Design perspectives for the future of work in Industry 5.0 environment: the digital and physical space in Augmented Reality uses

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Abstract

The advent of Industry 4.0 has introduced into the manufacturing environment a new level of interconnection between machines, operations and sensors that have been able to automate entire processes. Along with this decentralization of the workforce, the new concept of Industry 5.0 aspires to elevate humans to the focal point of cognitive, physical and digital activities, by bringing advanced technologies that autonomously work beside humans in a human-centered perspective.

This is proposed to go beyond the productive purpose by enhancing the experience and quality of work itself, generating questions about how design could intervene to foster effective communication (by limiting misunderstanding and conflict between the technology and the operator) especially in situations where digital and physical are blended.

The object of study is the manipulation of the operator's work environment through the use of Augmented Reality (AR), investigating how it can be integrated into the work experience in terms of performance and psychological response, with particular attention to the type of interface placed in the worker's own spatial reality.

After an overview of the use of eXtended Reality (XR) modes and how such technology can support human work, the focus will be placed on the category of Spatial Augmented Reality (SAR) aimed at operator training and assistance during production routine, which will then be analyzed from a design perspective involving reflections on how the discipline could intervene to enhance learning and use. These definitions point to raising the human factor above the task of assembly and the related operations, therefore the experience over the process, supporting the concept of human-centered manufacturing.

From a design point of view, this becomes subject of exploration not only regarding the configuration of the interface itself, but how its functionality can be manipulated to make the experience engaging in terms of tasks to be performed and human cognitive response, to arrive at considerations derived from a literature review with observations about possible ways in which the figure of the designer could act in such a typically engineering context.

Author keywords

human-centered manufacturing; spatial augmented reality; industry 5.0; interaction design; user experience design.

Introduction

The industrial sector is the protagonist of a current technological evolution characterized by an increasingly close interconnection between digital and physical systems, resulting in a loss of the human component in relation to ever more autonomous and sophisticated technologies. Hence the advent of a new stage of Industry, the 5.0: a vision that intends to implement a human-centric evolution that places operators and their well-being at the center of the production process (European Commission, 2021a).

The ways to achieve this goal will define the "work of the future" which, as cited in the thematic area of Cluster 4 that constitutes Horizon Europe's interventions, is intended to increase understanding of the human-machine relationship (European Commission, 2021b).

This concerns in particular the coexistence of the intangible digital and tangible physical reality that ever more often meet in working scenarios, opening new views of experimentation connecting those two worlds by using eXtended Reality (XR) as a tool: an evidence is the programme 2021-2022 of the Digital, Industry and Space cluster of Horizon Europe, which comprehends "eXtended Reality Modelling (RIA)" (CORDIS, European Commission, 2022a) and "eXtended Reality Learning - Engage and Interact (IA)" (CORDIS, European Commission, 2022b).

In this scenario, design is interpellated as a tool capable of elaborating new ways of relating humans and technologies around their workspace, so that two different but collaborative worlds can be merged. Indeed, if that of humans is unpredictable and subject to emotions, that of machines is predictable and automatic, but lacking human judgment, adaptability, and logic (Haight and Kecojevic, 2005). The goal of this intervention is to establish fluid communication that fosters and accommodates progress in favor of optimized processes for production and those who work in it, combining the skills of both.

The article takes eXtended Reality technology as its object of study, observing how its use is able to meet the goals of the new industry of the future and how it promotes inclusiveness and involvement of the human component.

The exploration is articulated in a literature review focusing on the uses and limitations for which design needs to be involved, so that new development hypotheses can emerge in which the discipline is integrated into the design process of such technologies.

The aim is to be able to define a vision in which future industry grows naturally around humans, so that they can evolve spontaneously in circumstances in which they are now alienated: in front of machines and processes whose operations do not take into account human comprehensibility and presence. This with particular focus then not only on production, but on those circumstances in which cognitive capabilities (such as during learning and assistance) take center stage for the optimal performance of operations.

In the next chapters, the dimensions touched by XR in the factory will be investigated, starting with new work scenarios in the industrial 5.0 context and its current use, and then arriving at Spatial Augmented Reality (SAR) and how it can be designed to optimize the course of work without devices acting as intermediaries between humans and processes.

The evolution of industrial work and the XR

Industry 4.0 has introduced a new level of interconnection between machines, operations and sensors, ensuring that operators have technological support at their side, designed however to be primarily performance-centric, opening opportunities for possible human replacement in favor of automation (Coronado et al., 2022). The 5.0 view, on the other hand, opposes this probability by considering the machine only as a tool to complement/enhance human work (without replacing it) while also improving its quality.

