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CoBotCraftLab – Approaching Human-Robot Collaboration in Digital Craft

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ABSTRACT

This paper presents a research approach for human-robot collaboration in digital craft established through the CoBotCraftLab portal - a robot cell for automated collaborative manufacturing in construction - that is currently being installed at Bochum University of Applied Sciences (HSBO). The innovative approach is to enable simultaneous and collaborative manufacturing between humans and robots by setting up the large-scale device using several small-scale collaborative robots (cobots), allowing the precise and rapid production of a variety of prototypes from different materials at 1:1 scale. The portal, once installed, will present a significant contribution to the establishment of an interdisciplinary laboratory environment for research into working methods for collaborative manufacturing with craftsmen and robots in building construction.

Keywords: Automated collaborative fabrication, Digital building, Cobot, Robot cell, Human-robot-collaboration, Human-robot-cooperation, Human-machine-interaction, Digital craft, Digital building construction, Circular fabrication, Work safety, Digital timber construction

INTRODUCTION

In this paper we present CoBotCraftLab, a robot cell for automated collaborative manufacturing in construction. The laboratory environment creates the possibility of exploring automated construction processes to enable resource- and cost-efficient individual production of structures and components whose shape is optimally adapted to their intended task. The innovative approach is to increase the precision and diversity of possible components through simultaneous work between humans and robots, while at the same time physically relieving the burden on the craftsman. Different aspects of human-robot collaboration are investigated, such as ergonomic aspects, feedback mechanisms, techniques of typological transfer between analogue and digital crafts as well as automated joining techniques. The project aims to close the existing gap between human experiential knowledge and the precision and speed of robotics through a collaborative model that is essentially based on simultaneous collaboration over time and space. Knowledge is intended to be gained on the following questions:

- To what extent are human-robot collaborations able to map conventional manual processes, reanimate traditional techniques and transfer and scale them to match construction processes?
- Is it possible to create common workspaces (simultaneous in space and time) for craftsmen and robots that enable the production of building elements in an efficient way?
- How are occupational safety and ergonomics requirements changing in the context of digital crafts and demographic change?
- How can the existing gap between human experience and the precision and speed of robotics in the context of construction processes be closed?

COLLABORATIVE ROBOTICS IN THE BUILDING INDUSTRY – STATE OF THE ART

Robotic manufacturing in construction has become an active area of research and transfer, mainly due to the increasing need for productive and sustainable methods. It is currently concentrating on the use of large-scale stationary systems, such as the additive manufacturing of concrete (Pfeiffer et al., 2020), the cutting and assembly of wooden elements (Kyjanek et al., 2019; Weinand et al., 2018). Production is usually separated from human work in terms of time and space due to safety considerations (COBOD, 2025). Although robotic manufacturing can already be used to create complex three-dimensional building elements, the separation of machine and human creates process disadvantages. This is where the present project comes in. The ability of multiple robots to cooperate achieves flexible scalability, while their mobility and autonomy allow them to be used in both new and existing contexts and coordinate operations for direct and indirect interaction with humans. While experience has already been gained in the field of coexistence and cooperation between human and robotic actors in the construction process (Huang et al., 2021), the collaborative model, in which humans and machines really work hand in hand, in the same workspace and simultaneously on the same components, is still under-researched. The most important research question in the use of collaborative robotics is the transfer of human skills to the technical system (Boston Consulting Group, 2015), the so-called "skills". For cobots and humans to cooperate seamlessly, the robot must have knowledge of its "skills" so that they can be used in a targeted manner (Kragic et al., 2018). As part of the cooperation project, the skills necessary for wood handling are to be developed. The use of cobots makes it possible to let the robots learn through interaction (Goldberg, 2019) and thus to take artificial intelligence techniques into account in the project. In addition to the topics of safety and the enhancement of systems through artificial intelligence, another important factor is work ergonomics and how cobots can support this, whether as a "third hand" or by means of other assistive tasks (Michalos et al., 2018).

COBOTCRAFTLAB

To enable the precise and fast production of a variety of prototypes made of different materials on a 1:1 scale, the collaborative production cell is equipped with six Fanuc CRX i25, which are particularly user-friendly and flexible in use. The robots can be programmed with an intuitive, graphical user interface that requires no special programming knowledge. The robot can also be operated via a simple hand control that allows its movements to be controlled manually. It can be used in a variety of applications, including assembly, material handling, packaging, and palletizing. In addition to the cobots, 3 of which are each mounted on a linear axis, the manipulators (grippers) used on the cobots are essential for the safety and the range of applications of the collaborative production cell. Since the individual payloads of the cobots are far below the payloads of comparable conventional industrial robots, several systems must be provided for simultaneous use to cover the working area of $21m^2$. Figure 1 shows that the robots can be moved along the linear axes, so that they can handle total loads beyond their possible single loads. Therefore, the robots can collaboratively support larger structures and thus prevent or counteract deformations caused by bending. The grippers used can work safely with people and avoid injuries.

