This thesis makes a significant contribution to the field of robotic assembly systems, with a focus on their reconfiguration to meet the evolving demands of advanced manufacturing. It addresses the critical challenges inherent in reconfiguring these systems, which are essential for maintaining operational efficiency and competitiveness within a dynamic industrial landscape. A methodology for aggregating and updating diverse data th

Asset Selection and Optimisation for Robotic Assembly Cell Reconfiguration

Fan Mo, Jack C. Chaplin, David Sanderson, Atanas Popov, Svetan Ratchev

Institute for Advanced Manufacturing, University of Nottingham, Nottingham, NG8 1BB, Nottinghamshire, United Kingdom

INTRODUCTION

With the advent of Industry 4.0, the manufacturing industry has undergone significant transformation. Product manufacturing has become increasingly customised, a trend made possible by innovative techniques such as the reconfigurable manufacturing system. This system is designed from the outset for rapid changes in its structure, software, and hardware components to quickly respond to market changes. Robots play a crucial role in these systems, providing the agility and precision required to adapt rapidly to new manufacturing processes and customise and respond to market changes quickly action demands. Despite the critical application of robots in these systems, challenges persist. These include managing data from multiple sources, such as technical manual sensor data, and the need for robot applications to quickly adapt to ever-changing process requirements to meet customer demands. Further optimisation, particularly layout optimisation, is essential to ensure production efficiency after adapting to current process requirements. To tackle these challenges, this doctoral thesis introduces a framework for reconfiguring robotic assembly cells in manufacturing, comprising three parts: the experience databank, the methodology for optimal manufacturing asset selection, and the methodology for layout optimisation. The experience databank addresses the challenge of assimilating and processing heterogeneous data from various manufacturing sources by proposing a vendor-neutral ontology model. This model, designed for encapsulating information about robotic assembly cells, is applied to a knowledge graph. The resulting knowledge graph forms the experience databank, facilitating the effective organisation and interpretation of diverse data. An optimal manufacturing asset selection methodology adapts to changing processes and product requirements by identifying potential assets for evaluation. This approach integrates a modular evaluation framework considering multiple criteria such as cost, energy consumption, and robot maneuverability, ensuring robust selection in the face of changing market demands and product requirements. A scalable methodology for layout optimisation within reconfigurable robotic assembly cells is proposed to address further optimisation needs post-adaptation. This methodology synergizes a simulation environment, optimization environment, and robust optimisation algorithms, utilising insights from the experience databank for informed decision-making. This methodology enables robotic assembly cells to meet immediate production needs and adapt to the evolving manufacturing landscape. The validation of these methodologies includes software development and practical application across three distinct use cases.

OBJECTIVES

Objective 1: To develop an integrative approach for effectively managing heterogeneous manufacturing data within robotic assembly cells, which addresses the first research question, "How can data from various sources be efficiently processed by integrating diverse systems and technologies into robotic assembly cells?" and supports informed decision-making.

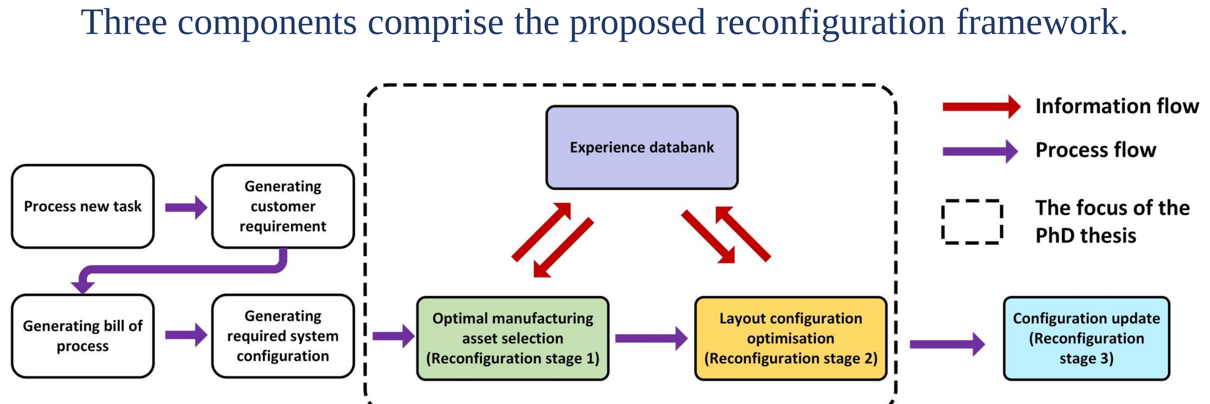
Objective 2: To design a reconfigurable robotic assembly cell system that exhibits agility and responsiveness to changing market demands and product requirements, thereby answering the second research question, "How can robotic assembly cells adeptly adjust to ever-shifting process requirements, reflecting the changing consumer market?"

