Moving into Co-Creative Robotics

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Keywords: Industry 4.0, IoT Cybersecurity, Industry 5.0.

Abstract: In the volatile, uncertain, complex, ambiguous (VUCA) world, robots should be able to adapt to different aspects of human life and create a positive impact. To achieve this, it is important to create and develop not only technically advanced but also, from a social point of view, adaptable, autonomous, creative, collaborative, and ethical robots. This paper introduces the concepts of *Co-Creative Robotics* and analyses the role of collaborative networks in advancing it. Alongside introducing technological dimensions of *Co-Creative Robotics*, the paper compares *Co-Creative Robotics* characteristics with computational creativity and traditional robotics. Finally, to support the advancement of this field, the authors investigated the role of different categories of collaborative networks for *Co-Creative Robotics* advancement.

1 INTRODUCTION

Robots have become integral components of various aspects of human life, deeply impacting society, industry, economy, and beyond (Cai et al., 2021). They designed for specific tasks in various domains share common advantages such as productivity (Cresswell et al., 2018) and reliability (Santos et al., 2021), efficiency (Leigh et al., 2020) and quality, consistency and accuracy improvement (Fragapane et al., 2022), assistance to humans (Narayan et al., 2022), enhancement of human capabilities (Kalaitzidou and Pachidis, 2023), cost reduction through automation, and continuous operation (Mor et al., 2022). However, despite the benefits that these specialized robots offer, they also have common limitations such as rigidity in operation, limited autonomy, lack of creative capacity, posing a challenge to current human skills and jobs, and limited versatility and adaptability in volatile, uncertain, complex, and ambiguous (VUCA) environments (Javaid et al., 2021; Liu et al., 2023). Moreover, they require specialized expertise and have difficulty addressing complex challenges and ill-structured problems in real-world scenarios (Wong et al., 2018). In response to these limitations, we introduce the new concept of **Co-Creative Robotics** for IoT, i.e., an interdisciplinary field combining the principles of computational creativity(Nikghadam-Hojjati and Barata, 2019), and robotics to develop robots able to generate human-like novel ideas, solutions, and artistic expressions or collaborate in creative tasks. Therefore, *Co-Creative Robotics* offers a transformative approach to robotics research and development, leveraging the naive concepts of creative robotics (Hooman, 2023) to the IoT domain and opening the path to new possibilities for innovation, collaboration, and societal impact.

By emphasizing adaptability, creativity, and inclusivity, *Co-Creative Robotics* unlocks the way for a future where robots play a central role in addressing complex challenges and improving the quality of life for human beings.

In presenting the new concepts of **Co-Creative Robotics**, the following Research Questions [RQs] have been addressed:

1. **RQ1** What is *Co-Creative Robotics* and what are the key differences with traditional robotics?
2. **RQ2** Which is a possible technical solution to support *Co-Creative Robotics* advancement?

The definition of *Co-Creative Robotics* and the answer to the proposed RQs are based on an overview of the most relevant literature and Focused Group Brainstorming, which involves stating research questions, selecting participants, and setting ground rules. Focused Group Brainstorming participants engage in

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Nikghadam-Hojjati, S., Marchetti, E., Barata, J. and Calabrò, A.
Moving into Co-Creative Robotics.
DOI: 10.5220/0013000400003825

In *Proceedings of the 20th International Conference on Web Information Systems and Technologies (WEBIST 2024)*, pages 307-314
ISBN: 978-989-758-718-4; ISSN: 2184-3252

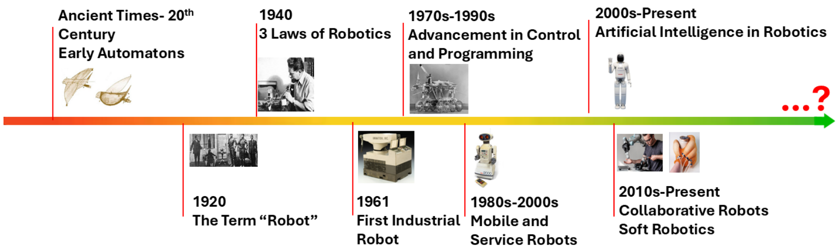

Figure 1: Main Milestones in Robotics History.

5 in-person and five online brainstorming meetings, generating and discussing ideas. Results are anonymously presented to a validating group (including 8 experts), and the most effective ideas were selected in individual meetings during the validating phase.

