Applying Co-creation Principles to Requirement Elicitation in Manufacturing

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Abstract. This paper presents an industrial case of applying co-creation principles for the design of smart industry 4.0 solution within the context of three distinct end-user organizations ranging from aeronautics, robot and furniture manufacturing. The purpose was to develop a digital solution that monitors the operators and their environment to recognise the context and determine whether an operator requires support, subsequently triggering the most appropriate interventions for the operator to excel at their work whilst maintaining their well-being. The paper documents the process followed, results and lessons learnt in applying co-creation principles in the elicitation of requirements in human centered manufacturing work environments.

Keywords: Manufacturing requirement elicitation · Co-creation · Digital enhanced operator

1 Introduction

The digitalized factory is a foundational pillar of the European "Factories of the Future" strategy [1] to compete globally. The increasing adoption of automation solutions is essential to stay competitive by facilitating the manufacturing capability to provide advanced products at lower costs. These advances are changing the manufacturing workplace [2], often requiring higher and more specific skills and knowledge levels for workers to succeed. Enterprises' ability to utilize new technologies is a most important competitive advantage, and the specific skills, experiences, competences, and flexibility of workers are pivotal to and at the core of this ability. Consequently, to succeed in the next generation manufacturing requires moving from a production centric perspective, to a human-centric business with greater emphasis on the human capital [3]. To increase the competitiveness of European manufacturing companies while at the same time creating attractive workplaces, it is necessary to create an optimal environment for human automation integration and cooperation that harnesses and leverages the workers' capabilities to increase efficiency whilst improving employee's well-being. However, the ever-increasing introduction of automation and consequent growing

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complexity of tasks are not accompanied by the necessary support for the operator, resulting in inefficiency and misuse (non-optimal use) of workers' capabilities and potential. A key challenge in creating innovative solutions that supplement the human potential within the manufacturing workplace [4], is understanding the requirements of the worker taking into account the rich multi-dimensional context. It is not uncommon that the resulting solution does not address the needs of the worker or there is insufficient acceptance of the solution by workers. This paper describes the co-design process and worker engagement activities in the HUMAN project [5], focusing on the co-design workshops that yielded insights that contradicted the initial perspectives of the project. In addition to describing the tailored co-design methodology, and the key findings from the workshops, the paper also reflects on the lessons learnt on the realization of such activities within manufacturing companies.

2 The HUMAN Project

The HUMAN project [5] is a European research project that aims to digitally enhance the human operator on the shop floor thus assisting them in performing their tasks with the desired quality, whilst ensuring their well-being.

An overview of the conceptual framework of HUMAN, illustrated in Fig. 1 is composed of two distinct cycles:

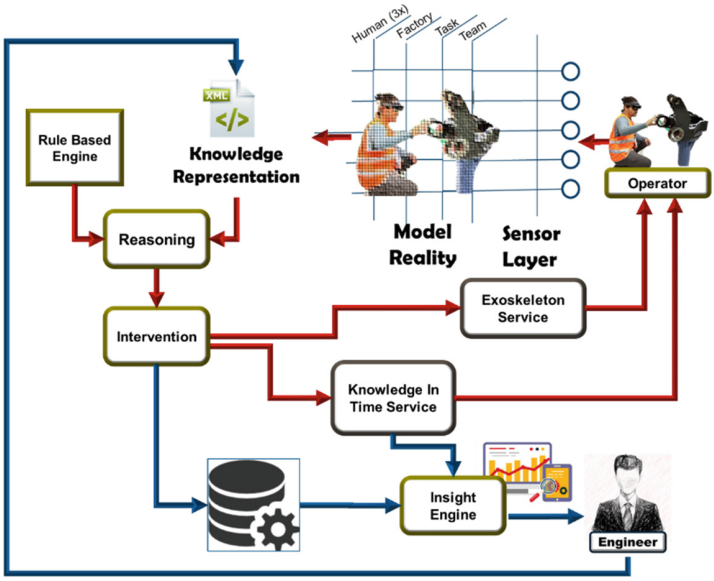


Fig. 1. The HUMAN conceptual framework with short-term reasoning (red track) and long-term reasoning (blue). (Color figure online)

