Establishing an On-Site Construction Pilot for Collaboration Between Humans and Heavy-Duty Robots

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***Abstract*— This paper presents a pioneering pilot within the FORTIS EU project, aimed at enhancing the integration of autonomous heavy-duty robots in construction environments. The pilot has been established to assess the potential of these robots to revolutionise industry standards, specifically in tasks involving transportation and assembly. The paper offers insights into the challenges that will be addressed within FORTIS associated with human-robot interaction (HRI) in dynamic construction settings, where safety, efficiency, and adaptability are paramount. By contemplating the application of autonomous loaders and telehandlers, this study lays the groundwork for future research and development in construction robotics. We highlight the study's contributions to the field through the development of specific use cases and the application of an existing HRI taxonomy to categorise interactions between humans and robots. This position paper aims to inform the audience about the significant pilot underway, rather than presenting conclusive results, setting a foundation for ongoing scientific exploration and practical application in the industry.**

I. INTRODUCTION

The construction sector, historically slow in adopting technological advancements, is poised at the brink of a revolution, driven by the digitisation wave and the advent of Construction 5.0 [1]. The construction pilot of the FORTIS EU project described in this paper exemplifies this vision, showcasing human-robot interaction (HRI) solutions tailored for dynamic and unpredictable construction environments.

A. Background

The construction industry has traditionally relied on manual labour, lagging behind other sectors in adopting robotics and automation technologies. However, with the advent of Construction 5.0, the sector is poised for a transformation that integrates advanced robotics into various construction tasks, such as demolition, excavation, 3D printing, and others, aiming to enhance efficiency and safety [2]. One of the primary goals of integrating robotics into construction is not to replace human workers but to augment their capabilities, reducing their physical strain and mitigating the risks associated with construction work.

Despite these advances, construction sites poses unique challenges for collaborative robots, such as adapting to changing layouts and uneven terrain [3]. Research has focused on safety, communication, and task allocation, with developments in sensor-based safety systems [4], natural language processing [5], and gesture recognition [6] to facilitate interaction with such robots.

As the sector approaches a technological revolution, robotics, HRI, and human-robot collaboration (HRC) are key to reshaping practices, driving efficiency, and enhancing safety. The challenges include developing adaptable, intelligent robots capable of integrating into construction's complex landscape, as proposed in the FORTIS project.

B. FORTIS EU Project Overview

The FORTIS EU project, initiated in January 2024 and spanning four years, stands at the forefront of integrating autonomous robots into challenging pilots, with the construction industry taking a central stage. The project aims to revolutionise traditional practices through innovative technologies, including autonomous heavy-duty robots capable of performing critical construction tasks, such as material transportation and sandwich panel assembly. With a strong focus on HRI, the project intends to ensure that such robotic systems work seamlessly alongside human workers, enhancing productivity, while maintaining high safety standards.

To achieve this, FORTIS foresees three tangible expected outcomes (TEO), which will be validated in the hereby presented pilot:

- **TEO1. FORTIS Human-Centric Toolkit**: Toolkit modelling human behaviours to ensure optimal interaction tailored to each individual's status.
- **TEO2. FORTIS Robot-Centric Toolkit**: Toolkit for crafting multi-robot solutions capable of human interaction, retrofitting machines into AI-embodied systems.
- **TEO3. FORTIS HRI Toolkit**: Toolkit combining TEO1 and TEO2 with tools to monitor, simulate, and optimise HRI, featuring digital twin and resource allocation and optimisation.

Through the lens of the FORTIS EU project, rather than presenting definitive solutions, this position paper seeks to engage the academic and industrial communities, showcasing the pilot as a significant step toward addressing the long-standing barriers to automation in construction. The next section introduces the on-site construction pilot established within the context of FORTIS, as well as the related use cases which will be considered in the development and evaluation of the aforementioned TEOs.

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II. ON-SITE CONSTRUCTION PILOT

This section delves into the heart of the construction pilot, which serves as the real-world testing ground where the FORTIS's disruptive technologies will be put to the test in an environment that closely mirrors the challenges of a construction site. Such challenges include dust and debris, non-flat terrain, GNSS-denied or impaired areas, and distributed assets across different regions. The pilot has been established at Ingeniarius' headquarters, located in the Porto district of Portugal[1]. This proximity to the FORTIS technological partner of the construction pilot and the construction company Garcia, Garcia, SA. [2], is of paramount importance for continuous on-site problem-solving.

Under the auspices of FORTIS, significant transformations have taken place to create an environment that closely resembles the challenges of real-world construction sites. The pilot offers approximately 1.000 square meters of outdoor space (with a L-shaped site). Basic features are included, such as scattered ground vegetation and trees, as well as other amenities, such as:

- Closed-circuit television (CCTV) monitoring system: To enhance security and monitoring (e.g. for annotation/labelling purposes) for all ongoing activities;
- WiFi coverage: To ensure seamless wireless connectivity for inter-agent communication;
- Ultrawide band (UWB) positioning infrastructure: To provide a ground-truth assessment of robots' odometry estimation capabilities.

The most notable enhancement was the development of a dedicated metallic structure, known as the FORTIS tower (Fig. 1), purpose-built to facilitate precise and efficient trials for sandwich panel assembly - a task critical to the FORTIS construction pilot objectives (Section II.B). The FORTIS tower is a robust 2x3x6 meters metallic structure, strategically engineered to replicate the complexities of real construction challenges. It integrates existing structures alongside a digital model, simulating demanding architectural features, such as corners, doors, and panel placements.

A. Use Cases

The FORTIS construction pilot encompasses two use cases that exemplify the transformative potential of collaborative robotics in the construction sector, as presented next.