Objective 3: To formulate a post-adaptation optimisation process for robotic assembly cells, focusing on layout optimisation using artificial intelligence, knowledge graphs, and simulation methodologies, in response to the third research question, "How can a reconfigurable robotic assembly system efficiently optimise its operations, especially in layout, after adapting to current process requirements?"

Objective 4: To validate the strategies of the preceding three objectives through software development and testing within use cases.

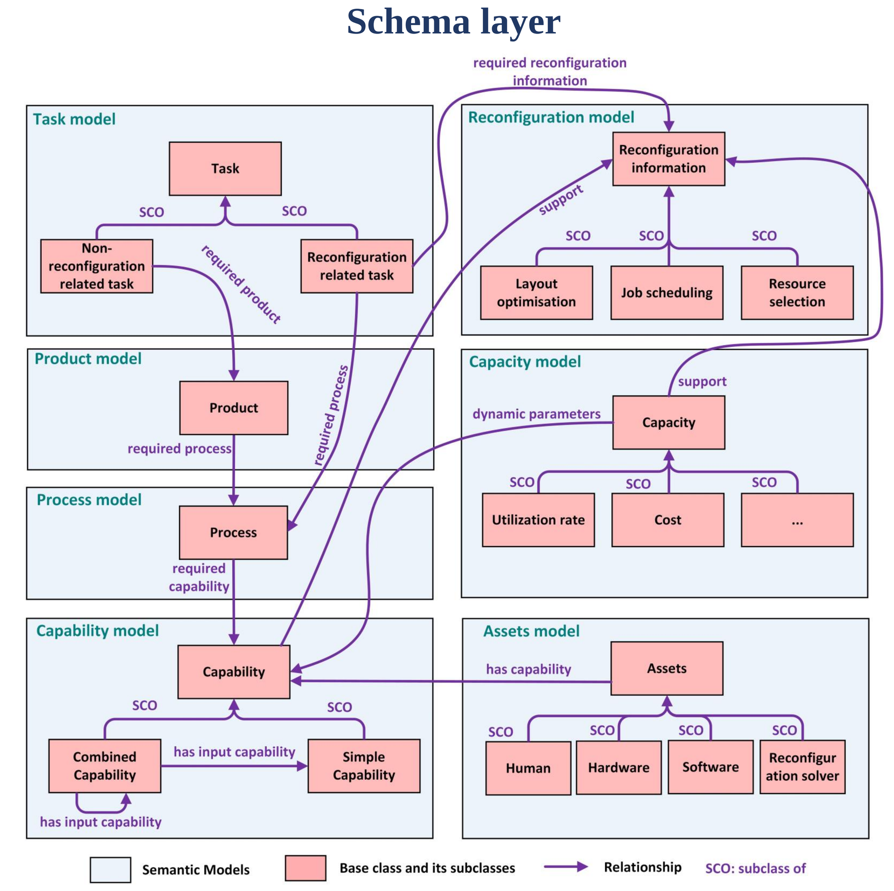
METHODS

Three components comprise the proposed reconfiguration framework.