2 BACKGROUND

The development of the robotics field results from human creativity and continued efforts to achieve higher efficiency and automation in different tasks. From ancient civilizations´ early mechanical birds, which used steam to propel themselves (Archytas - 350 B.C.) (Yao, 2021), until today's cutting-edge machines, which try to think and perform better than humans, robotics has evolved through a series of significant milestones (Horáková and Kelemen, 2008). These milestones, summarized in Figure 1, not only highlight technological progress in robotics but also underscore the potential of robots to transform industries and improve the quality of human life. However, with the evolution of technology, real-world challenges and opportunities are also becoming more volatile, uncertain, complex, and ambiguous (VUCA), which requires a change in current robotics. Future generations of robots/cobots need to navigate and positively contribute to diverse societal, economic, and environmental contexts and interact with humans in their performance. To develop robots with the mentioned capabilities, this paper proposes integrating two emerging fields in the newly conceived *Co-Creative Robotics* discipline: computational creativity (Nikghadam-Hojjati and Barata, 2019) and robotics. This interdisciplinary approach aims to utilize computational methods and techniques from computational creativity to model, simulate, or enhance human creativity. It will leverage artificial intelligence, cognitive psychology, philosophy, and art to study, emulate, motivate, and enhance human creativity to achieve specific goals:

- Developing models, methods, and computer-based programs that can stimulate and enhance human creativity without necessarily being creative themselves.
- Developing models, methods, and computer-based programs that can generate human-level creative ideas.
- Better studying and understanding the nature and processes of human creativity and applying a computer perspective on human creative behavior.

3 CO-CREATIVE ROBOTICS DEFINITION

The proposed *Co-Creative Robotics* emerges as a natural extension of this concept, where the principles of computational creativity are applied to robotics to create technically proficient and creatively capable robots. In this regard, and reply to the [RQ1]: "What is the *Co-Creative Robotics*, and what are the key differences with traditional robotics?" authors proposed the following definition as:

Co-Creative Robotics is an interdisciplinary field that integrates computational creativity and robotics principles to develop machines capable of demonstrating or supporting creative behavior by generating human-like novel ideas, solutions, and artistic expressions or collaborating in creative tasks.

As detailed in Table 1 the *Co-Creative Robotics* includes:

- Developing computational creativity-based robots that support humans in their creative tasks and stimulate and enhance their creative behavior without being creative themselves.
- Developing computational creativity-based robots that can generate human-level creative ideas, learn, and demonstrate creative behavior from their interacted environment.
- Understanding human creativity and collaborative creativity from various perspectives, such as philosophy, neuroscience, psychology, anatomy and

Table 1: Overview of differences within Co-Creative Robotics, Computational Creativity and Traditional Robotics.

Criteria	*Traditional Robotics*	*Cocreative Robotics*
Creativity	Typically, not designed for creative asks and mainly are limited to predefined tasks and environments	Capable of generating novel solutions, ideas, and artistic expressions independently or in collaboration
Autonomy	Often require human supervision or control and have limitations in adaptability outside of their predefined tasks	Capable of operating autonomously in various environments and adapt to changing conditions creatively
Physical Capabilities	May have advanced physical capabilities for tasks such as manipulation, navigation, or assembly	Capable of physically manipulating objects, interacting with the environment, and expressing creative behavior
Human Interaction	Limited ability to engage in natural interactions or understand human emotions; Often lack social and emotional intelligence	Can engage in meaningful interactions with humans, collaborate on creative tasks, and respond to emotional cues
Adaptability	Limited adaptability to new situations or environments outside of predefined tasks and environments	Capable of adapting to dynamic and uncertain environments and tasks creatively
Ethical Considerations	Typically follow predetermined rules and algorithms without consideration of broader ethical implications	Can consider ethical and cultural dilemmas and make value-based judgments
Learning	Limited learning capabilities beyond predefined tasks and environments	Capable of learning from experience and feedback to enhance creativity over time

biology, cognitive science, and art, is essential for studying its nature and processes.

Table 1 presents the main limitations of traditional robotics. While *Co-Creative Robotics* could overcome these limitations, even though they may have restrictions in representing human behavior due to physical capabilities, task complexity, and interaction with unpredictable environments.

Figure 2 provides a schematic summary of the technological perspectives involved in the proposed *Co-Creative Robotics* discipline that can be inherited from the Computational creativity or robotics area. They encompass components and principles that enable robots to engage in creative tasks and behaviours as the main actors or collaborators.

