of the project can be confirmed by the survey. However, it is shown that the implementation of recycling management strategies with the intention of extending the service life of industrial plants in order to increase performance and resource efficiency has so far tended to fail due to internal hurdles. Therefore, new acquisitions are currently still preferred to refurbished or remanufactured equipment. The respondents are much more open when it comes to the topic of function retrofitting or extension. 80% of the participants consider it relevant or very relevant to retrofit functionalities that allow conclusions to be drawn about the condition of the equipment or the production process. The focus here is primarily on technologies under the keyword "I4.0". The respondents stated that there are plans to retrofit these in the near future. The majority of the respondents see the planned investment costs at >100000€.

Another overall objective is the need to improve the maintenance process, emphasizing the methods of refurbishment and re-manufacturing. The extension of plant functionality achieved through refurbishment and re-manufacturing enables increased resource efficiency by reducing the unnecessary and wasteful use of resources along with health status monitoring, which can extend the life of large industrial plants. The survey shows that the

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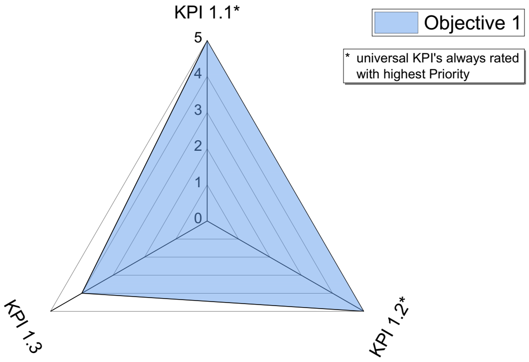
RECLAIM approaches to the topic of "refurbishment and re-manufacturing" are viewed very positively across all industries. The industry representatives hope that the implementation of RECLAIM will lead to a general increase in OEE. By implementing the measures targeted in RECLAIM, the primary aim is to achieve better machine utilization, reduce the probability of failure, which increases with the age of the machine, and produce less waste. Thus, a cost reduction is achieved, which has a positive effect on the OEE.

RECLAIM involves big data analytics, predictive analytics, and optimization models using deep learning techniques, and digital twin models with the aim of facilitating the stakeholders to make an informed decision about whether to refurbish, remanufacture, upgrade, or repair heavy machinery that is towards its end-of-life. Here again, the evaluation of the survey shows that the approaches and goals formulated in RECLAIM are meeting with great interest in the industry. When asked what the previous approaches in the area of PHM look like, the vast majority of the respondents said that no approaches exist yet. Only a few industry representatives indicated that they would be willing to analyze their recorded data. The MTTF and the MTBF are primarily determined. The OEE is also used as a general evaluation criterion.

### 4.1.4 Analysis related to RECLAIM KPI's

The first objective describes the Vision of RECLAIM and covers almost the entire project duration. The KPI's 1.1 and 1.2 are therefore very project-specific and do not evaluate a specific technological development. Due to their general applicability and the direct relation to the project's success, they were given the highest priority. KPI 1.3 contains possibilities for fast decision making which are represented by the DSF and PHM Toolkit. The survey shows that companies has only reacted to machine failures so far. There is no proactive action yet. When asked about the reasons, many of the respondents indicated internal processes (i.e. standards) or lack of interest or ignorance on the part of decision-makers (supervisors/organizations). However, the interviewees stated their interest in PHM methods as high. The derived weighting of the KPI's of the first objective is visualized in Figure 9.

**O1** **To devise and deploy circular economy strategies addressing the end-of-life issue of large industrial equipment, aiming to extend the lifetime of machines, improve performance and increase resource efficiency of heavy machinery**




| | |
|---|---|
| **KPI 1.1** | Fulfilment by at least 85% of user's requirements concerning lifetime extension methods in old machines |
| **KPI 1.2** | Improvement by at least 90% of the usability of current services and solutions |
| **KPI 1.3** | Circular Economy Enhancement |

*Figure 9: Weighting of the KPI's of the first objective*

The second objective describes the development of appropriate tools and decision support methodologies for fault diagnosis as well as planning and preparing the necessary refurbishment or remanufacturing of large industrial equipment. An objective evaluation of "machine health" based on key figures is hardly ever carried out by any company. When asked whether there are any specific plans to recondition machines, around 55 % answered "*no*". So far, new purchases have always been made. However, 2/3 of those questioned said that they had already purchased a refurbished machine and about 80% of those questioned can imagine buying refurbished machines in the future. The reasons for this are primarily cost

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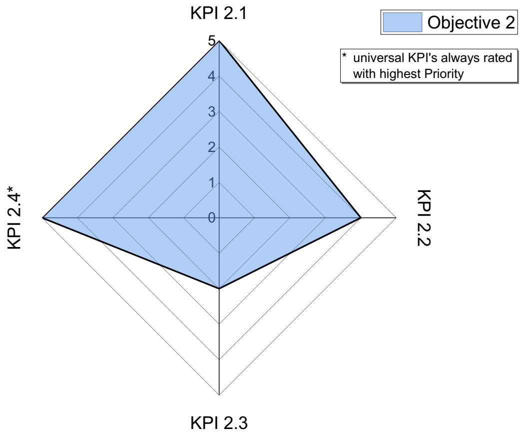
savings and faster availability of the equipment, but also environmental aspects. Another reason for refurbishing older equipment that should not be neglected is that the required machines are no longer available on the market in some cases, making it impossible to buy new ones. In summary, clear strategies must be delivered to the industry to increase interest in refurbished and re-manufactured equipment. Furthermore, the benefits of the RECLAIM concept must level the advantages of a new purchase. KPI 2.4 is again RECLAIM specific and is therefore a high priority. The derived weighting of the KPI's of the second objective is visualized in Figure 10.

**O2** **To develop the appropriate tools and decision support methodologies for:**
**a) the inspection and assessment of malfunctions;**
**b) the planning and preparation of the necessary refurbishment or re-manufacturing of large industrial equipment**




| | |
|---|---|
| **KPI 2.1** | Cost from physical inspection |
| **KPI 2.2** | Effectiveness Detection of failures |
| **KPI 2.3** | Automation metrics of RECLAIM |
| **KPI 2.4** | Reported Recovery Decision of End-user Impact |

*Figure 10: Weighting of the KPI's of the second objective*

The third objective is to use a network of sensors to enable almost real-time monitoring of the machine status and the production line. Sensors and sensor technology are of great importance in future plant systems. By upgrading sensors via refurbishment plans, the integration of the latest safety standards is the main focus. This is followed by I4.0 technologies, an increased level of automation, general functional expansions and extended process data recording. The survey shows that up to now, operating hours have been used primarily to determine statements about machine health. Furthermore, the depreciation period of the equipment is used as an instrument. The sensor networks targeted in RECLAIM have not been used at all to date, even though data from several sensors is recorded and collected. In addition, the data is only analyzed in isolated cases and not in an overall view. About 55 % of the respondents stated that in-situ repairs were a priority. Only 30 % of the survey participants stated that they had a minimum level of intelligence for predictive maintenance in the production systems used. For the analysis, the temperature, motor data and energy consumption of the machine are primarily analyzed. Here, too, the respondents stated that they were very interested in implementing such technologies and that they would invest in them. The derived weighting of the KPI's of the third objective is visualized in Figure 11.

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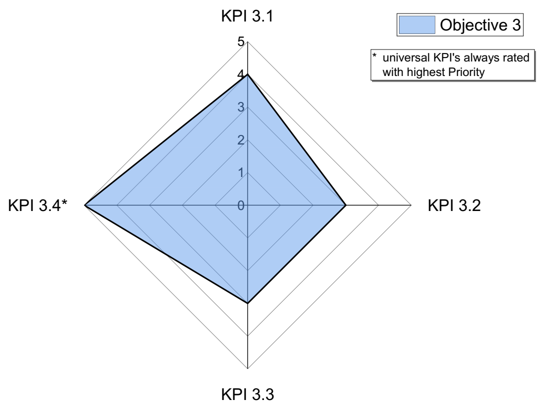
**O3** **To deploy an adaptive sensorial network and fog computing framework for near real- time monitoring of the machinery health status and the production line**

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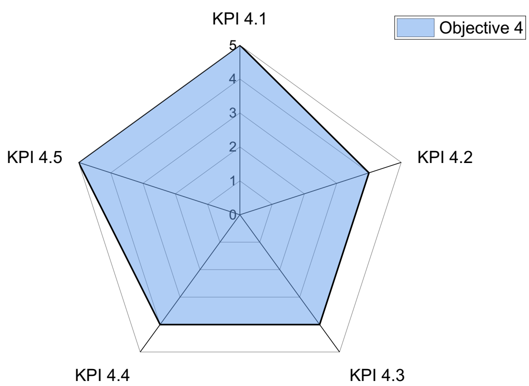
|---|---|
| **KPI 3.1** | About 20-30% increase/modernization of sensorization in pilot demonstration lines |
| **KPI 3.2** | At least 20% improvement of electro-mechanical machines' and productions' monitoring through Optimization Toolkit for Refurbishment and Re-manufacturing Planning |
| **KPI 3.3** | At least 20% increase in data flow from the shop-floor to the DSF through Digital Retrofitting Infrastructure |
| **KPI 3.4** | Machine Health Index |

*Figure 11: Weighting of the KPI's of the third objective*

The purpose of the fourth Objective is to monitor and predict the performance and status of factory assets in order to optimize maintenance activities. When asked about the benefits, the unanimous opinion of the participants is a noticeable cost reduction, caused by less machine breakdowns, improved machine utilization, reduced maintenance costs. This improves OEE on the one hand and improves the working conditions of the workers on the other. The derived weighting of the KPI's of the fourth objective is visualized in Figure 12.

**O4** **To adapt and implement a simulation engine to perform fault diagnosis and predictive maintenance to contribute to effective damage repair**




| | |
|---|---|
| **KPI 4.1** | Time spent on predictive maintenance |
| **KPI 4.2** | Number of fault diagnosis |
| **KPI 4.3** | Operating capacity of the simulation infrastructure |
| **KPI 4.4** | Reduction of over 20% in the downtime due to unscheduled maintenance |
| **KPI 4.5** | Maintenance effort required is decreasing at 50% |

*Figure 12: Weighting of the KPI's of the fourth objective*

The fifth objective is to optimize the planning of refurbishment and re-manufacturing activities and processes. As a result of the survey, it is clear that there are almost no plans for refurbishment and re-manufacturing activities in the industrial environment. The majority of respondents therefore see the machine manufacturer as the main responsible entity for refurbishment and re-manufacturing activities. Nevertheless, some of them also see their own company as being obliged to implement such a process. The lowest percentage of participants wants to hire specialized companies. When asked about the OEE target, respondents indicated that it should be at least 85%. The derived weighting of the KPI's of the fourth objective is visualized in Figure 13.