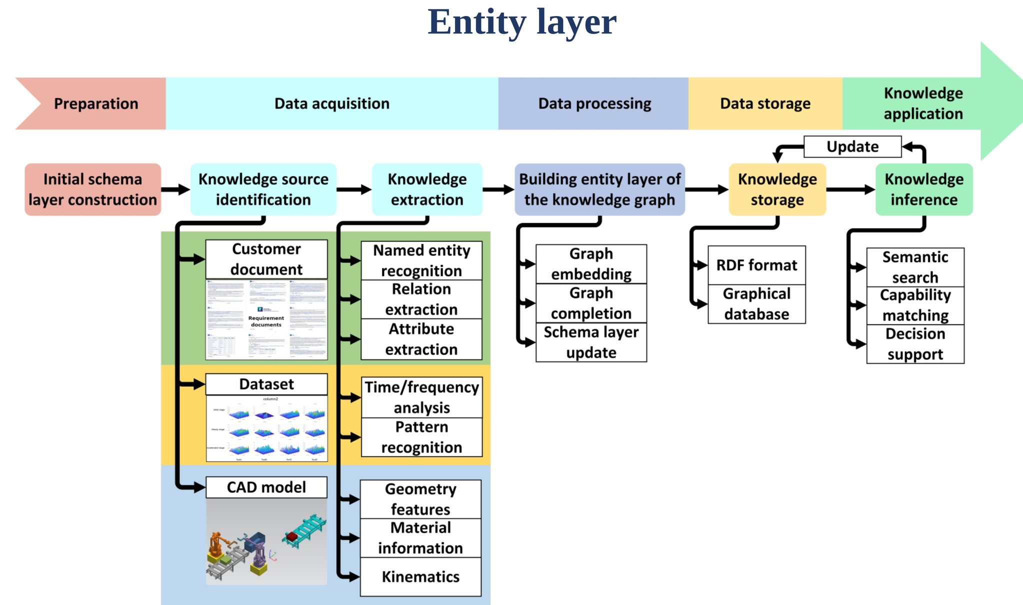


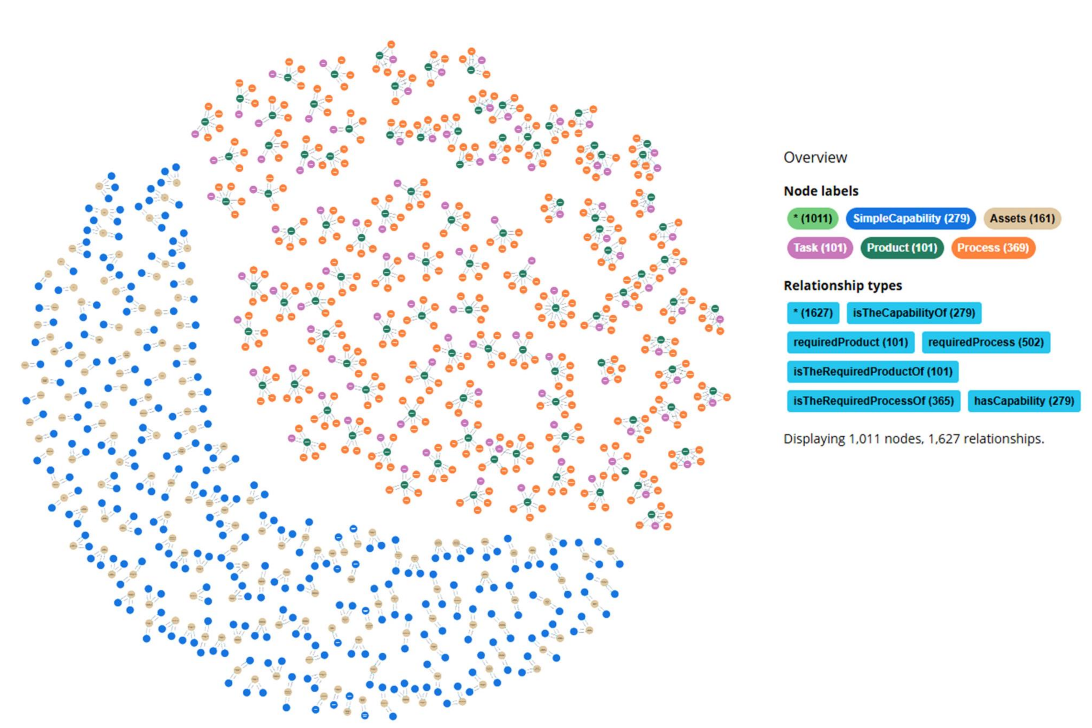
1. Development of the experience databank, which is achieved by a knowledge graph consisting of a schema layer and an entity layer