We thus move away from the sole purpose of production and closer to a more experiential conception of work itself, which is currently instead focused on a dehumanization that worries not only operators but also society and governments (Grabowska et al., 2022). Indeed, the same authors state how the term "human-centric" classifies a still narrow segment of research that needs to become a key area of it.

The human factor is therefore a fundamental requirement in the design of Industry 5.0, which places it no longer as an element to be discarded but rather in a position of understanding the technological complexity through a clear dialogue with it, suitable preparation, and a directional openness to development (İşcan, 2021).

It is evident how as technologies and operations within the factory progress, work is destined to evolve, opening new possibilities for work performance and well-being, and defining new figures and duties: the use of cognitive skills in tasks, is capable to increase engagement and interest while working, making individuals more flexible. This evolution toward more cognitive rather than mechanical contributions is the result of adaptation to an increasingly digital environment, that makes the operator of the future able to dialogue with and be assisted by machines.

The recent production methodologies open up new possibilities for increasing human capabilities: Romero et. al (2016) classifies various typologies in which humans are combined with specific technologies, describing their figure in relation to how they are assisted by them. Specific examples may be the "Augmented Operator," the result of the combination of the operator and Augmented Reality, or the "Virtual Operator," derived from the combination of the operator and Virtual Reality. Both types describe an operator whose skills are enhanced, whether in mobility, vision, or processing, and refer to a type of cognitive interaction between humans and the mechanisms of the workspace. The latter is included in an industrial context characterized by Cyber-Physical Systems (CPS), in which information is transmitted by physical and virtual elements, that through feedback and data acquisition generate automated operational decisions. A new dimension of human-machine interface is able to place humans between cyber systems and the physical world, through an enhancement of the human: it is the concept of Human Cyber-Physical Systems (H-CPS) elaborated by Romero et. al (2016) that aims precisely at a dynamic interaction with machines in the cyber and physical worlds, enhancing human skills and senses through the technologies themselves.

Indeed, industry is following the current technological trend toward immaterial universes, as evidenced by the report of Accenture Technology Vision 2022, which states that "the most ambitious companies will bring to life new physical and digital worlds, populated by both people and artificial intelligences [...] gathering not only advantages over automation, but experimenting with new forms of collaboration between humans and machines" (Daugherty et al., 2022). This evidence is closely related to the use and development of eXtended Reality technologies, whose work is to reduce the distance between humans and the virtual through different manipulations and representations of reality, in this case intended as the work environment.

As described by Rauschnabel et al. (2022), the main definitions of XR, namely Augmented Reality (AR) and Virtual Reality (VR) can be easily distinguished based on the presence of the physical environment as part of the experience: if there is a local presence, it is referred to as AR. The latter can be declined into types such as Mixed Reality (MR), Tangible Augmented Reality (TAR), and Spatial Augmented Reality (SAR) that will be discussed later.

In industrial settings, the most widely used XRs are MR and AR. They, once integrated, are capable of improving several aspects of the industrial system, in particular:

- » Time management: AR is leveraged for long and advanced tasks in manufacturing, such as "complex setups, operations with many tasks/long cycle time and advanced maintenance" (Fast-Berglund et al., 2018), and the same authors state how connecting digital/cyber/virtual and physical worlds can lead to significant time savings in that application area. Doolani et al. (2020) also call XR technologies into question, introducing new features such as increasing time-room flexibility.
- » Personnel training: one of the major applications of augmented reality concerns the training of operators, who today need to be prepared and resilient precisely as a response to increasingly advanced technologies. Doolani et al. (2020) define how AR can be used in this regard, especially for tasks that include "monitoring assembly line, sorting, picking, keeping, assembling, installation, inspection, packing, cleaning routines (process, shovel, sweep, clean work areas) and using hand tools, power tools and machinery". Werrlich et al. (2018) testify how a virtual assembly phase, tested before going physical, can improve the training transfer.

- Communication with machines: scope of use can include the communication between workers and technologies in the industrial environment, as mentioned by Materna et al. (2018) regarding the programming of collaborative robots, in which workers were able to program, collaborate and readjust the cobot to new uses with a reasonable time.
- Cognitive load on workers: the experiment by Hou et al. (2013) demonstrates how animated AR systems cause a positive effect of cognitive facilitation on workers in training, no longer having to rely solely on their memory to complete an assembly, and therefore reducing errors.

SAR design for the workplace

Augmented reality applications help increase human presence in a clear dialogue with the surrounding digital and intangible environment, especially when it comes to Spatial Augmented Reality (SAR). In fact, Doyle Kent and Kopacek (2021) among the categories of intervention to foster efficient collaboration between operators and machines, include confidence in the use of surrounding technologies and an exploitation of them that, however, do not make the human figure redundant.