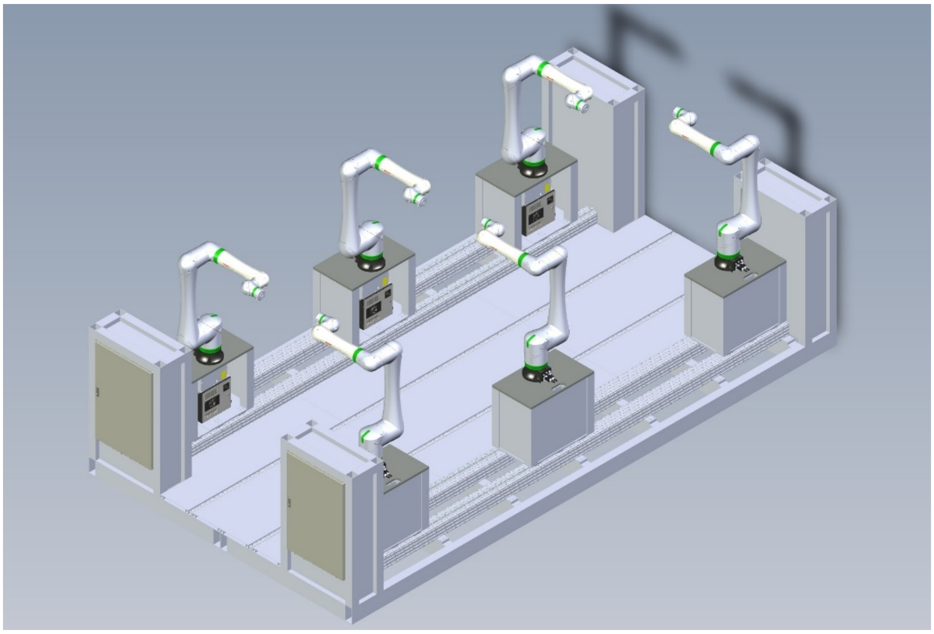

Figure 1: CoBotCraftLab (DFG large-scale equipment initiative), illustration of the collaborative process to produce dismountable wooden structures.

RESEARCH APPROACH

The definition of the production process, and consequently the abstraction and integration of sequence and robot motion planning into design processes, is crucial to explore the design space. Therefore, the basis for the development of secure collaborative workflows is to build an information model for intention-based human-robot collaboration (Schilberg and Schmitz, 2016). This information model provides general motion sequences for robots, from which humans can clearly recognize the intention behind the movement, i.e. which goal is to be achieved by the movement. Here, processes such as lifting, palletizing, sawing, milling, joining, etc. and their combination are examined, with special consideration of aspects of safety and ergonomics in human-robot cooperation. Concrete robot trajectories are then derived from the information model. Since collaboration between humans and robots in construction is a non-deterministic system, tools of probabilistic robotics are applied to deal with inaccuracies. In order to generate a goal-oriented path planning from necessary individual movements, a Q-learning approach is applied to obtain a situation-adapted path planning for the respective production sequences.

APPLICATION SCENARIOS

The research applications intend to address the high consumption of resources and the limited recycling of components and materials predominant in the construction industry. With a growing level of knowledge, work on the following topics is conducted.

- Joining processes: Due to its high degree of prefabrication, timber construction is predestined to investigate the potential of human-robot collaboration for the prefabrication of individualized components. Typologies of traditional joining techniques in timber construction are to be transferred into the present with the help of digital and automated processes. As a result, the potentials of human-robot collaboration (e.g. precise joining, quality assurance, flexibility and work ergonomics) for individual prefabrication of vernacular joints in timber construction are to be identified.
- Additive Processes: Collaborative methods are to be developed for additively manufacturing individualized, multifunctional lightweight components. The methods are to be applied in constructions for housing.
- Design-to-Disassembly: In order to address the high consumption of resources and very limited recycling of components and materials in the construction industry, collaborative processes between craftsmen and robots will be investigated for their potential in terms of the detachability and reusability of joints and the separation of composite materials by type. The sorting and evaluation of the material and material components with non-destructive testing is also to be tested.
- Design with Robots: The integration of robot motion planning into design processes is crucial to explore the entire design space. The aim is to develop a design and robot motion planning environment

for the efficient design planning of robotically assembled structures. The multidimensional design space of these is a direct result of the kinematic behaviour of the robots, which cannot be intuitively described in conventional CAD applications. In addition to the movement of the robots, the definition of the production process is crucial.

- Process Safety and Ergonomics
  In construction processes, robots must be adaptable and flexible. Especially if direct cooperation with human craftsmen is also to take place, safety and ergonomic aspects must be considered. The existing gap between human experience and the precision and speed of robotics is to be closed by a collaborative model to move ergonomically and safely within the same workflow. The aim is to make this workflow visible and assessable by means of the production of prototype demonstrators and thus to gain insights into sensible protocols for occupational safety and ergonomics.

CONCLUSION AND OUTLOOK

The interdisciplinary application of domain-specific methods of the project partners from architecture and mechatronics maximizes the scientific knowledge gained. With the CoBotCraftLab, a new research focus for collaborative robotics in building construction will be established at Bochum University of Applied Sciences (HSBO), which will enable the interdisciplinary transfer of scientific findings into applications in cooperation between the faculties of mechatronics and mechanical engineering and architecture. To answer all the research questions outlined in the application scenarios, an extensive database is required. The more extensive the data collected from the collaborative work processes, the more extensive the associated research fields are regarding knowledge-oriented research. The procurement of the proposed large-scale equipment will therefore strengthen HSBO's infrastructure across departments and lay a correspondingly broad basis for further funding. It is planned to establish further cooperations on these topics and to submit funding applications. Future research will be conducted into how these generic assembly and disassembly processes are further specified and developed in collaboration with craftsmen into an agile process. Due to the modular design of the large device used, scaling effects can also be realized. Sustainable construction processes for future demountable constructions can then potentially be developed for scenarios in small and medium-sized enterprises.

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