Schema layer

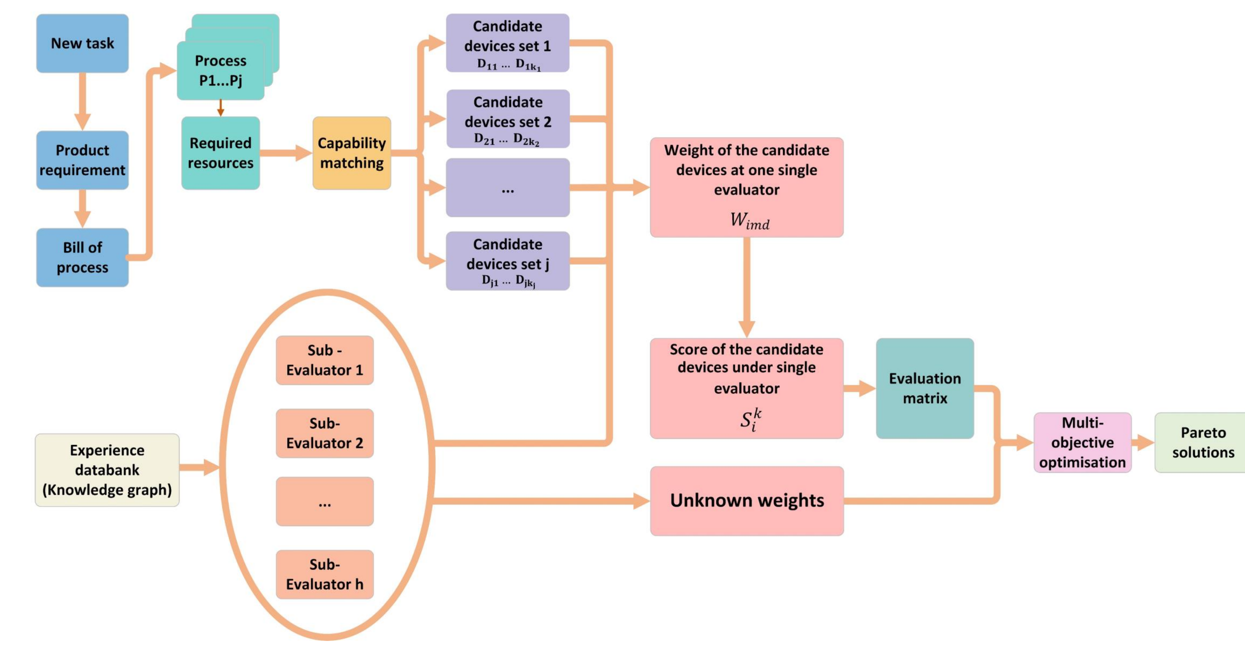


Entity layer

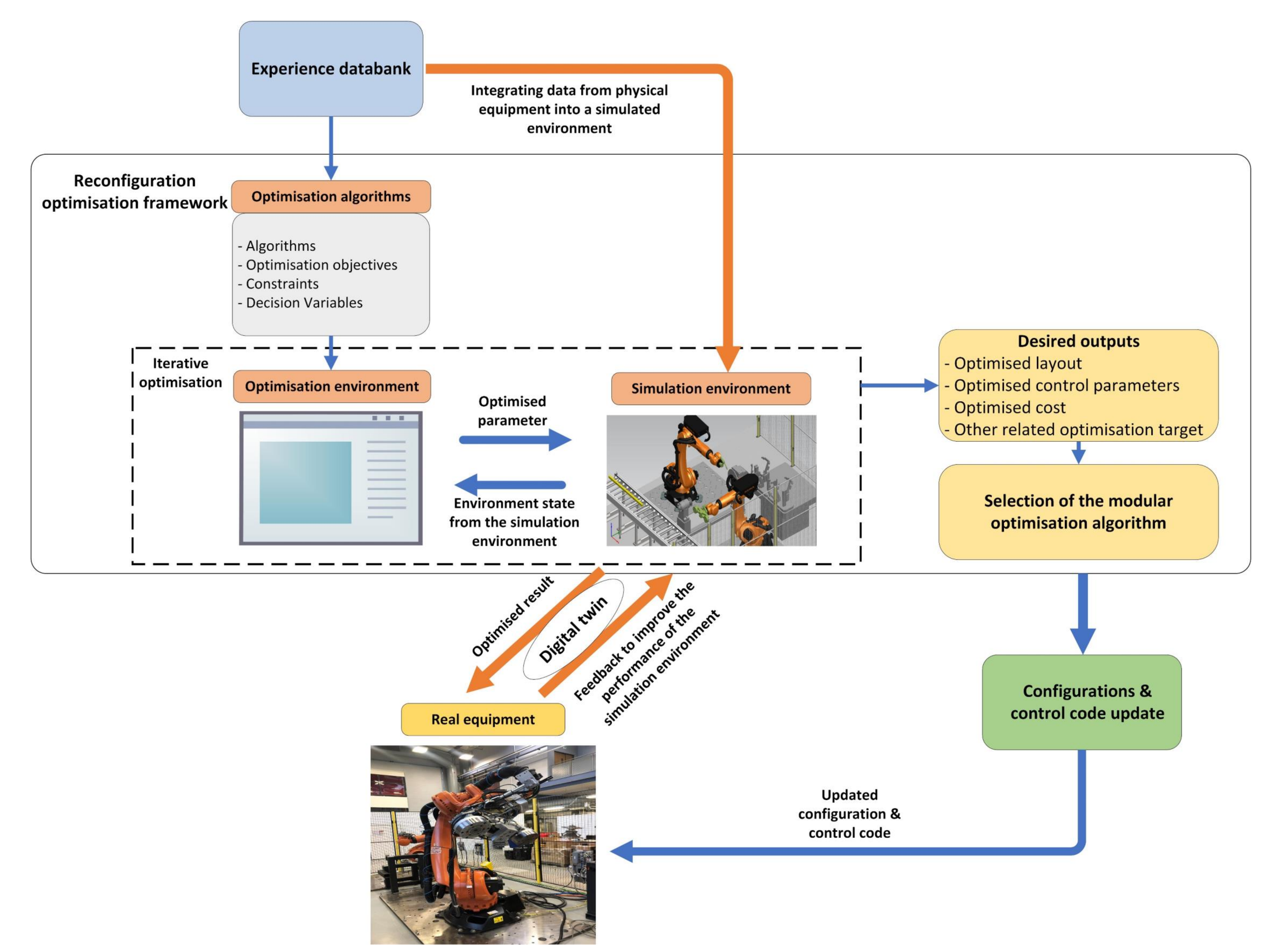




2. Development of the asset selection methodology

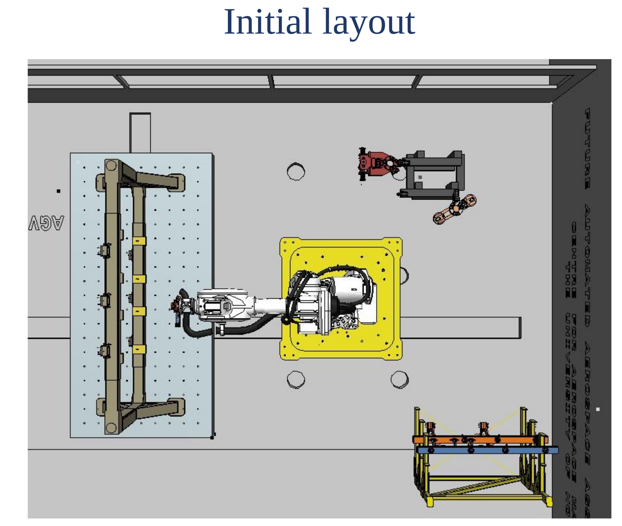


3. Development of the layout optimisation methodology

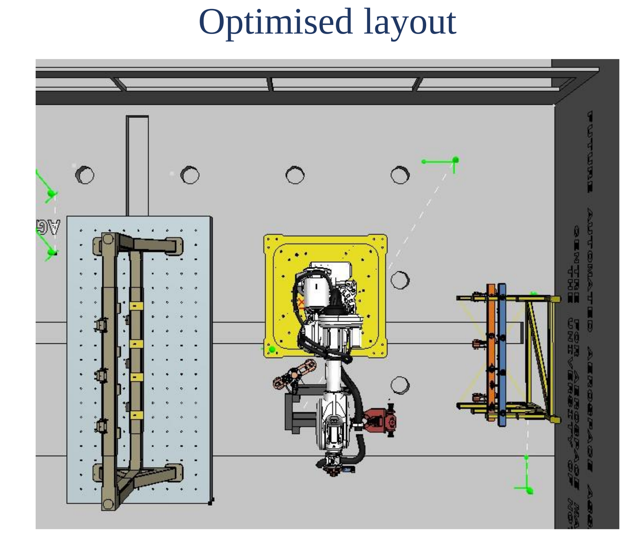


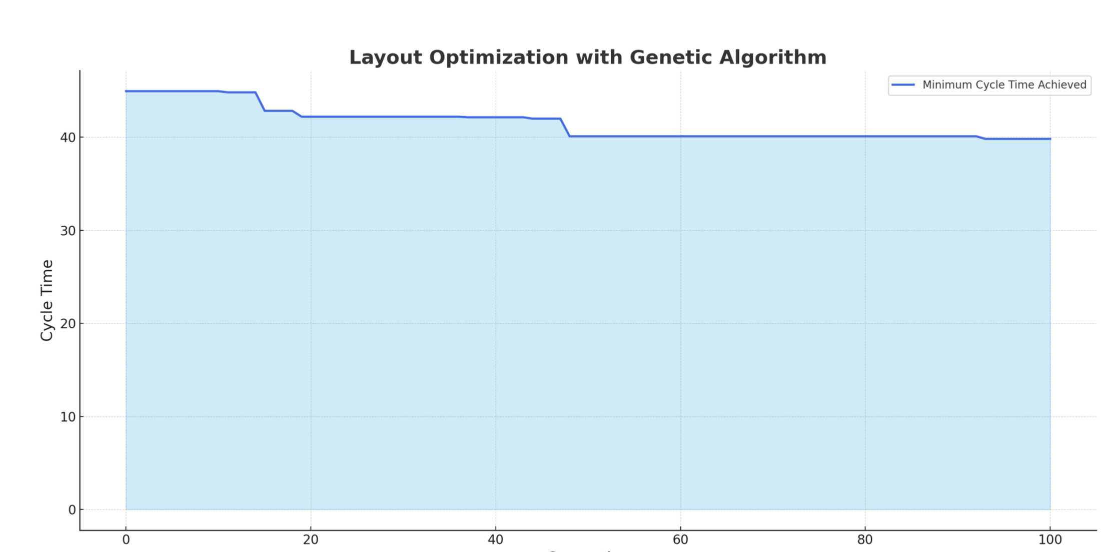
Results

Initial layout



Optimised layout





CONCLUSIONS

This thesis contributes to the field of robotic assembly systems, focusing on the reconfiguration of these systems to keep pace with the changing demands of advanced manufacturing. The research addresses essential challenges in reconfiguring these systems, which are vital for sustaining operational efficiency and competitiveness in a dynamic industrial setting. To fulfil Objective 1, a methodology for aggregating and updating diverse data through an experience databank and ontology model, enhancing decision-making within robotic assembly cells, has been established. To meet Objective 2, a methodology has been formulated to facilitate modular asset