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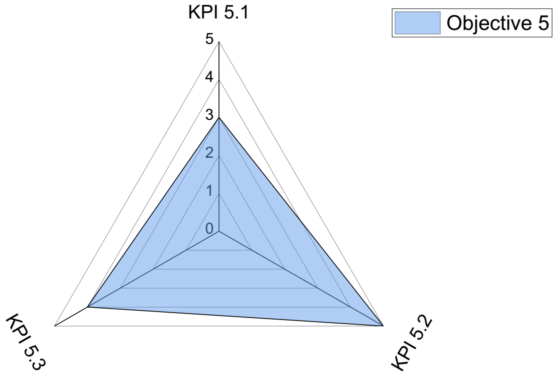
| | |
|---|---|
| **O5** | To optimise the planning of refurbishment and re-manufacturing activities & processes |

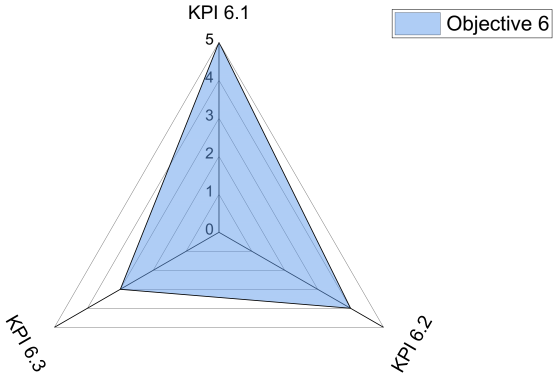



| | |
|---|---|
| **KPI 5.1** | At least 40% more accurate service activity reliability |
| **KPI 5.2** | 99% Overall equipment effectiveness after refurbishment/re-manufacturing process |
| **KPI 5.3** | 99% Success of refurbishment/re-manufacturing processes on the production floor |

*Figure 13: Weighting of the KPI's of the fifth objective*

The biggest lever to extend the lifetime of a system is to save repair costs through predictive maintenance and situational awareness. This approach is one of the main objectives of the RECLAIM project and reflected in Objective six. According to the survey, 50% of respondents see an estimated saving of 20-40% compared to a new installation, the other half estimate the potential savings to be even higher. The estimated repair costs for the next 5 years were estimated by 65% of the respondents at around €50,000 to €100,000. 14% even stated that they wanted to invest >1 million euros. The derived weighting of the KPI's of the fourth objective is visualized in Figure 14.

| | |
|---|---|
| **O6** | **To deploy novel HMIs for refurbishing/re-manufacturing large-scale electrical and mechanical machinery** |




| | |
|---|---|
| **KPI 6.1** | Amount of Time to Resolve a Failure |
| **KPI 6.2** | Uptime (or Downtime) During an Incident |
| **KPI 6.3** | Demonstrate effective maintenance to potential failures and stoppages of >98.5% |

*Figure 14: Weighting of the KPI's of the sixth objective*

Objective 7 deals with the situational awareness through the in-situ repair process. Complete awareness of the health status of the machine and situational of the shop floor during maintenance activities decrease the effort of in-situ repair. The survey shows that the overall age of a machine is not a reason for replacement. The main reason is much more the amount of time and the repair costs to be spent. According to the respondents, if these costs are in the range of 70% of a new machine, reconditioning is no longer sensible. Another reason is the productivity of the machine. If this is no longer sufficient, a new acquisition must be considered. The same applies if new products can no longer be produced on older machines. When asked what is expected from a refurbishment, half of the respondents said that defective machine parts are replaced. The derived weighting of the KPI's of the seventh objective is visualized in Figure 15.

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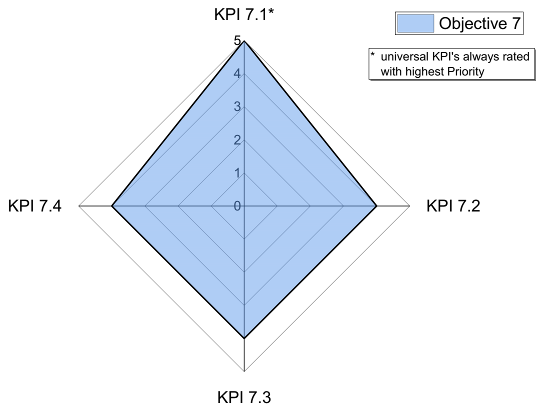
**O7 To raise situational awareness through the in-situ repair process**

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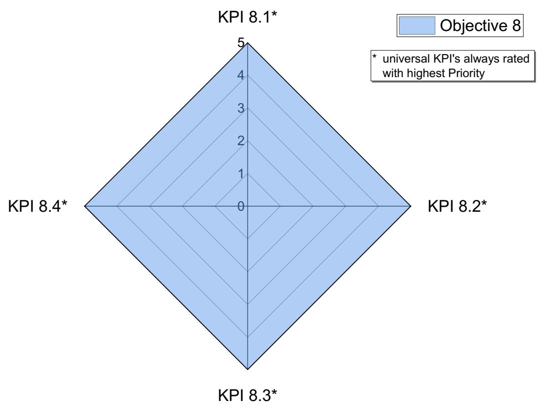
| **KPI 7.1** | Satisfaction of Industries with the Repairs Service |
| **KPI 7.2** | Average number of working days to complete all repairs |
| **KPI 7.3** | Situational Awareness through in-situ repair process |
| **KPI 7.4** | 50% Increase of Mean Time To Repair |

*Figure 15: Weighting of the KPI's of the seventh objective*

The eighth objective serves to validate and demonstrate the RECLAIM proposed solutions by using the 5 pilots. Due to their direct relation to the project's success, they were given the highest priority. The derived weighting of the KPI's of the eighth objective is visualized in Figure 16.

**O8 To validate and demonstrate the proposed solutions through a set of real-life pilot sites**




| | |
|---|---|
| **KPI 8.1** | Number of pilots in operational environments under the direct responsibility of the end-users involved |
| **KPI 8.2** | Number of machines of components to be refurbished or re-manufactured |
| **KPI 8.3** | Extended useful lifetime of machinery |
| **KPI 8.4** | Decrease in maintenance cost per machine |

*Figure 16: Weighting of the KPI's of the eighth objective*

The ninth objective is about the safe and secure operation of the refurbished/ remanufactured equipment. As mentioned above, there is a broad consensus among respondents to buy refurbished or re-manufactured equipment in the future. However, the basic prerequisites for this are that the equipment either comes from a certified dealer or that the equipment has been recertified by the responsible institutions. The derived weighting of the KPI's of the tenth objective is visualized in Figure 17.

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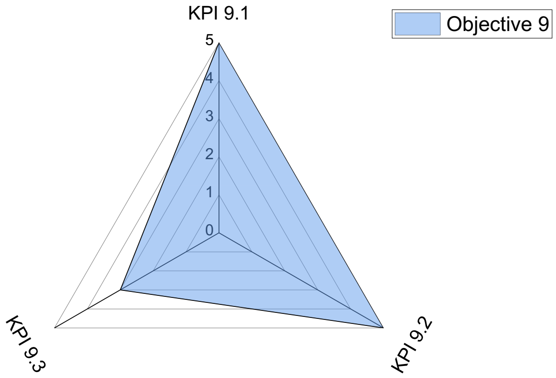
| O9 | To ensure the safe and secure operation of the refurbished/ remanufactured equipment |
|---|---|

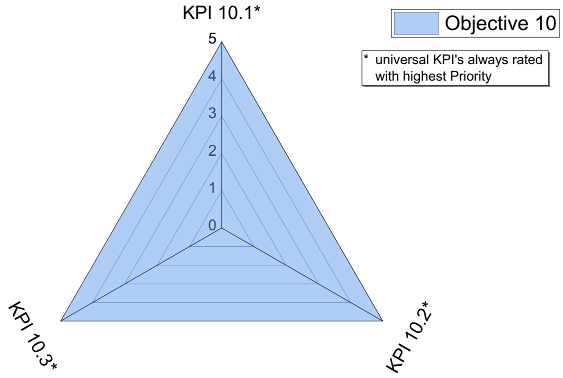



| | |
|---|---|
| **KPI 9.1** | On Standard Operating Efficiency |
| **KPI 9.2** | Refurbishment and Re-manufactured Machines Safety |
| **KPI 9.3** | Lost Time Injury Frequency Rate <5 |

*Figure 17: Weighting of the KPI's of the ninth objective*

The tenth objective includes indicators to assess the potential exploitation of RECLAIM results beyond the project duration. To this end, increased emphasis is laid on building a community around the research and technological achievements of the project to raise awareness about project activities and appeal to potential stakeholders, researchers and the general public. For meeting these targets, a very wide set of key communication activities has been included in the project work-plan. Due to their general applicability and the direct relation to the project's success, they were given the highest priority. The derived weighting of the KPI's of the tenth objective is visualized in Figure 18.

| O10 | To scale-up to other industrial environments through a virtual replication design |
|---|---|




| | |
|---|---|
| **KPI 10.1** | Replicate the RECLAIM's result |
| **KPI 10.2** | Number of attracted future stakeholders/providers >30 |
| **KPI 10.3** | Business plans available for all identified exploitable assets, including the overall RECLAIM system |

*Figure 18: Weighting of the KPI's of the tenth objective*

### 4.1.5 Survey Analysis related to RECLAIM Building Blocks

Not all parts of the survey allow a conclusion to be drawn about the nine building blocks on which the RECLAIM architecture is based. Therefore, the upper Table in Figure 19 gives an overview of the questions used for the preliminary assessment of the building blocks. The resulting weighting from 1 – Low priority to 5 – high priority is based on the analysis of the related questions. Thus, the survey represents a result that reflects the weighting of the building blocks outside the RECLAIM Consortium. The Radar Chart visualize the weighting of the Building Blocks coming from the survey response.

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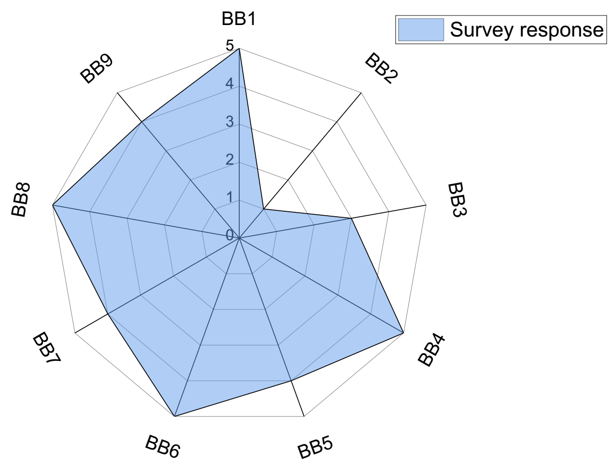
| Building Block | BB1 | BB2 | BB3 | BB4 | BB5 | BB6 | BB7 | BB8 | BB9 |
|---|---|---|---|---|---|---|---|---|---|
| survey related question | Q27<br>Q29<br>Q34<br>Q37 | Q33 | Q30<br>Q37 | Q24<br>Q34 | Q26<br>Q31<br>Q34<br>Q37 | Q28<br>Q34<br>Q37 | Q29<br>Q34<br>Q37 | Q27<br>Q30<br>Q34<br>Q37 | Q34 |
| Rating | 5 | 1 | 3 | 5 | 4 | 5 | 4 | 5 | 4 |




| | |
|---|---|
| **BB1** | Adaptive Smart Sensorial Network and Digital Retrofitting Infrastructure |
| **BB2** | Embedded Cybersecurity for IoT devices |
| **BB3** | Decision Support Framework (DSF) for Optimal Lifetime-Extension Strategies |
| **BB4** | Cost Modelling and Financial Analysis Toolkit |
| **BB5** | Prognostic and Health Management Toolkit |
| **BB6** | Fault Diagnosis and Predictive Maintenance Simulation Engine using Digital Twin |
| **BB7** | Optimization Toolkit for Refurbishment & Re-manufacturing Planning |
| **BB8** | In-Situ Repair Data Analytics for Situational Awareness |
| **BB9** | Novel shop floor AR-enabled Multimodal Interaction Mechanisms |

*Figure 19: Weighting of the Building Blocks coming from the survey response*

## 4.2 Pilots rating of Building Blocks

In order to elucidate the emphasis of each building block for the five RECLAIM Pilots, the respective responsible persons were asked to estimate the weighting of each block with respect to their Pilot's needs. To do so, a measure of weighting from 1 – Low priority to 5 – high priority has been defined.