This type of Augmented Reality under consideration is capable of enhancing the user's visible scenario and influencing the operator's involvement by offering the real and virtual worlds in the same view, and promoting autonomous workflow by impacting on usability and cognitive workload (Rupprecht et al., 2021).

Such technology moves beyond traditional eye-worn or hand-held displays (Figure 1), exploiting "large spatially-aligned optical elements, such as mirror beam combiners, transparent screens, or holograms, as well as video projectors" (Bimber and Raskar, 2005).

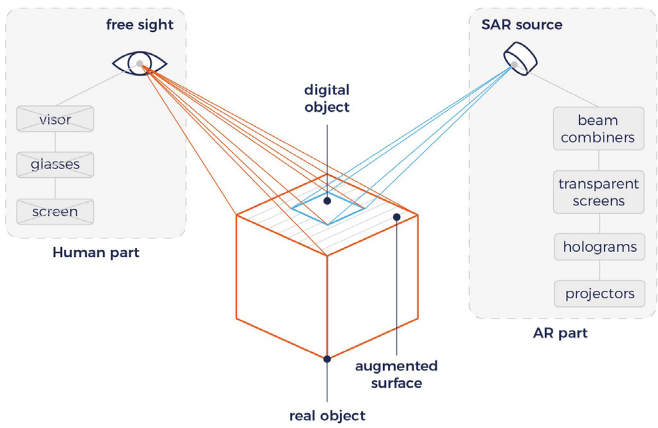

Figure 1. Principal elements for a SAR configuration.

This typology is the most ubiquitous form of AR currently in use (Giunta et al., 2018), in fact it increases the actual visible environment, influencing, in the case of the workstation, the involvement of the operator, who is present between the real and virtual worlds, improving the performance and experience (Uva et al., 2018).

In fact, wearable tools for augmented reality have limitations like those listed by Siltanen and Heinonen (2020), such as the difficulty in seeing the real environment through glasses or visors, or their battery life leading to complicating their use when connected to external power sources. In addition, weight and comfort are also relevant factors for dynamic use such as at work. SAR on one hand offers a solution to such limitations, but it also has disadvantages related to the environment on which it operates such as visibility, surface-based distortions, object relationships, brightness, contrast (Kruijff et al., 2010).

In the work environment it is supportive already from the design phase, Porter et al. (2010) in fact employ it as a means of iterative design, in which the design is projected onto the surface of the physical object and modified in real time, making the idea of the physical prototype and product much clearer and more direct than from the 3D model on a computer screen.

Regarding its purely industrial use, the benefits are evident particularly in assembly and production work tasks. In particular, Bosch et al. (2020) state how less experienced operators are able to operate without or with little supervision, with increased flexibility, employment and reduced training time, leading to an acceptance of the technology by most workers.

In the case of assembly, Uva et al. (2018) compared the instructions viewable by Head-Mounted Display (HMD), tablet, paper, and projections on the work surface. The result was that the latter method proved to be the fastest of the assembly times, with greater reduction of errors and lower cognitive load, collecting positive testimonies especially about having hands free during practice. Such use has proven successful particularly in those situations where even experienced operators are faced with assembling products that are different from each other or modified (e.g., resulting from mass customization), being able to follow the operations without relying only on their memory.

Funk et al. (2016) conducted a similar experiment, comparing the same types of instructions and demonstrating how direct projection to the work location leads to faster assemblies, fewer errors and cognitive load, while also appreciating the freedom in not wearing devices and having free hands.
The increase in productivity and quality given by projected instructions improves not only performance levels, but also the workload itself on the operator (Bosch et al., 2017).

Applications, limitations and opportunities

Analogous experiences related to SAR can be gathered in work domains different from industry, such as in medicine (Bin et al., 2020) or collaborative design (Ben Rajeb and Leclercq, 2013) with related activities such as prototyping (Morosi et al., 2018). Scenarios then extend by investing in wellness (Mousavi Hondori et al., 2013) and culture (Ridel et al., 2014) such as the exhibition and museum domain, where the authors' past experiences show how SAR can give not only contextual information, but also an immersive three-dimensional view, providing an immediate and shared experience, as the visitor's gaze remain free while interacting.