Just as examples, *Co-Creative Robotics* incorporates the computational creativity of the AI discipline. AI can be used for developing algorithms, methods, models, and computer programs that simulate or enhance human creativity, allowing robots to produce innovative ideas, solutions, and artistic expressions (Ventura, 2019). Indeed, ML, deep learning, and Natural Language Processing (NLP) could enable robots to autonomously learn, reason, and generate novel and appropriate ideas and solutions.

Considering Affective Computing inside the computational creativity, *Co-Creative Robotics* can exploit the algorithms and methods enabling robots to understand, interpret, and respond to human emotions, which is fundamental Human-Computer Interaction HRI (Kappas and Gratch, 2023).

Moreover, ethics and cybersecurity principles inside computational creativity can be used by *Co-Creative Robotics* to leverage ethical considerations as robots engage in creative tasks and interact with humans (Pawlicka et al., 2022). Indeed, for *Co-Creative Robotics*, it is imperative to uphold fairness, transparency, and accountability throughout the creative process while addressing privacy, safety, and societal impact concerns.

Finally, considering the complexity of designing, developing, and implementing *Co-Creative Robotics*, it must adopt the collaborative, interdisciplinary, multidimensional, and multi-actor approaches typical of computational creativity. By bringing together experts and involved entities from diverse fields, *Co-Creative Robotics* can tackle the multifaceted VUCA challenges and develop innovative solutions that push the boundaries of what creative robots can achieve.

Considering instead the Robotic technical dimensions, the *Co-Creative Robotics* can take advantage of the sensory systems management. Indeed, cameras, microphones, and tactile sensors can enable robots to perceive and understand their environment and interact with objects, people, and surroundings (Thuruthel et al., 2019). Additionally, robots require algorithms for planning, reasoning, and adapting creatively to dynamic conditions, enabling them to make independent decisions based on task comprehension, environmental factors, and objectives (Maroto-Gómez et al., 2023). The physical manifestation of robots, such as robotic arms, hands, or humanoid bodies, plays a pivotal role in *Co-Creative Robotics* by serving as the medium through which creative outputs are expressed. Furthermore, *Co-Creative Robotics* integrates feedback mechanisms that enable them to assess and learn from their actions, refining their creative abilities over time through iterative processes.

4 COLLABORATIVE NETWORKS FOR ADVANCEMENT

To answer the second research question, [RQ2], the focused group brainstorming sessions were performed as described in the introduction. Based on experts' understanding and opinion and analyzing the

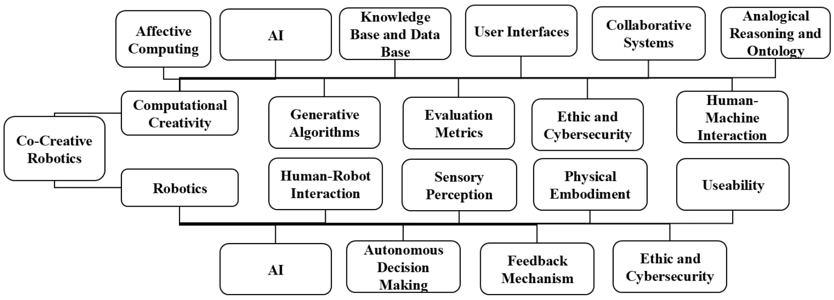

Figure 2: Main Technological Dimensions of Co-Creative Robotics.

proposals and distinct categories suggested, a common point has been identified in using collaborative networks (CNs) (Marchetti et al., 2023). A collaborative network is a system of interconnected entities, such as organizations or individuals, working together to achieve common goals. It leverages shared resources, information, and expertise to enhance performance and innovation. Participants in the network maintain autonomy while engaging in coordinated actions. The collaboration often spans across different sectors, disciplines, and geographic locations. Effective communication and trust are critical for the success of a collaborative network.

Thus, considering that hybridization is one of the main characteristics of fourth (Camarinha-Matos and Afsarmanesh, 2021) and fifth (Marchetti et al., 2023) generations of Cs, which represent collaboration between diverse entities, we can classify CNs based on the entities involved into seven main categories include Human-Haman CNs (HHCNs), Human-Machine CNs (HMCNs), Human-Nature CNs (HNCNs), Machine-Machine CNs (MMCNs), Machine-Nature CNs (MNCNs), Nature-Nature CNs (NNCNs), and Human-Machine-Nature CNs (HMNCNs)(Camarinha-Matos and Afsarmanesh, 2021) (Figure 3).