Overall, the assessment of the building blocks shows a heterogeneous picture, but with a focus on the following areas of interest for the industry. BB1 has high/highest priority in all pilots whereas BB2 is rated low by all pilots. There is also agreement on the rating of BB6 which is classified as high or very high. The evaluation of BB5 is much more split, it is evaluated either with highest or low priority. The BB4 is a low priority building block. BB3 and BB8 do not show any discernible trend, as the full range of valuations is available. The weighting of BB7 and 9 is approximately equal and both blocks have an average priority.

The next figures show the rating of priority for each Pilot.

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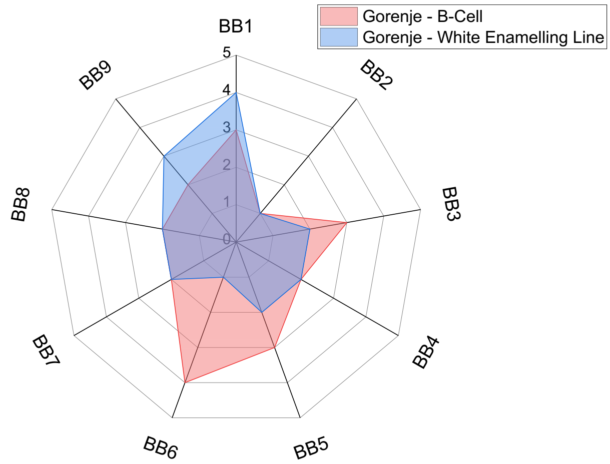
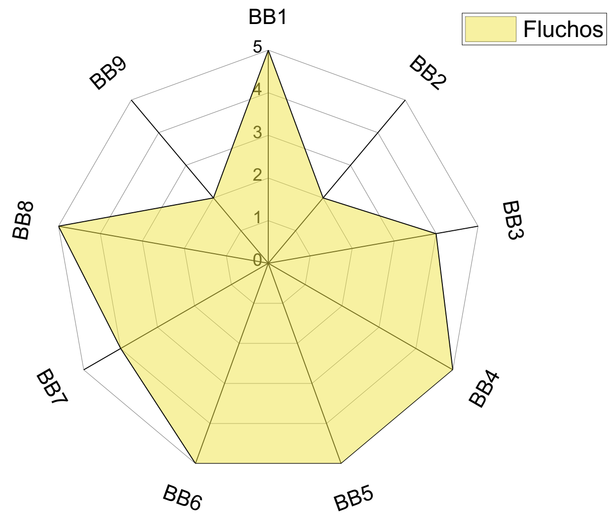



| | |
|---|---|
| **BB1** | Adaptive Smart Sensorial Network and Digital Retrofitting Infrastructure |
| **BB2** | Embedded Cybersecurity for IoT devices |
| **BB3** | Decision Support Framework (DSF) for Optimal Lifetime-Extension Strategies |
| **BB4** | Cost Modelling and Financial Analysis Toolkit |
| **BB5** | Prognostic and Health Management Toolkit |
| **BB6** | Fault Diagnosis and Predictive Maintenance Simulation Engine using Digital Twin |
| **BB7** | Optimization Toolkit for Refurbishment & Re-manufacturing Planning |
| **BB8** | In-Situ Repair Data Analytics for Situational Awareness |
| **BB9** | Novel shop floor AR-enabled Multimodal Interaction Mechanisms |

*Figure 20: Weighting of the Building Blocks for the Gorenje Pilots 1.1-B-Cell and 1.2-White Enamelling Line*




| | |
|---|---|
| **BB1** | Adaptive Smart Sensorial Network and Digital Retrofitting Infrastructure |
| **BB2** | Embedded Cybersecurity for IoT devices |
| **BB3** | Decision Support Framework (DSF) for Optimal Lifetime-Extension Strategies |
| **BB4** | Cost Modelling and Financial Analysis Toolkit |
| **BB5** | Prognostic and Health Management Toolkit |
| **BB6** | Fault Diagnosis and Predictive Maintenance Simulation Engine using Digital Twin |
| **BB7** | Optimization Toolkit for Refurbishment & Re-manufacturing Planning |
| **BB8** | In-Situ Repair Data Analytics for Situational Awareness |
| **BB9** | Novel shop floor AR-enabled Multimodal Interaction Mechanisms |

*Figure 21: Weighting of the building blocks for Pilot 2 from Fluchos*

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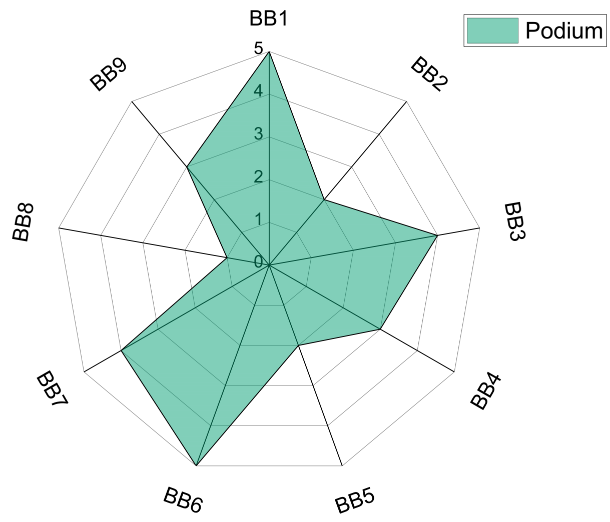
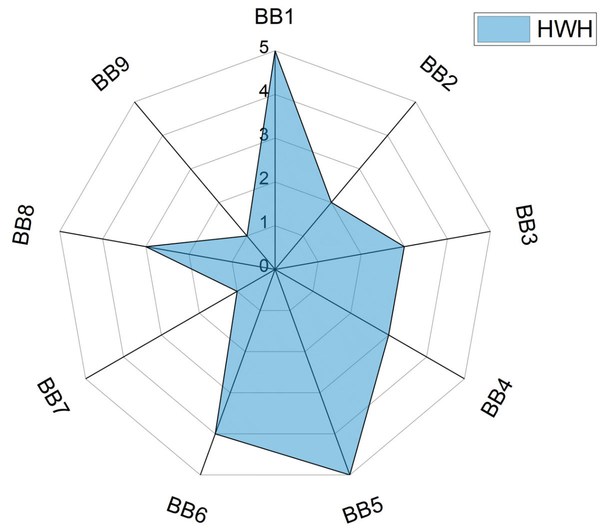



| | |
|---|---|
| **BB1** | Adaptive Smart Sensorial Network and Digital Retrofitting Infrastructure |
| **BB2** | Embedded Cybersecurity for IoT devices |
| **BB3** | Decision Support Framework (DSF) for Optimal Lifetime-Extension Strategies |
| **BB4** | Cost Modelling and Financial Analysis Toolkit |
| **BB5** | Prognostic and Health Management Toolkit |
| **BB6** | Fault Diagnosis and Predictive Maintenance Simulation Engine using Digital Twin |
| **BB7** | Optimization Toolkit for Refurbishment & Re-manufacturing Planning |
| **BB8** | In-Situ Repair Data Analytics for Situational Awareness |
| **BB9** | Novel shop floor AR-enabled Multimodal Interaction Mechanisms |

*Figure 22: Weighting of the building blocks for Pilot 3 from Podium*




| | |
|---|---|
| **BB1** | Adaptive Smart Sensorial Network and Digital Retrofitting Infrastructure |
| **BB2** | Embedded Cybersecurity for IoT devices |
| **BB3** | Decision Support Framework (DSF) for Optimal Lifetime-Extension Strategies |
| **BB4** | Cost Modelling and Financial Analysis Toolkit |
| **BB5** | Prognostic and Health Management Toolkit |
| **BB6** | Fault Diagnosis and Predictive Maintenance Simulation Engine using Digital Twin |
| **BB7** | Optimization Toolkit for Refurbishment & Re-manufacturing Planning |
| **BB8** | In-Situ Repair Data Analytics for Situational Awareness |
| **BB9** | Novel shop floor AR-enabled Multimodal Interaction Mechanisms |

*Figure 23: Weighting of the building blocks for Pilot 4 from Harms&Wende*

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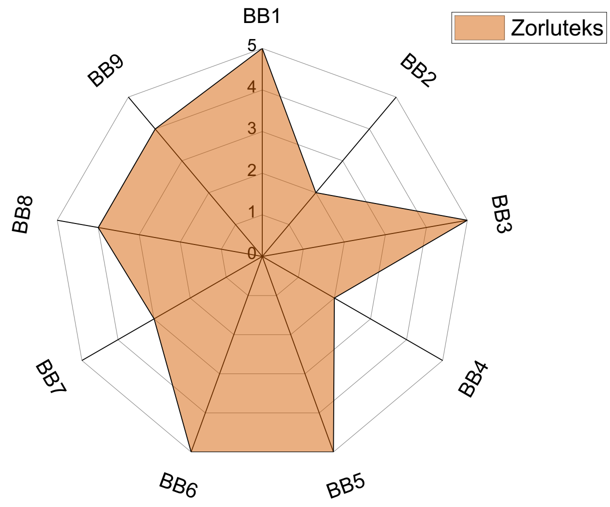
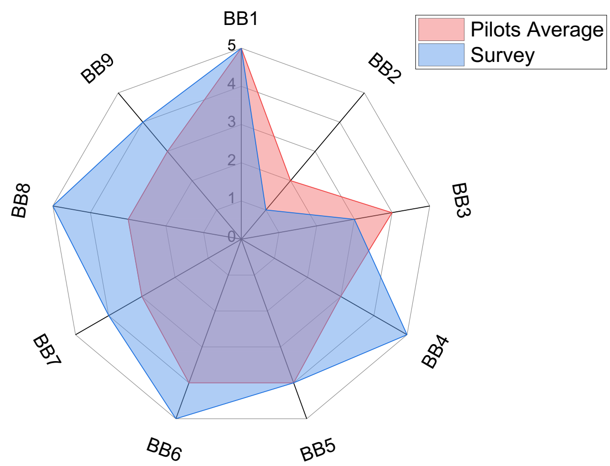



| | |
|---|---|
| **BB1** | Adaptive Smart Sensorial Network and Digital Retrofitting Infrastructure |
| **BB2** | Embedded Cybersecurity for IoT devices |
| **BB3** | Decision Support Framework (DSF) for Optimal Lifetime-Extension Strategies |
| **BB4** | Cost Modelling and Financial Analysis Toolkit |
| **BB5** | Prognostic and Health Management Toolkit |
| **BB6** | Fault Diagnosis and Predictive Maintenance Simulation Engine using Digital Twin |
| **BB7** | Optimization Toolkit for Refurbishment & Re-manufacturing Planning |
| **BB8** | In-Situ Repair Data Analytics for Situational Awareness |
| **BB9** | Novel shop floor AR-enabled Multimodal Interaction Mechanisms |

*Figure 24: Weighting of the building blocks for Pilot 5 by Zorluteks*

## 4.3 Comparison of the weighted Building Blocks

In the previous sections, the weightings of the nine building blocks were presented both for the pilots participating in RECLAIM and the distribution resulting from the survey for companies outside the RECLAIM Consortium. In the following, these are superimposed and compared to see if the view of the RECLAIM Associated Pilots correlates with the requirements outside the Consortium. This is visualized in Figure 25. The result shows a consistent view on the rating of BB1 and BB5. There is only a minimal deviation in the evaluation of BB2, BB3, BB6, BB7 and BB9. The pilots rated BB2 and 3 slightly higher, whereas the survey showed a higher prioritisation for BB6, BB7 and BB9. The greatest differences are found in building blocks 4 and 8. It can be summarized that the requirements of the RECLAIM Consortium and those of the surveyed companies go in the same direction, which shows that the formulated building blocks, the set objectives and the KPI's are correct.




| | |
|---|---|
| **BB1** | Adaptive Smart Sensorial Network and Digital Retrofitting Infrastructure |
| **BB2** | Embedded Cybersecurity for IoT devices |
| **BB3** | Decision Support Framework (DSF) for Optimal Lifetime-Extension Strategies |
| **BB4** | Cost Modelling and Financial Analysis Toolkit |
| **BB5** | Prognostic and Health Management Toolkit |
| **BB6** | Fault Diagnosis and Predictive Maintenance Simulation Engine using Digital Twin |
| **BB7** | Optimization Toolkit for Refurbishment & Re-manufacturing Planning |
| **BB8** | In-Situ Repair Data Analytics for Situational Awareness |
| **BB9** | Novel shop floor AR-enabled Multimodal Interaction Mechanisms |

*Figure 25: Summary comparison of the weighted building blocks as mean value (rounded) of the individual weightings per pilot and the analysis of the survey*

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## 4.4 Mapping of the RECLAIM KPI’s to the Building Blocks

The following table summarizes RECLAIM project objectives with their specific KPI's and the target values. In addition, the KPIs are mapped to the nine building blocks and the corresponding RECLAIM pilots.