Despite the wide variety of uses and purposes, however, as of today there is no consolidated UI language that could help both designing and understanding the possible interactions, even though there are promising experiments, e.g. Schmidt et al. (2018) have performed studies on User Interface (UI) and user response to interaction. Although the SAR paradigm allows for immediate interaction and does not require learning a new device, it still remains necessary to learn a new way of interacting with projected digital content, which

in 2023 does not yet have a widely shared gestural and cognitive identification.
This is a relative disadvantage compared to HMDs that, promoted by powerful industry players, have vocabularies, toolkits and guidelines at their disposal, such as Microsoft's Design Checkpoints (Microsoft Learn, 2022) in which interaction models, gestures and physical inputs, along with UX Elements and visual rules are well defined and distinguished.

However, there is no common line or framework among the SAR case studies , making the design process of SAR experiences rather challenging.

In the particular field of industrial SAR, effective experience design means not only gains of productivity, but also a facilitated state of mind for operators.

This can be achieved not only by optimizing the hardware part for greater adaptability and adoptability, but by exploiting the role of software often integrated into the systems, configured by the workers themselves on the factory floor.

Such intervention should be performed and studied following User Experience Design concepts (Figure 2) such as those classified by Hillmann (2021) for XR Design: comfort and safety, interaction (affordance, signifiers, feedback), environment and spatial components, sensory input (visual, audio, haptics), engagement (storytelling, gamification), constraints and inclusion, diversity, accessibility.

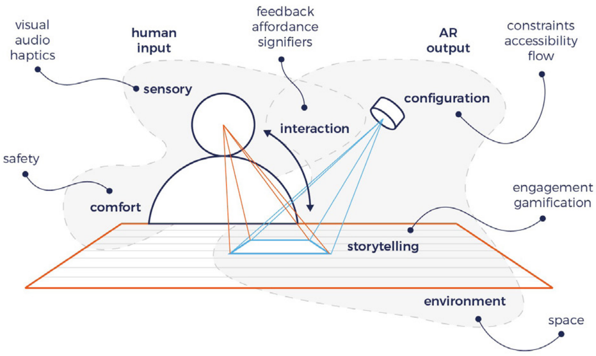

Figure 2. User Experience Design concepts for SAP configuration.

Indeed, authoring tools can be useful in configuring the activities to be followed by the operator, aiming for optimal use derived from a routine that is engaging, simple and not monotonous. The same ease must be present for those who program or modify the experience itself, whether they are the designer, engineer, or line manager. A practical example is the Arkite [1] system that provides both the hardware workstation and the software setup for operators' manual assembly guidance and training.

While there are multiple generic purpose AR authoring tools (e.g. Adobe Aero, Audodesk Forge, Vuforia Studio, Areeka Studio), for the purposes of industrial SAR these services will need to evolve by integrating domain-specific UX Design concepts in order to build an optimal process that takes into account not only the functioning of the various stages, but also the experience in its use, introducing more direct feedback concepts, rewarding systems and gamification.

Conclusion

As we have seen, SAR is capable of enhancing the user's visible scenario and influencing the operator's experience, despite being affected by the number and type of interactions within the augmented space and its positioning.

In order to ensure the optimal use of (S)AR in the industrial context, the presented desk research highlights the need of future research regarding (1) a design methodology that can be applied taking into account who will have to use or configure this technology, since "to advance the use of XR technologies in industrial maintenance and other similar hands-busy type of professional use, there is a need to develop an explicit list of UI and usability heuristics for XR context" (Siltanen and Heinonen, 2020), (2) the human engagement in monotonous workflows such as on assembly line, through the concept of gamification by investigating the design of motivational elements (also employed in the training beneficially influencing the learning process, as stated by Schuldt and Friedemann, 2017), (3) the elements of interaction from human/digital inputs and outputs, specifically investing graphical interfaces, physical interfaces, supporting devices, tasks to be performed, human response and feedbacks received by operators while performing tasks.

In particular, an upcoming experimental research of the authors will focus on how to reach a direct and natural gesture communication with projected and digital objects in order to develop a clearer interaction with the augmented interface, investing visual navigation and kinesthetics studies.

In the increasingly complex factory of the future, design research is fundamental for exploring and enhancing the operator's own senses, making them meaningful and augmented through technologies such as SAR: these could have the power to increase the level of human integration in the factory, especially in such an automated environment.

From the perspective of the Cumulus community of worldwide design schools, it would be particularly interesting to explore the differences between geographical regions and hence different cultures of factory work, which would influence the transversal applicability of new SAR solutions. On the other hand, design education might be influenced as well, preparing future designers to possible new branches of specialization, either by focusing on the technological medium, such as Design for XR experiences, or Design for the intelligent factory, focusing on the industrial domain as an area for systemic design interventions.

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1 The ultimate operator guidance platform. Arkite. From https://arkite.com/

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