- **Short-term.** The operator is sensorized by the use of wearable devices (e.g.: smart watches, depth cameras, HMD, thermo-graphic cameras, etc.) capturing a wide range of signals that are complemented with sensors in the work environment to generate a digital representation of the workplace environment by the existence of multiple models. Based on the contextual understanding of reality, the system reasons about any anomalies and discrepancies that represent a fallacy in the situation awareness of the operator. As a result, the system determines whether assistance is required and consequently an intervention is triggered that is tailored to the particular needs of the operator;
- **Long-term.** All the data from sensors and events generated from the system are captured for secondary usage through the use of data analytics and process mining by means of the insight engine. Unlike with short-term where the system reasons and determines the best course of action to support the operator, in the case of long-term, an engineer needs to be involved and makes decisions based on the generated insights.

The adoption of advanced manufacturing technologies demands new procedures and working practices as well as modified safety requirements and conditions that workers have to assimilate quickly. Cooperation and easy access to shared knowledge can reduce the reluctance of workers in embracing the change. The challenge is therefore upon modern organisations to come up with solutions for improving the current situation in order to achieve greater agility and reap the benefits of making improved use of their human capital. Changing work environments and their practices requires the engagement and commitment of the operators themselves in the development of the solution.

3 The Co-creation Process

Fostered under the broader field of Social Design and Design Thinking, Co-creation is applied in a variety of fields. Sanders [6] described it very generally as *"an act of collective creativity, shared by two or more people"*. The origin of these approaches can be traced back to the marketing and business fields as a highly facilitated team-based process, heavily dependent on the expertise and the domain knowledge of its practitioners. The participants in Co-creation approaches are experts coming from different fields, all working together in order to design, realize, and evaluate an innovation that will address a concrete need. Compared to other, more traditional user-centred design methods, this results in greater impact on the traditional roles of process participants. These roles are now shifted and the end-user becomes the expert, simultaneously participating in and profiting from the process. This new, active role of the participants/end-users applies to all the aspects of the process from knowledge development and idea generation to concept development.

A major decision of the project was to adopt design-thinking principles to support a co-design approach towards the identification of user needs and capture of user requirements. As such, the emphasis was on the involvement of the relevant stakeholders from each end-user organization, including the key beneficiary of the HUMAN

solution – the operator. The flow diagram of Fig. 2 depicts the overview of the co-creation process, with the rectangles representing activities and the circles representing outputs of those activities.

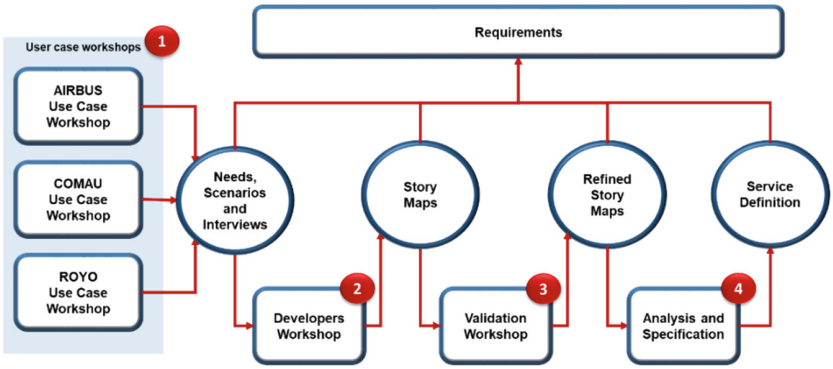
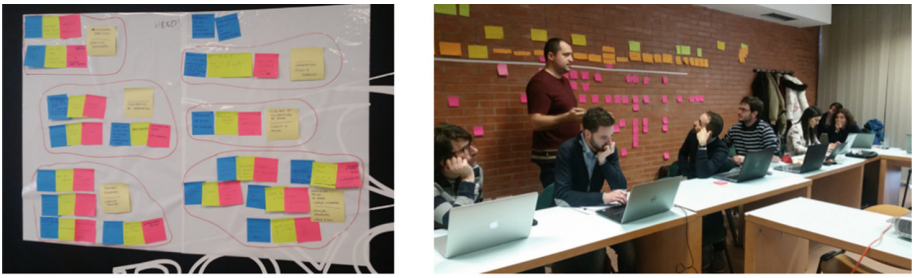