*Table 3: Mapping of the RECLAIM KPI’s to the Building Blocks*

| Objective | KPI | Definition | Target value | Building Block | Pilots |
|---|---|---|---|---|---|
| O1 | 1.1 | Fulfilment of user’s requirements concerning lifetime extension methods in old machines | >85 % | **all** | all |
| | 1.2 | Improvement of the usability of current services and solutions | >90 % | **all** | all |
| | 1.3 | Circular Economy Enhancement | 30 % faster decision making | **3** | 2,3,5 |
| O2 | 2.1 | Cost from physical inspection | -50 % | **6** | all |
| | 2.2 | Effectiveness Detection of failures | 80 % accuracy | **6** | all |
| | 2.3 | Automation metrics of RECLAIM | (a) Increased average automation level: 4.5 to 5 out of 5<br>(b) Increased automation effectiveness: 3.5-4.5 to 5 | **1** | all |
| | 2.4 | Reported Recovery Decision of End-user Impact | - | **all** | all |
| O3 | 3.1 | Increase/modernisation of sensorisation in pilot demonstration lines | +20 % - 30 % | **1** | all |
| | 3.2 | Improvement of electromechanical machines’ and productions’ monitoring through Optimization Toolkit for Refurbishment and Re-manufacturing Planning | >20 % | **7** | 2,3 |
| | 3.3 | Increase in data flow from the shop-floor to the DSF through Digital Retrofitting Infrastructure | >20 % | **3** | 2,3,5 |
| | 3.4 | Machine Heath Index | - | **5** | 2,4,5 |
| O4 | 4.1 | Time spent on predictive maintenance | -50 % | **6** | all |
| | 4.2 | Number of fault diagnosis | >95 % accuracy of known faults 90 % of possible faults and stoppages are identified | **6** | all |
| | 4.3 | Operating capacity of the simulation infrastructure | - | **6** | all |
| | 4.4 | Reduction of downtime due to unscheduled maintenance | >20 % | **6** | all |
| | 4.5 | Maintenance effort required is decreasing at 50% (MTBF) | -50% | **6** | all |
| O5 | 5.1 | Service activity reliability | >40 % | **7** | 2,3 |
| | 5.2 | OEE after refurbishment/ re-manufacturing process | >99 % | **6** | all |
| | 5.3 | Success of refurbishment/ re-manufacturing processes on the production floor | >99% | **6** | all |

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| | | | | | |
|---|---|---|---|---|---|
| O6 | 6.1 | Amount of Time to Resolve a Failure | -20 % time to resolve a failure | 8, 9 | 2,5 |
| | 6.2 | Uptime (or Downtime) during an Incident | -20 % cost of downtime | 7 | 2,3 |
| | 6.3 | Demonstrate effective maintenance to potential failures and stoppages | >98.5 % | 7 | 2,3 |
| O7 | 7.1 | Satisfaction of Industries with the Repairs Service | 85 % - 95 % | all | all |
| | 7.2 | Average number of working days to complete all repairs | -50 % | 7, 8 | 2,3,5 |
| | 7.3 | Situational Awareness through in-situ repair process | +50 % - 60 % | 7, 8 | 2,3,5 |
| | 7.4 | Mean Time To Repair | >50% | 6 | all |
| O8 | 8.1 | Number of pilots in operational environments under the direct responsibility of the end-users involved | - | all | all |
| | 8.2 | Number of machines of components to be refurbished or re-manufactured | >8 alternative industrial machines | all | all |
| | 8.3 | Extended useful lifetime of machinery | 8-10 years | all | all |
| | 8.4 | Decrease in maintenance cost per machine | 50 % | all | all |
| O9 | 9.1 | On Standard Operating Efficiency | - | 6 | all |
| | 9.2 | Refurbishment and Re-manufactured Machines Safety | -50 % | 6, 7 | all |
| | 9.3 | Lost Time Injury Frequency Rate | <5 | 6 | all |
| O10 | 10.1 | Replicate the RECLAIM's result | >3 other industrial sectors | all | all |
| | 10.2 | Number of attracted future stakeholders/providers | >30 stakeholders/providers | all | all |
| | 10.3 | Business plans available for all identified exploitable assets, including the overall RECLAIM system | - | all | all |

## 4.5 Literature Review

This section describes the outcome of a literature review which has been done in order to supplement the requirements analysis with additional aspects probably not covered by the Pilot and survey analysis. The major input has been gained by the results of previous EC projects such as ReBORN (FoF.NMP.2013; GA No. 609223) or Co-Factor (H2020-FoF-2014; GA No. 637178) in which some RECLAIM partners also participated.

### 4.5.1 Relevant EC projects

The ReBORN project's vision was to demonstrate strategies and technologies that support a new paradigm for the re-use of production equipment in factories. The proposed approaches intended to give new life to decommissioned production systems and equipment, helping them to be "reborn" in new production lines. ReBORN proposed to implement smart components ("VERSONs"), which implement models for self-assessment in terms of life-cycle information in order to realize equipment re-use.

T-REX (FoF.NMP.2013-8; GA No. 609005) promoted an integrated product-service solution. The idea was to shift from value in exchange to value in use to satisfy customer needs. In this new landscape, manufacturers do not sell a physical product, but its usage (renting,

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pay-x-use) or its outcome (pay-x-performance). T-REX identified different levers for making it's vision happen:

- Business Model suited for the new landscape that changes the way products are offered and customer relationships managed
- Product design techniques to extend the lifecycle, to foster upgrading and renovation, and to support serviceability
- Service design methods to develop new services consistent with the business models and re-engineering existing services
- d) Integrated local Condition Monitoring capacities and tools for Asset Health Management, customizable to the industry requirements

EASE-R3 (FP7-NMP; GA No. 608771) aimed at developing a novel Integrated framework for a cost-effective and easy Repair, Renovation and Re-use of machine tools within modern Factory (machining shop floor), oriented both to SME and large OEM/end-users, and covering the entire life cycle of the system (from design stage throughout operative life).

The vision of MONSOON (H2020-EU.2.1.5.3.; GA No. 723650) was to provide process Industries with dependable tools to help achieving improvements in the efficient use and re-use of raw resources and energy. By this, MONSOON aimed at establishing a data-driven methodology supporting the exploitation of optimization potentials by applying multi-scale model based predictive controls in production processes.

PERFoRM (H2020-EU.2.1.5.1.; GA No. 680435) aimed to the conceptual transformation of existing production systems towards plug&produce production systems in order to achieve a flexible manufacturing environment based on rapid and seamless reconfiguration of machinery and robots as response to operational or business events. By this, also the capability for reusing equipment will be strengthened.

### 4.5.2 State of the art review

In addition to the review of relevant EC research projects, a number of scientific publications has been carried out explicitly addresses the RECLAIM building blocks.

#### *4.5.2.1 Decision Support Framework of used industrial equipment for sustainable manufacturing*

With regard to decision support, a number of decision-making approaches have been developed to assess the comprehensive reusability or re-manufacturability of End of life products[i]. A multi-criteria evaluation system to select the best recovery option in terms of income, cost, compliance with regulation and environmental performance has been proposed by Remery et al. (2012)[ii]. Ondemir and Gupta (2014)[iii] built a mixed integer goal programming model to determine whether a product need to be remanufactured, disassembled, repaired or recycled to meet different market demands. In their study, Remaining Useful Life was utilized to represent the quality state of an EOL product. Ovchinnikov et al. (2014)[iv] presented an analytical model to assess the economic and environmental performances of product re-manufacturing strategies in service-oriented sustainable manufacturing. The goal of Ziout et al. (2014)[v] was to provide an Analytic Hierarchy Process (AHP)-based holistic and flexible decision-making model considering all the interests of stakeholders involved in the reverse logistics. Dhouib (2014)[vi] developed a fuzzy Measuring Attractiveness by a Categorical Based Evaluation Technique approach, which is a well-established interactive multi-criteria decision-making technique, to assess and rank the recovery options. Song (2015)[vii] proposed a hierarchical multi-criteria recovery decision-

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making framework based on product condition evaluation and life cycle analysis. Dehghanbaghi et al. (2016)[viii] developed a combined approach of fuzzy rule-based reasoning system and fuzzy AHP to determine the best recovery strategy. A two-phase comprehensive evaluation system was established to assess both product properties (i.e. technical and commercial properties) and process properties (i.e. economic return, service, environmental impacts). Some other studies took component recovery into account. Ma and Kremer (2015)[ix] designed a fuzzy-logic based assessment framework for recovery decision-making from the perspective of sustainability and designer's preferences.

#### *4.5.2.2 Refurbishment and Re-manufacturing Techniques of industrial equipment*

The purpose of refurbishment is to restore a system to satisfy its original specification via procedures like replacing components or modules of the system[x]. This process has been implemented in a variety of industrial sectors to extend system remaining useful life and there is growing interest for refurbishment in other industries including automotive[xi], electrical and electronics[xii]. Since refurbishment is able to restore the required reliability of a system at a lower cost than installing a new system, it has been identified as a measure to boost productivity and has been applied as a marketing strategy[xiii]. Refurbishment also reduces waste and thus it is eco-friendly[xiv], which results in a reduction of total life cycle cost of the system. In line with refurbishment, there is a noticeable trend in re-manufacturing to recover the product with same objective as refurbishment, i.e. extend the life of the product.

Remanufacturing is a value recovery option that is available at the end of a product's lifetime in order to extend its original lifespan (Chari et al. (2014))[xv],. An approach to develop business strategies for competition and collaboration in the re-manufacturing market of production equipment, while considering different market players having different characteristics as been proposed by Steingrımsson et al. (2011)[xvi]. Cunha et al. (2011)[xvii] established a technology road mapping technique to show the interrelations between market, equipment and technology parameters. Besides these more general approaches, a number of other studies focused on a specified type of production equipment. For instance, Schraven et al. (2012)[xviii] proposed a make-to-order production strategy for equipment used by automotive OEMs including a modular concept which permits to consider recovered equipment components in engineering and design. Sharma et al. (2015)[xix] investigated the re-manufacturing process and found out that re-manufacturing is the primary means by which the customer's requirements and needs are satisfied; it also provides effective product support services for heavy equipment. In the machinery industry, a large number of studies have addressed various problems encountered in re-manufacturing mainly from the OEM's perspectives[xx]. Many of these studies were devoted to machine tools[xxi]; some authors exposed re-manufacturing only for a special kind of production machines[xxii].