In the case of *Co-Creative Robotics* field evolution, collaboration within different types of CNs plays a powerful catalyst that increases the rate of advancement. Interdisciplinary, multidimensional, multifaceted, and hybrid collaborative networks support stakeholders in addressing the requirements *Co-Creative Robotics* and mitigating its advancement challenges through contribution in many aspects such as integrating diverse expertise, accelerating knowledge sharing, pooling resources, enhancing problem-solving capabilities, addressing ethical concerns, fostering cross-disciplinary innovation, and promoting global standards (Marchetti et al., 2023). To highlight the role of CNs in providing a possible technical solution to support the advancement of *Co-Creative Robotics*, in the next sections, a discussion about each of the mentioned CN categories is provided.

4.1 HHCNs

In this category of CNs, individuals or groups of humans collaborate with other individuals or groups to achieve common goals or solve problems (Guerrini and Yamanari, 2019). In *Co-Creative Robotics*, advancement, HHCNs facilitate interdisciplinary collaboration and knowledge exchange among researchers, psychologists, engineers, artists, and other stakeholders; they contribute to a deeper understanding of human creativity, cognitive processes, and socio-cultural influences.

HHCNs enable AI and ML experts to create cutting-edge algorithms and share high-quality datasets. These networks support developing creativity evaluation metrics for robotic systems, which consider creativity's subjectivity and context dependence. HHCNs, by involving interaction experts and psychologists, could support enhancing human-robot interaction (HRI). Their interdisciplinary collaboration can break down barriers and coordinate efforts to solve VUCA problems. In addition, these networks optimize computational resources, ensure robustness and reliability, and handle scalability issues.

They promote transparency in models, address ethical concerns, and ensure cultural sensitivity by integrating diverse perspectives.

Involving legal and policy experts, regulatory frameworks could be developed, and IP challenges could be navigated. Furthermore, by leveraging collective strengths, HHCNs can effectively address the multifaceted challenges in *Co-Creative Robotics*, fostering innovation and responsible practice.

4.2 HMCNs

HMCNs involve collaboration between humans and machines or AI systems (Kattel et al., 2020). In these networks, humans interact with machines to perform tasks, share information, or achieve specific

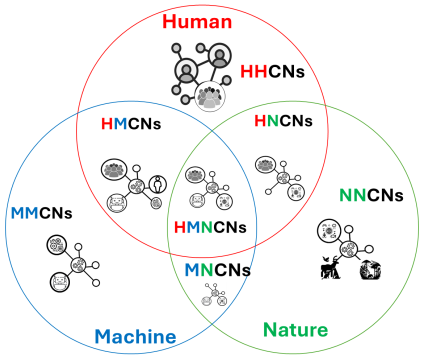

Figure 3: Categorization of Collaborative Networks based on the Involved Entities.

objectives, often combining human creativity, intuition, and decision-making with machine efficiency and computational power.

HMCNs can significantly advance *Co-Creative Robotics* by facilitating synergistic interactions between humans and machines. They facilitate the integration of diverse cognitive, emotional, and socio-cultural perspectives to enhance models of human creativity and, by combining human creativity with machine efficiency, develop innovative algorithms for VUCA problems. These networks facilitate balancing subjective human insights with objective machine analysis to create comprehensive creativity evaluation metrics for *Co-Creative Robotics* systems.

HMCNs, by enhancing communication and improving understanding, foster the trustworthiness and reliability of human-robot collaboration and interaction. They facilitate and enhance the collection and sharing of creative data, qualitative and diverse dataset development, and promote knowledge exchange and resource management through supporting interdisciplinary collaboration, increasing interoperability, and standardization. Interpretability and explainability are improved through transparent communication, making machine outputs understandable and culturally relevant.

HMCNs optimize computational resources by assigning tasks based on the strengths of both humans and machines. They enhance robustness and reliability by combining human oversight with machine precision, and improve scalability for handling larger datasets and VUCA tasks.

Ethical concerns can be addressed by incorporating human values into robotic system design and deployment. HMCNs ensure cultural sensitivity by involving diverse human inputs. In addition, HMCNs can potentially improve public and user acceptance by creating user-friendly and culturally relevant creative robots. They also can promote the utilization of sustainable materials by combining human expertise in sustainability with machine capabilities. HMCNs facilitate IP protection by establishing and disseminating clear guidelines for ownership and authorship, and benefit regulatory framework development through interdisciplinary collaboration.