selection, integrating knowledge graphs and multi-criteria decision-making algorithms, enabling rapid adaptation to changing manufacturing requirements. To address Objective 3, a methodology has been developed to enhance operational efficiency through layout optimisation in robotic assembly cells, incorporating simulation tools and multi-objective decision-making, facilitating continuous process improvements post-adaptation to changing requirements. The realisation of the software suite comprising experience databank, asset selection, and layout optimisation has been achieved, and three use cases have been proposed. This validation demonstrates that the impact of Objective 4 is not solely dependent on the software's functionality but also on its proven applicability within real-world industrial scenarios.

REFERENCES

Mo, Fan; Chaplin, Jack C.; Sanderson, David; Martínez-Arellano, Giovanna; Ratchev, Svetan. Semantic Models and Knowledge Graphs as Manufacturing System Reconfiguration Enablers. Robotics and Computer-Integrated Manufacturing, 86:102625, April 2024.

Mo, Fan; Rehman, Hamood Ur; Monetti, Fabio Marco; Chaplin, Jack C.; Sanderson, David; Popov, Atanas; Maffei, Antonio; Ratchev, Svetan. A Framework for Manufacturing System Reconfiguration and Optimisation Utilising on Digital Twins and Modular Artificial Intelligence. Robotics and Computer-Integrated Manufacturing, 82:102524, August 2023.

Mo, Fan; Chaplin, Jack C.; Sanderson, David; Rehman, Hamood Ur; Monetti, Fabio Marco; Maffei, Antonio; Ratchev, Svetan. A Framework for Manufacturing System Reconfiguration Based on Artificial Intelligence and Digital Twin. In FAIM 2022: Flexible Automation and Intelligent Manufacturing: The Human-Data-Technology Nexus, pp 361–373.

Martínez-Arellano, Giovanna; Niewiadomski, Karol; Mo, Fan; Elshafei, Basem; Chaplin, Jack C.; Mcfarlane, Duncan; Ratchev, Svetan. Enabling Coordinated Elastic Responses of Manufacturing Systems through Semantic Modelling. IFAC World Congress 2023, 56(2):7402-7407, 2023.

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CONTACT

Email: omnifactory@nottingham.ac.uk