#### *4.5.2.3 Smart Sensor Networks for Industrial Environment*

Real-time monitoring of machine tools for the maintenance planning has been extensively stressed in literature[xxiii],[xxiv]. A number of monitoring systems have been employed in a number of occasions; to identify the tool wear and to provide the availability of the machine in[xxv]. Roberto et al. (2010)[xxvi] described the necessity for the use of real-time monitoring in. The authors identified that the main requirements for monitoring systems in production are the robustness, the capability for reconfiguration, the reliability, the intelligence, and the cost efficiency. Monitoring of machines and their components are done by various sensors. Among others vibration, acoustic, and temperature are used[xxvii]. In previous literature, monitoring systems have been proposed for the purposes of preventive maintenance[xxviii], remaining useful life estimation[xxix], and cutting tool reconditioning[xxx] among others. The application of monitoring devices in the shop-floor to track the availability of machine tools, results in an adaptive holistic scheduling has been introduced in[xxxi].

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#### 4.5.2.4 Prognostic and Health Management (PHM)

In general, three different approaches can be distinguished: a) the physics of failure-approach, b) the data-driven approach, and c) the fusion approach. In the physics of failure approach, physical understanding of the system failure mechanism is modelled mathematically to predict the remaining useful life (Pecht et al., 2010)[xxxii]. The physics of failure approach takes both the hardware configurations and the life cycle loading into the failure model. Major inputs with respect to hardware configurations include material properties, geometry, and architecture, while the life cycle loading includes operational loads such as duty cycles and environmental loads such as the environment temperature. In the data-driven approach, data are acquired in-situ using a network of sensors that monitor the system. Features that carry the health information of the system are extracted from the sensor signals through a series of procedures, such as noise reduction, outlier removal, and redundancy reduction. The health states of the system are then estimated based on the extracted features via methods for decision making, such as machine learning techniques. Based on the use of historic data, machine learning techniques can be classified as supervised learning techniques and unsupervised learning techniques. The precondition for the implementation of prognostic and health management is a physical model of the failure mechanism of interest, as in the case of electromechanical migration on circuit boards (He et al., 2011)[xxxiii]. In various cases, PHM have been implemented to reduce losses due to reliability issues (Pecht, 2012)[xxxiv]. Sun et al. (2012)[xxxv] compiled an overview of the benefits and challenges of PHM

#### 4.5.2.5 Cost Analysis and Cost Modelling Tool

The cost analysis and modelling intents to cover the costs throughout the product life cycle. This includes the design, manufacturing, service and disposal of a product. The manufacturing cost analysis and modelling was well researched. Manufacturing cost normally include materials cost, machining cost and assembly cost, and the machining and assembly cost are normally estimated based on the process planning accomplished by production engineers[xxxvi]. For every operation defined in the process, the processing time can be estimated based on the work rate for the resource used to accomplish the operation. When the processing time is known the machining or assembly cost can be estimated using the cost rate for the utilization of the resource. For example, Xu et al. adopted this approach to estimate the manufacturing cost in different applications, e.g. for aircraft life cycle cost modelling[xxxvii] and automotive product manufacturing and re-manufacturing cost modelling[xxxviii]. Maintenance cost is normally researched in the life cycle cost modelling covering different aspects. Xu et al. developed aircraft life cycle cost modelling by using Systems Engineering approach[xxxix]. Lanza and Ruhl adapted the Monte Carlo method to estimate the costs of providing maintenance service[xl].

#### 4.5.2.6 Optimization Planning for Refurbishment and Re-manufacturing

Remanufacturing has former been classified into two categories, strategic level and operational level. On the strategic level, the economics of re-manufacturing is studied by Ferrer (1997)[xli]. In his study, the feasibility of re-manufacturing is investigated considering the value of recoverable parts and market specification. Salomon et al. (1996)[xlii] develop a design of product return network. And Guide et al. (2001)[xliii] find the optimal selling and acquisition process for re-manufacturing product. In contrast to that, most previous researches on re-manufacturing focus on operational level. The major research area is forecasting, production planning/control, inventory control/management and scheduling. Fleischmann et al. (1997)[xliv] give a good overview on quantitative models for recovery production planning and inventory control. Jayaraman et al. (2003)[xlv] extend the PUSH and strategies to control a system in which all returned products are remanufactured and no planned disposal occur. Also, in the same work, they discuss reverse distribution, and propose a mathematical programming model and solution procedure for a reverse distribution problem. Their model builds upon the single-source plant location model developed by Pirkul et al. (1996)[xlvi].

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#### *4.5.2.7 Digital Twin Simulation for Machinery Fault Diagnosis*
Digital twins integrate the life cycle of a machine[xlvii], and achieve a closed loop and optimisation of the machine design, production, operation, and maintenance, etc. With the Digital Twin model, it can also facilitate the verification of product functions, structures and manufacturability. In the production phase, the whole manufacturing process can be real-time controlled and optimised by Digital Twin. From the input of raw material to the output of finished products, the information of geometrical, equipment, tools, and environment are managed to allow moving from mass production to customised production. During the operation phase, the performance data of a product is collected systematically as a part of the Digital Twin to verify and update the existing models. In the service phase, Digital Twin can provide value-added services with the support of physical simulation and data driven intelligence. A variety of services, such as fault diagnosis, troubleshooting, remaining useful life prediction, and maintenance can be implemented to make timely decisions and reduce the risk of accidents. In Magargle et al.[xlviii], a multi-physical twin model is built to monitor the status of the brake system through multiple angles. NASA hopes to realise the health management and residual life prediction of the aircraft by building a multi-physical, multi-scale Digital Twin model[xlix].

#### *4.5.2.8 Cybersecurity for IoT devices for connected smart environments*
Currently, the poor usability of cybersecurity solutions tends to be the effect of security constraints. Finding the right trade-off between usability and security or preferably integrate usability and security requirements is part of a major research challenge, which recently has been addressed by scholars[l]. For instance, user-centred approaches are recommended as means to accomplish usable security, while the definition of objectives for both security and usability is suggested as a way to decide on the right balance between the two[li]. Understanding the security and usability collectively is recognised as a critical factor for the successful development, implementation and usage of information systems[lii]. As far as the IoT is concerned, usability and security are among the 4 major research challenges identified (the other two are performance and reliability), together with privacy concerns growth, as IoT device manufacturers for the smart-home are acquired by large corporations, such as Google[liii]. Most recent research suggests new usable security frameworks particularly for modelling security and privacy risks in smart homes at consumer level. For example, the framework presented in [liv] aims to support home users with a highly usable security decision support tool. However, it still needs to address improvements on usability and scalability and validate real utility offered to the user.

#### *4.5.2.9 Augmented Reality on the Plant Floor*
Augmented Reality (AR) is seen as an emerging technology that can help maintainers as it enhances users' perception of and interaction with the real world[lv]. This is realised by displaying virtual information on top of it[lvi]. The information needed about maintenance procedures can be provided to the user directly on the workplace through a real-time interaction[lvii]. Many applications of AR in maintenance have been studied, but the research remains at an exploratory stage[lviii]. Currently, to study the feasibility of AR integration in maintenance[lix], emerging topics in the area have emerged, such as authoring and context awareness[lx]. Authoring is a system component that allows the maintenance experts to create, edit and update AR contents for applications, while context-awareness is a system that uses the context to provide relevant information and/or services to the user, where relevancy depends on the user's task[lxi]. These key features for AR focus on how maintenance information is acquired, transformed and presented to the maintainers, so they can increase their performance in an affordable manner.

### 4.5.3 Conclusions
This section provides a set of general conclusions on the requirements for the RECLAIM approach which can be derived from the literature review. This is done by comparing the

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benefits proposed by the RECLAIM approach for each building block with the output of the survey and the expressed needs of the Pilots.

For the Decision Support Framework of used industrial equipment for sustainable manufacturing, RECLAIM proposes to make a step beyond the state of the art by achieving health-based recovery planning at both machine- and component-level while considering economic and environmental effects. By this, RECLAIM targets on assisting the machinery operators and machinery manufacturers in making efficient end-of-life decisions at different service-life periods. When looking at the results of the survey as well as on the Pilot needs, end-users are interested in the decision support for entire machines or even machine parks. The management of recovery planning is seen from an “eagle-eye perspective”, taking into account the interrelation between recovery planning, maintenance planning and production schedule. On the other hand, the machine manufacturers or equipment vendors concentrate on “their” machines and the individual components. They are interested to obtain a clear picture of the machines’ state, including all components. By this, they intent to provide maintenance services specifically tailored to the end-user’s needs. In addition, they are seeking for new business models, in which the servitisation is plays a crucial role. Business models based e.g. pay-per-use or pay-per-part require reliable decisions on the state and (future) reliability of a machine.

Building Block 7 will develop a set of novel tools and methodologies which enhance the refurbishment and re-manufacturing process for industrial electromechanical machines and robotic systems, differentiating the approach according to the level of action (whole machine, modules and components). While the general importance is seen to be pretty high (rated to rank 4 out of 5 in the survey), the Pilot users put different emphasis on this building block. As we are proposing a set of different tools useful on different levels of action, we are guessing that most of the survey responses indicated the general importance of such tools and thus, rated their importance quite high. In contrast to that, some of the Pilots require very specific tools (which will be developed during the project), while other do not see much importance in the frame of their factory environment.

When looking at the area of the smart real-time control and data analytics, a very clear picture on their importance is available. Four of five Pilots ranked their importance in the highest level (rank 5), one Pilot to rank 4. Also, the survey indicates that the RECLAIM approach enabling automated knowledge extraction from big data in order to allow for prescriptive and preventative actions is very important. Thus, digital retrofitting and subsequent knowledge extraction plays a significant role for the lifetime extension of equipment. Fortunately, a significant number of scientific publications on the one hand, and also reliable technology on the other hand are available. Thus, RECLAIM can build on a solid basis in order to address these needs in very detail.

Digital retrofitting is directly linked with building block “Prognostics and Health Management Toolkit”. As a consequence, also this building block has been identified to be very relevant both to the Pilots and also for the general manufacturing industry as indicated in the survey. In contrast to that, Pilots and survey responses differ in the rating of the importance of the Cost Analysis & Cost Modelling Tool. While most of the Pilots responsible persons do rank such a tool rather low, high importance is identified by the responsible persons answered the survey. A possible explanation of the different rating between Pilots and survey responses is, that probably the Pilots responsible are more related to the technical functionality and innovation and are thus, not that concentrating much on the economic aspect. In contrast to that, also CEO’s or other managers responded to the survey. Those people are more related to the business models and financial aspects of manufacturing. As a consequence, cost analysis will remain as an important aspect within the RECLAIM framework. However, its demonstration will probably not be covered within a Pilot case.

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As expected, the necessity of dedicated technical innovations such as digital twins or augmented reality technology highly depends on the specific industrial setup and target. In general, the ranking of those technologies is pretty high when looking at the survey responses. This shows that the general aim of RECLAIM with respect to these technologies is perfectly right. When looking at the aims of the Pilots, very specific needs and specific implementation and integration of these technologies need to be done. This is especially true for the AR technology: While most of the Pilots do not see a significant benefit, two Pilots explicitly mentioned AR as an interesting technology, while at the same time, the technology need to be adopted to their specific needs.