4.3 HNCNs

In HNCNs, humans collaborate with natural elements, such as ecosystems, animals, or natural phenomena (Kluger et al., 2020). They may involve studying nature for inspiration, working with natural processes to address environmental challenges, or integrating nature into human-designed systems.

To advance *Co-Creative Robotics*, HNCNs have the potential to integrate diverse human perspectives with natural models of creativity observed in biological systems and enhance our understanding of creativity to the development of innovative algorithms. By taking inspiration from nature, HNCNs facilitate the creation of comprehensive creativity evaluation metrics, improve human-robot collaboration, and optimize data collection. They also foster interdisciplinary collaboration, optimize computational resources, and enhance creative robotic systems' robustness, reliability, and scalability.

HNCNs can improve interpretability and explainability by using natural analogies to make machine outputs more comprehensible. They can support addressing ethical concerns by incorporating human values and natural principles, ensuring cultural sensitivity, and fostering public acceptance through user-friendly and culturally relevant robots. In addition, HNCNs promote sustainable materials and support the development of regulatory frameworks to ensure responsible innovation. Furthermore, they help establish clear guidelines for intellectual property protection, ensuring fair and transparent practices.

4.4 MMCNs

MMCNs involve collaboration among different machines, including intelligent autonomous systems, to accomplish tasks or solve problems. These networks often rely on machine-to-machine communication, data sharing, and coordinated actions to achieve common objectives efficiently (Nóbrega et al., 2023).

MMCNs provide a multifaceted approach to address the diverse challenges of advancing *Co-Creative Robotics*. By harnessing distributed computing power, MMCNs facilitate a deeper understanding of human creativity by aggregating and analysing large amounts of data from various sources. They enable the development of complex algorithms that navigate VUCA problem spaces while balancing novelty and appropriateness in creative outputs.

Moreover, MMCNs support enhancing human-robot collaboration by improving communication, adaptability, and trust through seamless interaction and intuitive interfaces. By pooling resources and automating data processing, MMCNs mitigate data availability and quality limitations, supporting the development of robust and generalizable *Co-Creative Robotics* systems.

MMCNs also optimize computational resource usage, ensure scalability, and enhance interpretability and explainability, addressing ethical concerns and promoting cultural sensitivity. By fostering public acceptance and regulatory compliance, MMCNs facilitate the responsible and sustainable integration of *Co-Creative Robotics* into various fields, ensuring reliability, safety, and adherence to ethical standards.

4.5 MNCNs

in MNCNs, collaboration happens between machines and elements of the natural world. These networks may include deploying machines for environmental monitoring, utilizing nature-inspired design principles in machine engineering, or developing technologies to work harmoniously with natural ecosystems (Camarinha-Matos and Afsarmanesh, 2018).

MNCNs, by integrating machine intelligence with insights from the natural world, can provide novel solutions to VUCA problems. They can leverage biomimicry to simulate creative processes observed in nature, such as the collective intelligence of social insect colonies or the adaptive problem-solving strategies of animals. MNCNs can draw inspiration from ecological systems, where complex interactions lead to emergent behaviors.

Moreover, they address *Data Limitations* challenges by employing bio-inspired data collection and processing techniques. MNCNs can also serve as platforms for integrating expertise from diverse fields, mirroring the interconnectedness of ecosystems.

Furthermore, MNCNs contribute to ”Scalability” by leveraging principles of self-organization and scalability observed in natural systems. They can take inspiration from natural systems' ability to adapt to changing environments and stakeholder feedback.

4.6 NNCNs

NNCNs represent CNs where elements of the natural world (including humans) collaborate (Camarinha-Matos and Afsarmanesh, 2018). These networks encompass interactions and relationships between different components of ecosystems, ecological processes, or natural phenomena, contributing to the functioning and resilience of natural systems.

Through observation of processes and outcomes of NNCNs, *Co-Creative Robotics* field experts can take inspiration from observed principles in natural systems to develop innovative solutions to different challenges and requirements of this field. For instance, insights from biological systems can support robotic system designers to design and develop more adaptive and resilient robotic algorithms by replicating how different natural organisms respond to environmental changes.

Additionally, NNCNs can facilitate interdisciplinary collaboration by bringing together biology, engineering, and computer science experts to exchange ideas and develop novel approaches to *Co-Creative Robotics*. Moreover, NNCNs can contribute to developing more sustainable and environmentally friendly robotic systems by incorporating principles of biomimicry and utilizing eco-friendly materials and energy sources.