Fig. 2. Co-creation process adopted in HUMAN project

There are four steps in the co-creation process:

- Step 1 – Use Case Workshops: The kick-start to the process was the realisation of 1.5 day workshops at each of the end-user organizations. The process engaged different stakeholders of the end-users, involving operators and management. The output was the prioritisation of operator needs on the shop floor, which then were analysed to create initial scenarios to provide direction for what the HUMAN solution should be. In parallel with the workshops, individual interviews were conducted with operators.
  - Methods and Tools: Brainstorm, Scenarios, Interviews
- Step 2 – Developers Workshop: The analysis of the use case workshops was complemented with thematic analysis of the interviews to define the HUMAN services of interest to the end-user organizations. A workshop involving both researchers and developers used story maps to define each service identified.
  - Methods and Tools: Story Maps, Thematic Analysis of Interviews
- Step 3 – Validation Workshop: A workshop involving the end-user organization representatives, researchers and developers to refine the story maps and contextualise the services.
  - Methods and Tools: Story Maps
- Step 4 – Analysis and Specification: All the outputs from each previous step was analysed to specify the HUMAN solution in terms of the platform that makes sense of the environment and operator's task execution. A set of five distinct services were defined.
  - Methods and Tools: Use case diagrams, activity diagrams, Story Maps

The analysis of the collated data results in a set of requirements for human-centered manufacturing environments (Fig. 3).



i) ii)

Fig. 3. (i) illustration of one of the many outputs of step 1; (ii) illustrative example of the story map resulting from the developer's workshop

4 Shifts in Understanding

The engagement of the targeted stakeholders, namely shop floor operators, yielded a deeper understanding of the worker needs and the associated contexts, which led to important insights that have actually challenged the initial assumptions made concerning the interests and focus of the end-user organizations. At the onset of the project, the preliminary analysis of the needs yielded into four distinct use cases of interest to the end-user organizations:

- **Physical Adaptation.** The HUMAN solution intervenes with a physical adaptation to support the operator when they experienced physical stress or tiredness. Without the intervention, the operator slows their productivity and may in some cases result in physical injuries as a result. The technology used would be the exoskeleton, mainly aimed at the upper limb;
- **Cognitive Adaption.** The HUMAN solution intervenes with a cognitive adaptation that supports the worker in performing their task. This intervention is triggered when the operator manifests cognitive stress, tiredness, distraction or cognitive overload. Without the intervention, the operator not only reduces their performance, but may commit errors that impact negatively the production. The key adopted technology would be augmented reality;
- **Knowledge Sharing.** All three end-user organizations rely on highly skilled operators, which have acquired their knowledge through experience over time. The HUMAN solution augments the operator with additional knowledge and provides the means for workers to share their tacit knowledge. The key adopted technology would be social networks supported by gamification for ensuring engagement of the operators;
- **Workplace Redesign.** The analysis of KPIs resulting from the HUMAN monitoring and assessment, complemented by reporting from the operators, triggers cases where there is a need to redesign the workplace to optimise the production. The key technologies to use are augmented reality and virtual reality.

In all cases, both the environment and the operators would need to sensorized for the HUMAN solution to have the necessary situation awareness to intervene when the

operator requires support. After the initial co-design activities, the interest of the end-users in the four user cases changed as captured in the Table 1.

Table1 .

Use case	Robot manufacturing	Furniture manufacturing	Aeronautics
Physical Adaptation	High → Low	High	Low → High
Cognitive Adaptation	Medium	High	High
Knowledge Sharing	Medium	Medium → High	High
Workplace redesign	High	High → Medium	Medium → Low

5 Lessons Learnt

Upon reflection of the process, one can distil the following guidelines and recommendations:

- A key ingredient to a successful co-creation workshop is the involvement of end-users and the relevant stakeholders that have an impact in the adoption and usage of the resulting platform. The purpose is to facilitate the process such that end-users move from passive sources of information to active forces that shape the solution. Consequently, the workshop success depends on the involvement of the relevant participants' from the end-user organization, thus it is necessary to have adequate advance preparation to identify and recruit the stakeholders. This type of activity requires the support of management.
  - **Recommendation 1:** Early in the preparation identify and recruit a champion within the end-user organization. This person will represent the team facilitating the workshop, garner support within the organization, negotiate the constrains of the organization, and recruit the participants of the workshop. Consequently, it is necessary to ensure that the champion has the access and reach to support the process.
- In addition to leveraging the expertise and experience of the end-users, one fosters the ownership of the solution by the participants. However, this implies expectations are created that need to be carefully managed to avoid discouragement and disenchantment.
  - **Recommendation 2:** Establish and maintain an open dialogue with the end-users, keeping clear the differences between the phases of discovery and definition of the solution. Do not refrain from frequent and necessary reality checks, to ensure the expectations are managed correctly.
- The very nature of a multidisciplinary team entails the involvement of stakeholders from different disciplines with different expertise and experience, working towards creating new enriched solutions through the intersection of the different perspectives. To engage a multidisciplinary team over a period of time requires frequent and continuous communication amongst the key participants to refine the understanding of the user needs and common shaping of the foundational concepts.

  - **Recommendation 3:** Ensure that the multidisciplinary team, in particular when geographically distributed, is aware in advance of the necessary commitment for high level of communication on a continuous basis with frequent interactions. It is not possible to work in isolation as common understanding comes through dialogue.
- In the Co-creation process, namely for the discovery phase, various methods and tools are used with strong visual emphasis (e.g. scenarios, timeline, and storyboards) that are beneficial for facilitating the discussion amongst the different stakeholders. Although the visual artefacts are relevant for exploration, one needs to gauge carefully how to transition to the definition phase and towards ultimately proceeding with development. Otherwise, there is a risk in increasing the specification gap between initial design and implementation, blocking progress.
  - **Recommendation 4:** Attribute a short expiration date to the visual artefacts and adopt the driving principle of discarding the stories and storyboards soon after validation with the end-users.
- The Co-creation process results in visual artefacts supported by some documentation, but a significant amount of tacit knowledge is generated that is not externalised as the effort required makes it impractical considering the fast pace of change. Concepts are shaped by the interplay amongst all the stakeholders; consequently, it is not possible for the co-creation process to be facilitated just with the artefacts created, irrespective of the experience of the facilitator.
  - **Recommendation 5:** Ensure that the co-creation process is facilitated by a team of individuals that remain consistent throughout the process to ensure continuity of the tacit knowledge generated throughout all co-creation activities.

6 Conclusions

The strong emphasis on the operator in the digitized manufacturing workplace puts in question traditional approaches to requirements gathering, thus the adoption of co-creation methods and tools resulted in a four-step process driven by engagement with the end-users complemented by experimentation.

- **Use Case Workshops.** These consisted of co-creation workshops aimed to identification and understanding of the needs of each of the end-user organization. The workshops were organized with multiple stakeholders of each organization, with different roles and responsibilities, but with strong involvement of the operators themselves, whom are the primary end-user of the HUMAN solution. The co-creation approach empowered the stakeholders as experts and active contributors in the process, increasing their engagement and contributing to their ownership as they actively shape the solution from inception to development. The result was a set of relevant needs to be addressed by HUMAN, along with a set of "discovered" scenarios that defined the landscape of the HUMAN solution. Complementing the co-creation workshops were the use of exploratory in-depth interviews that would contribute as rich sources of information in shaping the potential solution.

- **Developer Workshop.** The concept of the HUMAN platform that could perceive the work context and determine what intervention to trigger was crystalized with the analysis of the outputs from the first step. The analysis of the different scenarios, contributed to the identification of services, thus the aim of the developer workshop was to further explore the services and create relevant storymaps that captured the user experience along with the key supporting platform features. In the process of the workshop, where a multidisciplinary team of developers were involved in the elaboration of the storymaps, some of the identified services were discarded as beyond scope of the project, thus contributing to the definition of the HUMAN solution.
- **Validation Workshop.** This workshop involved the multidisciplinary team along with user surrogates and stakeholders representatives of the end-user organizations. The purpose was to further refine and validate the storymaps with the end-users.
- **Analysis and Specification.** The final step consisted on the analysis and specification of the requirements of the HUMAN solution. Unlike the previous steps, this step did not involve a physical meeting with all the discussions leading to maturation of the requirements done by means of virtual meetings and collaboration.

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