Finally, the analysis of the responses and Pilot’s requests with regard to the cyber-security shows, that people do not want to spend much emphasis to this point. We’re guessing, that people are more interested in the project’s output in terms of technology for refurbishment and remanufacturing rather than expecting sophisticated solutions for cyber-security. However, the capabilities of the proposed RECLAIM solution for resilience to cyber-attacks and perform intrusion detection and prevention, are still very important: As major technical innovations within the RECLAIM solution rely on data access, data communication and data processing, proper methods that ensure seamless and trusted service provisioning over different data. In addition, the proposed capabilities related to the dynamic coupling of micro-services offered and embedded devices involved are a part of the group specifications of some of the most relevant automotive OEM’s. For that, RECLAIM definitely contributes to fulfilling the future security standards.

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# 5 Requirements Review and Retrospective Process

One of the main challenges in the projects with a large consortium is to manage the amount, complexity and priority of requirements defined by project pilots. On one hand, pilots should guide and indicate how new or existing technologies are relevant for the business, and in the other hand, demonstrate how the requirements impact their own business and report a competitive advantage towards the initial conditions.

Since in RECLAIM project there are 5 different pilots, some of the requirements are definitely unique, but some of them might be overlapping or even conflicting. Conflicting requirements are one of the most difficult to handle since one technology dimension that should maximized is generalization. If generalization cannot be reached, the effort to develop new technology of each specific requirements is overwhelming. Thus, in order to understand the overlapping and commonality of requirements and ensure the technology can be developed or used in a broader sense, a constant follow-up of their evolution should exist.

For the RECLAIM project, an iterative process of requirements' review and retrospective is employed, composed by three different iterations. These iterations are suited for the different stages of the project where a follow-up process is defined. Together with iterations, requirements will be evaluated in many dimensions according to predefined metrics. This allows not only to understand the suitability of requirements but also to assess their evolution along time. It is important to make sure that, at the end of the project, the fulfilled requirements are relevant and consistent to pilot business goals and expectations.

In the next two sub-sections, the evaluation metrics for the requirements are presented and the employed process in each iteration is detailed, building ultimately a roadmap for the review and retrospective of RECLIAM project requirements.

## 5.1 Evaluation Metrics

As previously detailed, the evaluated metrics are used to 1) make sure that requirements are suitable and aligned with the project goals and 2) their progress can be followed throughout the technology and demonstration implementation. Since only as the project progresses the first results are achieved, the potential and relevant can realistically be estimated at later stages by the pilots. This may cause for the requirements to change, e.g. in priority. Additionally, since the success of some technologies is also dependent on pilot information and data, it is also important to understand how far and realistically the requirement can be achieved. Since all these dimensions are important to contemplate, a set of five evaluation metrics were used for the requirements. All these metrics should be rated between 0 and 5, where the correspondence of each rate is detailed among each metric.

- Validity: The functions proposed by pilots should be aligned with the project goals and what needs to be performed. It may be found later that there are additional or different functions / requirement that are required instead. Validity ratings:
  - 0 – Requirement not valid;
  - 1 – High probability of being not valid but worth being kept in the requirements list;
  - 2 - Still unclear if the requirement is valid and further discussion is required;
  - 3 - Valid requirement with major changes in the future;

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- 4 - Valid requirement with minor changes in the future;
- 5 - Valid requirement with no foreseen changes in the future;

- Consistency: Requirements in the document shouldn't conflict or different description of the same technology / functionality. Consistency ratings:
  - 0 - Requirement does conflict with others and merging / removal is required;
  - 1 - High probability of being inconsistent but worth being kept in the requirements list;
  - 2 - Still unclear if the requirement is conflicting and further discussion is required;
  - 3 - Requirement is consistent but major changes are required;
  - 4 - Requirement is consistent but minor changes are required:
  - 5 - Requirement is consistent and does not conflict with others;
- Completeness: The requirement should include all the information necessary such as constraints, connection to technologies or other requirements, input and outputs, hardware requirements, etc. Completeness ratings:
  - 0 - Requirement is not complete and removal must be considered;
  - 1 - Requirement is not complete or information is completely misplaced but worth being kept in the requirements list;
  - 2 - Still unclear if more information is needed and further discussion is required;
  - 3 - Requirement has all the necessary information but major changes are required;
  - 4 - Requirement has all the necessary information but minor changes are required;
  - 5 - Requirement is complete;
- Realism: Ensure the requirements can actually be implemented using the knowledge of existing partners, technology, budget and schedule. Realism rating:
  - 0 - Requirement is not feasible and consider its removal;
  - 1 - High probability of not being feasible but worth being kept in the requirements list;
  - 2 - Still unclear if the requirement is feasible and further discussion is required;
  - 3 - Requirement is completely feasible but major changes / further alignment are required;
  - 4 - Requirement is completely feasible but minor changes / further alignment are required;
  - 5 -Requirement is completely feasible in the context of the project;
- Verifiability: Requirements should be written so that they can be tested. This means you should be able to write a set of tests that demonstrate that the system meets the specified requirements. Verifiability rating:
  - 0 - It is not possible to test the requirement and consider its removal;
  - 1 - It is not possible to test the requirement but worth being kept in the requirements list;
  - 2 - Requirement not completely testable and further discussion is required;
  - 3 - Requirement is testable but major definitions in the roadmap are required;
  - 4 - Requirement is testable but minor definitions in the roadmap are required;
  - 5 - Requirement is testable and clear roadmap is defined;

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## 5.2 Review and Retrospective Process

In this sub-section the process for each of the three iterations of the requirements review and retrospective will be detailed. This process is a definition of the main results / post-conditions that should come out of each of the iterations, considering the pre-conditions of the sub-sequent iteration. The first iteration starts at month 7 and ends up in month 13, as four months later in month 17 the second iteration starts, ending up on month 21 and five months later the last iteration starts at month 26 and finishes at month 30. The next parts detail each of the iterations.

### 5.2.1 Iteration 1 (M7-M13)

The purpose of this iteration is to make a **Validation by Discussion**. A discussion should be fostered with the proponents of just requirements to investigate in a great detail the provided information and to check for errors, inconsistency, conflicts, and any ambiguity. Very often an ambiguous requirement is ambiguous because the business value is unclear. A debate might be started on the semantics of a term and discover we are solving the wrong problem and end up throwing out the requirement completely. This is particularly important in EU projects where multiple cultures and languages may use the same terms with different meanings. So, the idea is to iterate through potential requirements, understand the business value and fit them together in a logical way.

For this case the metrics defined previously represent a significant role classifying this ambiguity and maturity of a requirement. After this classification, a negotiation with the proponent should be fostered to solve the problems and errors found. The major outcome of this is iteration is to discover ambiguous requirements (verification) and fix them, and unneeded ones (validation). This way we can only remain with the most important requirements.

To achieve the proposed outcomes for this iteration, and discussion among all partners will be organized so all requirements can be revisited and classified.

### 5.2.2 Iteration 2 (M17-M21)

The purpose of this iteration is to make a **Validation by Prototyping**. By prototyping one should understand a user interface still with no business logic behind it (preferably) so the proponents can assess the progress of technology development and propose any adjustment required. Alternatively, a set of wireframes or mockups can be presented as well, since it provides some sort of visual feedback. Hence, prototyping can be used to bullet proof some of the requirements. So, with some functionality already developed or a quick design of the system it is possible to make a detailed validation. If it fails, we then refine the requirement, and a second check should be made again, until it meets the pilot and project needs. This definitely will decrease the cost as a result of having clear, understandable, consistent requirements.

Together with the prototype feedback that will be used for requirement refinement, it is also the goal for this iteration to create a test scenario for each prototype. A good requirement means that it is testable. If a test is difficult or impossible to design, this usually means that the requirements will be difficult to implement and should be reconsidered. The term “tests” here does not mean to write and run some code for every function. It means to write a textual description of the “inputs”, “expected value”, and “steps taken” to perform each function, so one can be aware of the final result. This way, all the test scenarios are used as guidelines for the implementation and test phases where the main goal would be to reach such a solution that should pass such tests.

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Next is presented a template for each test that could be used for the final requirement validation process during pilot demonstration.

| Date run | Time run | Tester | Pass/Fail | Summary of Failure |
|---|---|---|---|---|
| | | | | |

| Assumptions: | | | |
|---|---|---|---|
| Here you write your assumptions; the pre-conditions; or the initial state. | | | |
| System Requirement Covered: | | | |
| The number of the function that's being tested | | | |
| Exclusions: | | | |
| Exclusions, like any un-desired values. | | | |
| Setup: Steps taken | | | |
| Write the steps that should be taken by the user for this function | | | |
| User Action | Value(s) | Expected Results | Pass/Fail/Untested |
| What are the inputs | List all the values that will be entered by the user | The expected output | |

*Figure 26: Test Scenario template to be used per requirement definition*

To achieve the proposed outcomes for this iteration, and discussion among all partners will be organized so all requirements can be revisited and re-classified, together with definition of all test scenarios. Since a presentation of prototypes is something to be made among technology providers and pilots, dedicated meetings for each pilot will be promoted.

### 5.2.3 Iteration 3 (M26-M30)

The purpose of this iteration is to make a **Validation by Test Scenarios**. As in the previous iteration the test scenarios were defined, in the present iteration the purpose is to actually validate if the developed technology can already pass those tests, or if until the end of the project these would be possible to be tested successfully. Together with a re-evaluation of the requirements using the defined metrics, a good sense about if the requirements will be completed fulfil can be achieved. Additionally, if some tests fail, some adjustments in the technology might be made in time for the final project demonstration.

Related to this latter point about pilot demonstration, one main outcome of this iteration is an initial alignment on how the final roadmap and script for the project demonstrations. As initially all requirements as focus, not only, on system needs that will be used in the project, they should be explicitly included into the final demonstrated as they bring further value and success to the project.

To achieve the proposed outcomes for this iteration, a discussion among all partners will be organized so all requirements can be revisited and re-classified, together with validation of all test scenarios into success or fail. Since this validation is something to be made among technology providers and pilots, dedicated meetings for each pilot will be promoted.

In sum, for each of the iteration a set of main outcomes can be summarized:

**Iteration 1 – Validation by Discussion**

- Classification of Requirements through evaluation metrics;
- Set of modification proposals to all requirements.

**Iteration 2 – Validation by Prototyping**

- New classification of requirements through evaluation metrics;

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- Presentation technology prototypes for business value and expectation alignment;
- Definition of test scenarios for each prototype.

**Iteration 3 – Validation by Test Scenarios**

- New classification of requirements through evaluation metrics;
- Final report on requirement evolution throughout the project;
- Alignment of requirement with the project demonstrations.

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# 6 RECLAIM solution

This chapter describes the conclusions derived from the requirement analysis. Firstly, a set of overall requirements are presented that must be taken into account when specifying the RECLAIM architecture. After that, an initial version of the architecture in is illustrated.

## 6.1 Overall requirements

Based on the requirements analysis described above, some general aspects on the design of a system for refurbishment and remanufacturing can be derived. A number of non-functional -and in this case organisational- requirements and some relevant functional requirements for the design of an architecture have been identified.