4.7 HMNCNs

HMNCNs integrate collaboration between humans, machines, and natural elements. They leverage human creativity, machine intelligence and efficiency, and natural processes to address VUCA challenges and requirements, promote sustainability, or enhance society's and the environment's well-being (Zhuge, 2020).

This complex category, which integrates human expertise, ML algorithms, and insights from natural systems, addresses key challenges across various fronts. From understanding the complexity of human creativity to navigating algorithmic challenges, HMNCNs leverage interdisciplinary collaboration to develop innovative solutions. These networks facilitate robust human-robot collaboration, improve data collection and sharing, optimize computational resources, and enhance the interpretability and reliability of *Co-Creative Robotics* systems.

Moreover, HMNCNs foster ethical considerations, cultural sensitivity, and public acceptance by engaging diverse stakeholders and aligning with societal values. Promoting sustainability, regulatory compliance, and intellectual property protection ensures responsible and ethical innovation in the field of *Co-Creative Robotics*. HMNCNs harness the collective intelligence, creativity, and adaptability of humans, machines, and natural systems to drive progress and overcome the complex challenges in advancing *Co-Creative Robotics*.

5 CONCLUSION AND FUTURE WORKS

The current generation of robotic systems is required to operate in VUCA environments and solve VUCA problems. These dynamic and unpredictable conditions demand robots to possess high adaptability, autonomy, creativity, interaction, and decision-making skills. We can significantly improve robots' performance and reliability in tackling complex real-world challenges by developing robots with these advanced capabilities. For such, this paper presented a conceptual expansion research work that investigated the historical background, nature, characteristics, and technological dimensions of *Co-Creative Robotics*, as well as the difference between traditional robotics and *Co-Creative Robotics*. The authors showed that traditional robots are mainly designed for specific tasks in controlled settings, struggle to adapt to dynamic and unpredictable conditions, and lack the autonomy and creativity necessary for innovation.

A new paradigm of *Co-Creative Robotics* through integrating computational creativity with robotics principles has emerged to address these limitations. *Co-Creative Robotics* can generate novel ideas, solutions, behaviour, and artistic expressions independently or in collaboration with humans. This interdisciplinary field incorporates AI, affective computing, sensory perception, and HRI technologies to empower robots with creativity, adaptability, and ethical decision-making capabilities. *Co-Creative Robotics*, by adopting a collaborative and multidimensional approach involving experts from various fields, aims to overcome the challenges of VUCA environments and push the boundaries of what robots can achieve in diverse contexts. Inspired by the role of collaboration in life evolution, it has been considered a valuable approach in advancing *Co-Creative Robotics*. In this regard, the authors answered the second research question of this work, which investigates the role of CNs in *Co-Creative Robotics* advancement. The authors proposed a new categorization of CNs based on the involved entities, including human-human, human-machine, human-nature, machine-machine, machine-nature, nature-nature, and human-machine-nature CNs.

Based on this categorization, experts propose possible roles and impacts of CNs during several focused group brainstorming sessions. CNs' contributions to *Co-Creative Robotics* advancement include facilitating interdisciplinary collaboration, knowledge sharing, resource pooling, problem-solving, and addressing ethical considerations. These networks enable the integration of diverse perspectives and expertise to address the challenges of *Co-Creative Robotics*, fostering innovation, reliability, and responsible practice.

Future research in the field of *Co-Creative Robotics* has significant potential for advancing the capabilities and applications of robotic systems. One area for future exploration is developing the interdisciplinary nature of *Co-Creative Robotics* by integrating insights from cognitive science, neuroscience, psychology, and design. Also, research could focus on better adaptability and resilience of *Co-Creative Robotics* to navigate VUCA environments effectively. Also, innovative approaches to ML, sensor technologies, and decision-making algorithms that enable robots real-time learning and adaptation are needed. Furthermore, ethical and societal implications of *Co-Creative Robotics*, including privacy, autonomy, and the impact on human well-being, are investigable. In CNs, it is important to conduct empirical studies to examine how various collaborative network configurations impact the development and implementation of creative robotic systems. Additionally, developing frameworks or methodologies for establishing and managing CNs in the context of *Co-Creative Robotics*, including strategies for building trust, fostering communication, and aligning goals among diverse stakeholders, are required.

ACKNOWLEDGEMENTS

This work was funded by the Portuguese "Fundação para a Ciência e Tecnologia" through "Strategic program UIDB/00066/2020" (UNINOVA-CTS).

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