**Adaptability and scalability**

- Even within RECLAIM, the setup and the complexity of the Pilots varies much
- When looking beyond the project, the complexity and the range of setups is even wider
- As a consequence, the architecture must be adaptable and scalable for very different setups of manufacturing systems

**Efforts for adopting the system**

- In order to guarantee a smooth uptake of the RECLAIM technology, the efforts for adopting the system must be as low as possible
- Services and data management must be separated into common-usable components and such components consisting of specific functionality. The number of common-usable components should be significantly higher than the number of specific components
- Standards should be used

**Managing legacy equipment**

- The system shall be able to extend the lifetime of already existing and productive equipment
- The performance of already existing systems shall not be hampered by the introduction of new functionalities. Therefore, legacy equipment shall preferably be enhanced by e.g. attaching new hardware and software rather than modifying the equipment itself
- Hide specific knowledge (in order to keep IPR and to develop common-usable technology/components)

*Figure 27: Overall Requirements Overview*

## 6.2 RECLAIM initial architecture

The requirement analysis, the prioritisation of the RECLAIM building block and the mapping of the stakeholder's needs to the objectives and KPI's provides a profound basis for deriving an initial architecture of the RECLAIM solution. First of all, the architecture must fulfil the requirements of the RECLAIM Pilots. It must be as specific as possible to lower the efforts of individual adoption to the respective Pilot. On the other hand, the architecture must be open in order to allow for easy adoption to additional needs not know or not in focus at the moment. Furthermore, the architecture shall also fulfil the requirements of stakeholders beyond the consortium. Consequently, it must contain each RECLAIM building block, allowing to put individual emphasises to the building blocks depending on the individual needs. The following figure provides an overview of the initial architecture.

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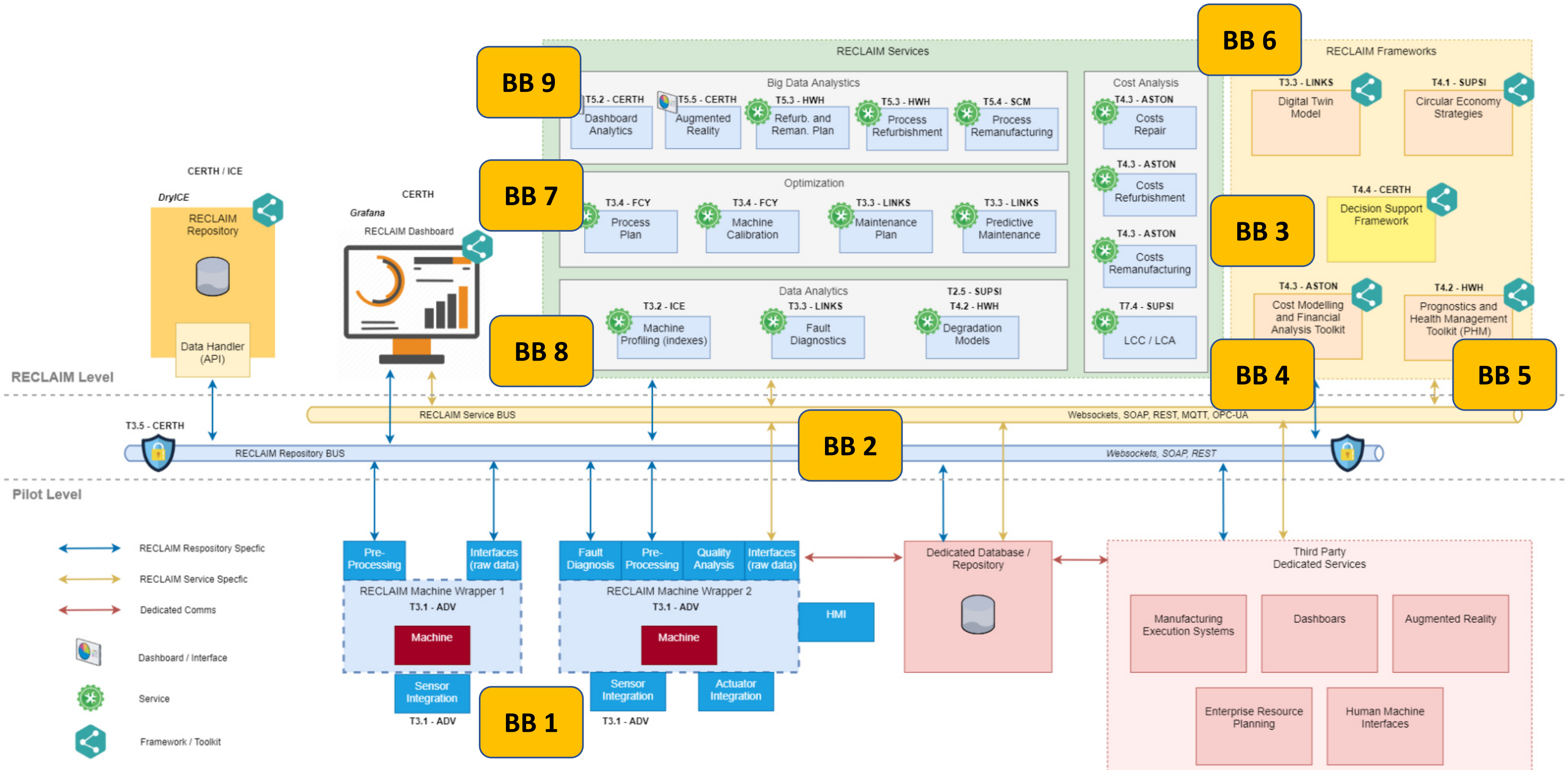


*Figure 28: RECLAIM initial architecture*

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The architecture basically consists of two levels:

- The Pilot level in which the machines, individual databases and third-party products and services are located. The RECLAIM solution contributes to the Pilot level by adding technology such as machine wrappers[1], sensors, or local data analysis services.
- The RECLAIM level which adds various services and frameworks for supporting the lifetime extension of machines and equipment on Pilot level.

Both levels are connected by two data busses: a) the RECLAIM service bus and b) the RECLAIM Repository bus.

The RECLAIM building blocks (BB1 – BB9) are assigned to the various components in the architecture. Common interfaces between the components allow for a fast and individual customisation of the architecture to specific needs. The next two figures provide examples for individual setups by putting different emphasis on the building blocks.

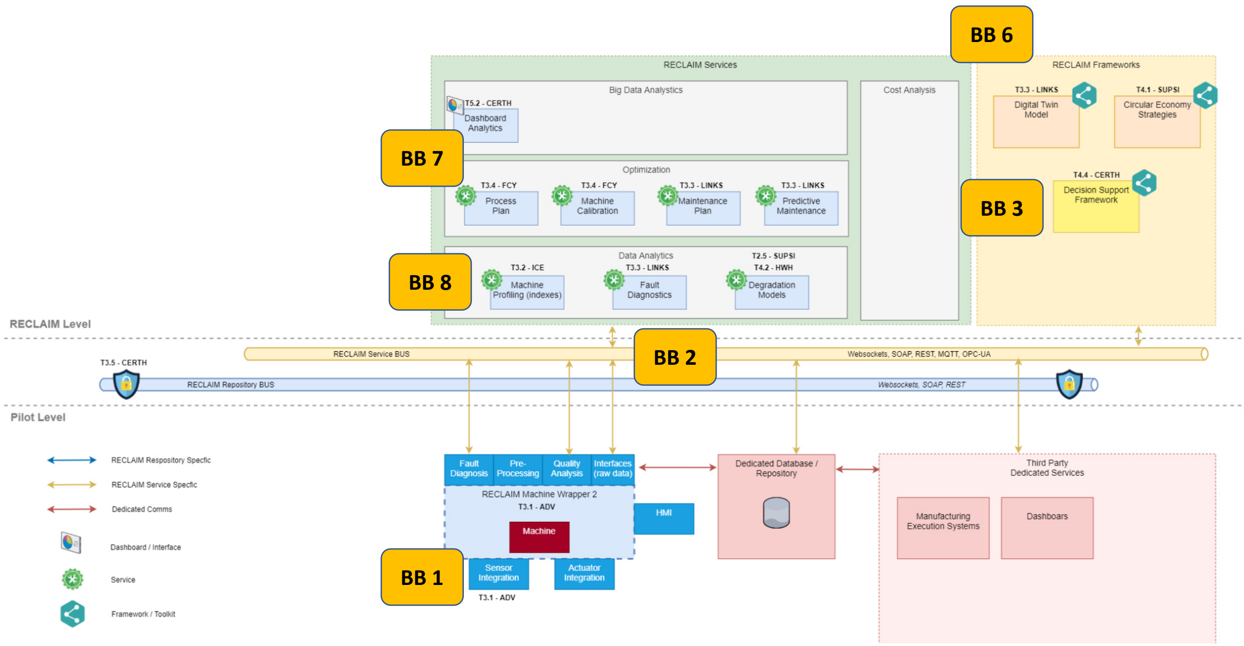


*Figure 29: Deployment of RECLAIM architecture to Pilot with emphasis on optimisation with digital twin approach including 3rd party tools*

[1] Similar to the „Administration shells" in the RAMI4.0 architecture model. See also Schweichhart, K. Reference architecture model Industrie 4.0 (RAMI 4.0), fromhttps://ec.europa.eu/futurium/en/system/files/ged/a2-schweichhart-reference_architectural_model_industrie_4.0_rami_4.0.pdf, accessed July 16, 2020

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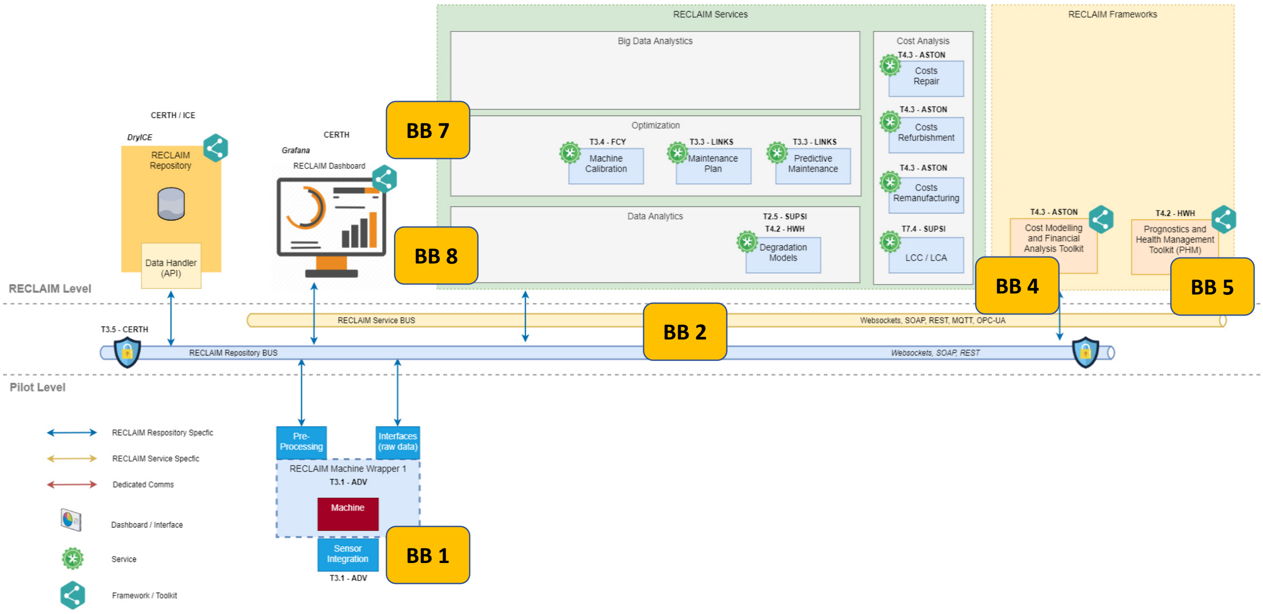


*Figure 30: Deployment of RECLAIM architecture to Pilot with emphasis on cost modelling and predictive maintenance strategies*

The initial architecture provides a profound basis for the further specification and development within RECLAIM. It will further be detailed and adapted based on the experiences of integration into the Pilots. The detailed specification of the first version of the architecture will be provided in D2.3 "The RECLAIM architecture specification" (M10) and will be refined based on the finding to be reported in D2.4 "Lessons Learned and updated requirements report" (M28).

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# 7 Conclusion

This Deliverable report presents the initial requirements for the RECLAIM overall framework. The document contains the high-level requirements based on end-user needs. Those requirements have been mainly been driven by the needs of the RECLAIM Pilots. In order to widen the scope of requirements, an online survey has been developed and spread to different stakeholders by using various communication channels. By this, a high bandwidth of industrial sectors, company types, products and manufacturing equipment has been reached.

Based on the analysis of the results, a weighting of the RECLAIM technical building blocks has been derived. As a result, the emphasis of each building block with relation to each RECLAIM Pilot has been figured out. In addition, a general view on importance of the building blocks has been gained by mapping the relevant results of the survey to each block. It turned out that each building block significantly contributes to the RECLAIM overall goal on equipment lifetime extension by developing strategies, methodologies and technology for refurbishment and remanufacturing. However, it also turned out that different setups of industrial manufacturing system do require different emphasis on the building blocks.

The analysis of the survey also included a mapping between relevant survey questions and the RECLAIM KPI's as defined in the DoA. By this, the relevance of each KPI for each industrial setup can be derived.

Based on the findings described above, an initial architecture has been developed. It defines a two-level model in which the location of each building block is defined. The major contribution of RECLAIM is on the "RECLAIM level" by providing various services and frameworks and the respective interfaces. However, the data required by the RECLAIM level is provided by the Pilot level, in which RECLAIM contributes by providing technology for adding local services to equipment. The present document also outlines the approach for the individualisation and customisation of the architecture to different industrial needs and setups. Further work will concentrate on the refinement of the architecture and on the iterative refinement of the requirements and subsequent deployment of the technology to the Pilots.

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This project has received funding from the European Union's
Horizon 2020 research and innovation programme under grant

# 9 Annex 1

## 9.1 A.1 One example of a completed survey

This project has received funding from the European Union's
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# #6

COMPLETE

**Collector:** Web Link 1 (Web Link)
**Started:** Monday, March 09, 2020 3:32:09 PM
**Last Modified:** Tuesday, March 10, 2020 8:17:12 AM
**Time Spent:** 16:45:03
**IP Address:** [redacted]

## Page 1: General information

### Q1

European Data Protection RegulationComplying with the European General Data Protection Regulation (GDPR), the personal data you give here are saved, used and elaborated by the RECLAIM partner Harms & Wende GmbH & Co. KG, according to their privacy policy. For the sole purpose of RECLAIM activities, these data will be shared within the RECLAIM consortium and in the frame of Horizon 2020 periodic reporting with the European Commission, as well as published in the frame of RECLAIM public deliverables (reports).Please note that the fields concerning personal data (name and surname, name of organisation, email and website) are all optional.

**I do agree that my personal data (name and surname, name of organisation, email and website) can be used and published if provided in my answers.**

## Page 2: General company data

### Q2

In what year was your company founded?

39

### Q3

What is your organisation type?

**OEM**

### Q4

What was the companies turnover last year?

**> EUR 50 million**

### Q5

How many employees does your company have?

**≥ 250**

### Q6

What are the major products your company produces/sales?

Major product 1 **Home Textile**

**Q7**

Name of your organisation (optional)

**Respondent skipped this question**

**Q8**

Website (optional)

**Respondent skipped this question**

**Q9**

Your name and surname (optional)

**Respondent skipped this question**

**Q10**

Your email (optional)

**Respondent skipped this question**

## Page 3: Existing equipment

**Q11**

Which types of machines do you use for production?

**Machining,**

**Additive manufacturing**

**Q12**

Which are the most relevant/critical machines, equipment and tools in your production system?

Surface Modification

**Q13**

How old are these machines in average?

**12 – 20 years**

**Q14**

How old is your oldest machine that is still used for production?

**> 20 years**

**Q15**

Do you intent to replace old machines within the next months?

**No, I do not have plans for replacing machines yet**

**Q16**

I replace old machines usually when ...

**The machine is not capable to produce new products**

## Page 4: Refurbishment of existing equipment

**Q17**

Do you already have strategies in place to refurbish old machines?

**Yes**

---

**Q18**

Refurbishment targets or will target on the following technical issues:

**Include I4.0 technology e.g. for data communication or predictive maintenance technology**

---

**Q19**

Refurbishment is done by

**Company specialised in refurbishment**

---

## Page 5: Use of refurbished equipment

**Q20**

Have you ever bought refurbished equipment?

**No**

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**Q21**

Would you buy refurbished equipment in future?

**Yes**

---

**Q22**

If “yes”: Why would you use refurbished equipment instead of new equipment?

**Save costs,**

**Environmental aspects**

---

**Q23**

Which requirements do you have for buying refurbished equipment?

**Equipment must be certified,**

**Certified dealer**

---

**Q24**

Cost savings in buying refurbished equipment are expects to be x% of new equipment.

**between 20% and 30%**

---

**Q25**

Are you open to new business models for equipment purchasing?

**Yes, I would accept a “pay per use” business model,**

**Yes, I would accept a leasing model**

---

## Page 6: Technology for life cycle management

**Q26**

Do you have any measures for calculating the life time of your equipment?

No

---

**Q27**

Do you already have advances technology in place for extending the lifetime of your equipment?

**In situ repair**

---

Page 7: Refurbishment and maintenance approaches

**Q28**

How reliable do your assets are and need to be?

| | |
|---|---|
| Current OEE level: | **58** |
| OEE target: | **65** |

---

**Q29**

Which of the following activities do you currently perform in your daily operations?

**Analyse and classify assets (equipment, machines and tools) and their components criticalities**

**,**

**Calculate/estimate the breaking points and wear of the equipment, machines, tools and components according to the future production rate**

**,**

**Collect data from sensors & PLCs,**

**Visualise and Analyze data to predict impending failures**

---

**Q30**

Which of the following approaches does mostly fit with the current maintenance approach of your company? Please rank.

| | |
|---|---|
| Reactive Maintenance: the practice of performing immediate maintenance on a machine only after it becomes damaged or problematic. | **1** |
| Corrective Maintenance: the practice of performing maintenance on a machine after a problem becomes apparent but before the machine fails. Corrective Maintenance corrects problems before reactive maintenance is necessary. | **2** |
| Preventive maintenance: the practice of performing standard maintenance functions on a scheduled basis in order to prevent breakdowns. | **3** |
| Predictive maintenance: a maintenance approach that tests and monitors each machine individually in order to predict failures. | **4** |
| Prescriptive maintenance: a maintenance approach that collects and analyzes data about an equipment’s condition to come up with specialized recommendations and corresponding outcomes to reduce operational risks. | **5** |

**Q31**

Which prognostics and health management (PHM) indicators and data do you currently monitor/collect? E.g, data from machines/equipment sensors (e.g. vibrations, temperature, etc) to estimate machine status.

Speed, consumptions, temperature, pressure, stops

**Q32**

Which prognostics and health management (PHM) KPIs do you currently use to plan and make equipment/machines maintenance, refurbishment and replacement activities? E.g. KPIs (OEE, MTTF, RUL)

Actual Speed, Online Quality, online control of key indicators of machines,

**Q33**

Which are the most relevant barriers you faced trying to achieve an advanced asset management approach? Please add any relevant detail.

**Lack of necessary talent, e.g., data scientists,**

**Lack of a clear business case that justifies investments in underlying IT architecture**

**Q34**

Which of the following activities do you expect to integrate into your daily operations by the next 5 years? Please add any relevant detail.

**Visualise and analyze data to predict impending failures**

**,**

**Create and optimize maintenance, refurbishment and replacement programs**

**Q35**

How much do you plan to spend in maintenance over the next five years?

**>1 Mio.€**

**Q36**

How much do you plan to spend in refurbishment and/or replacement of current assets over the next five years?

| | Relevance | Costs |
|---|---|---|
| Buy new machines to substitute obsolete ones | **less relevant** | **<10% of the purchase costs of the entire machine park** |
| Buy refurbished machines to substitute obsolete ones | **not relevant** | **<10% of the purchase costs of the entire machine park** |
| Refurbish of existent machines | **highly relevant** | **20%-30% of the purchase costs of the entire machine park** |

**Q37**

How much do you plan to spend to improve existent assets' health management system over the next five years?

| | Relevance | Costs |
|---|---|---|
| Integrate I4.0 technology, e.g. for data communication, data analysis, predictive maintenance, etc. | **highly relevant** | **>1 Mio.€** |
| Hire new human resources to manage and improve assets' health management system | **highly relevant** | **50.000€ - 100.000€** |
| Outsource health management to 3rd parties | **not relevant** | |
| Outsource health management to suppliers | **less relevant** | **<10.000€** |

**Q38**

Rate from 1 (very important) to 5 (not important) the following benefits you would achieve through maintenance, refurbishment and/or replacement of machinery based on your priorities. Please add any relevant detail.

| | |
|---|---|
| Material cost savings | **1** |
| Improved forecasting of planned shut-downs | **1** |
| Enhanced spares planning and inventory optimisation | **2** |
| Reduced buffer WIP due to increased reliability | **2** |
| Reduced spend on logistic (e.g. high priority shipments) | **4** |
| Improved resource planning, with less unplanned overtime | **3** |
| Improved safety and sustainability | **1** |
| Reduced inventory carrying costs | **3** |
| Reduced maintenance planning time | **3** |
| Reduced overall maintenance costs | **2** |
| Improved Health, Safety & Environment compliance | **1** |
| Less time spent on brute-force information extraction and validation | **3** |
| More time spent on data-driven problem solving | **2** |
| More confidence in data and information leading to ownership of decisions | **3** |
| Increased OEE | **1** |
| Increased Throughput and On-Time Delivery | **2** |
| Improved Quality | **1** |
| Reduce waste and output defective | **2** |
| Re qualification of workers and improved skills development | **3** |
| Increased awareness and circular economy approach along value chain | **2** |
| Increased health and safety of workers | **1** |
| Increased social and sustainable responsible approach within the value chain | **2** |

## Page 8: Implemented Standards

**Q39**

Table 1: please indicate standards implemented in your organisation covering the whole internal value chain (e.g. inputs - materials; process; technology, product…).

| | |
|---|---|
| National | **TS-ISO** |
| International | **ISO** |

**Q40**

Which are the main problems encountered in implement the standards (e.g. skills, process, staff …)?

**Time consuming activity**

**Q41**

What are main areas of improvement for the above mentioned standards?

| | |
|---|---|
| Content (e.g. obsolete requirements, process, testing methods, inconsistency with market needs ....) | **x** |

**Q42**

Why are you implementing those standards? (please explain)

| | |
|---|---|
| Regulatory requirements (international, EU, national) | **x** |

**Q43**

What type of competitive advantage, if any, does it provide?

?

**Q44**

Are there any other standards you're going/willing to implement? What type of benefit are you expecting?

Not yet

**Q45**

Are there any issue within maintenance, refurbishment and/or replacement of machinery not covered by standards? (please explain)

**Respondent skipped this question**