1) Material Transportation: The first use case deals with the transportation of construction material, centred on optimising the logistics of moving materials on-site. This process typically involves a well-coordinated workflow performed by heavy-duty machinery, like loaders, while taking human operations into account. Therefore, this use case contemplates the autonomous operation of a retrofitted compact loader (Fig. 2). The development of the loader robot employed started in 2017, within the context of the SEMFIRE[3] and SAFEFOREST[4] projects led by Ingeniarius [7], [8]. The loader adopts the Robot Operating System (ROS) as a retrofitted Bobcat T190 machine, which seamlessly integrates multiple computing and sensing resources for autonomous operation under challenging environments, such as those from the agriculture, forestry and construction sectors.

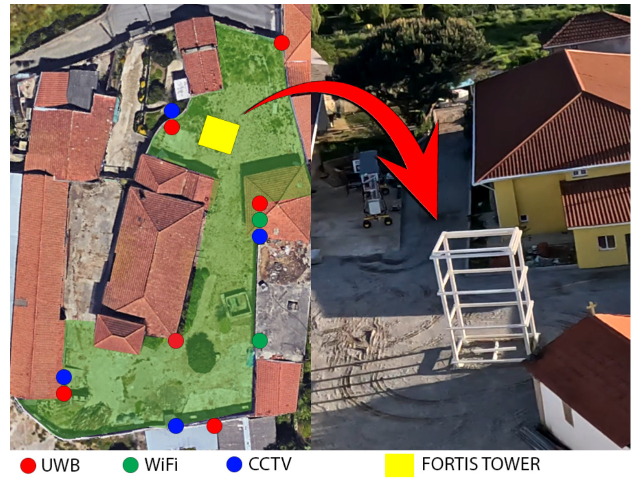

Fig. 1. Top view of the outdoor pilot site and the FORTIS tower.

2) Sandwich Panel Assembly: The second use case deals with sandwich panel assembly, emphasising on the streamlined installation of building components. This use case involves the use of a rotating telehandler, as well as multiple collaborative human workers for the successful installation of sandwich panels on a building's façade. The telehandler robot will be retrofitted from a Manitou MRT 2260 (Fig. 2), receiving the same ROS toolkit as the loader robot. This robust technical foundation will empower the telehandler to perform a wide range of material handling tasks autonomously, with a particular focus on the sandwich panel assembly, which demands precise physical collaboration with human workers to ensure efficient and safe panel installation.

III. COLLABORATIVE ROBOTS

The FORTIS construction pilot integrates two types of heavy-duty mobile robotics platforms to tackle the anticipated challenges on construction sites. The project harnesses the capabilities of multiple standards and well-established ecosystems, including ROS [9] as previously mentioned, and industry standards prevalent in heavy-duty machinery, such as the CAN SAE J1939. This integration facilitates seamless data communications between high-level routines (e.g. path planners, decision-making, artificial perception, etc.) and the machine's electronic control units, enabling complete automation without constant human intervention [8]. However, considering the complex dynamics of construction sites, which already involves multiple humans and is expected to involve multiple robots working in tandem, FORTIS places a significant emphasis on two interconnected domains: interaction and communication.

[1]https://ingeniarius.pt/
[2]https://www.garcia.pt/
[3]https://semfire.ingeniarius.pt/
[4]https://safeforest.ingeniarius.pt/

Robot Description & Illustration

The **loader robot** (top) is a retrofitted Bobcat T190 compact loader equipped with a forklift attachment, built to perform autonomous material handling tasks in construction environments. This **telehandler robot** (bottom) is a retrofitted Manitou MRT 2260 telehandler, built to collaborate with human workers, namely physically through shared object manipulation, up to a maximum payload of 6 tons.

Field of Application

service

Exposure to

robot
embodied

setting
field

Robot Task Specifications

transport
manipulation

Human Role

supervisor
collaborator (telehandler only)
cooperator
bystander

Robot Morphology

	a	z	t
appearance	□	□	■
communication	■	□	■
movement	□	□	■
context	□	□	■

a (anthropomorphic)
z (zoomorphic)
t (technical)

Degree of Robot Autonomy

	-		+
information acquisition			x
information analyses		x	
decision-making			x
action implementation			x

Team Composition

$N_H > N_R$

Communication Channel

input
electronic
acoustic
optic

output
acoustic
visual

Proximity

temporal
synchronous

physical
following (telehandler only)
approaching
avoidance

Fig. 2. HRI description of both loader and telehandler robots.

A. Human-Robot Interaction

This section categorises the robots to be employed in the construction pilot as per the taxonomy proposed by Onnasch & Roesler [10]. Fig. 2 demonstrates this taxonomy, showcasing its application to both loader and telehandler robots within a single table to optimise space usage.

Among the many aspects covered in Fig. 2, some are key and should be addressed. Both platforms are distinguished by their service-oriented functionality for construction, focusing either on material transport and sandwich panel assembly, aligning with ISO 8373:2021 standards. Also, both robots are expected to exhibit high autonomy in information acquisition through advanced sensors and computing capabilities, supporting minimal human intervention for initial setup and occasional adjustments. The loader already demonstrate a blend of autonomy across information analysis, decision-making, and action implementation, highlighting a medium to high autonomy level that accommodates human oversight. The same toolkit and adopted approaches will be transferred to the telehandler. Furthermore, while both robots share similar roles in enhancing HRC, the telehandler distinguishes itself in the manipulation tasks and its interaction with human collaborators. This interaction, especially in the context of sandwich panel assembly, showcases a unique synergy where humans guide the robot's actions indirectly, exemplifying advanced collaborative efforts in construction tasks. Communication between humans and robots encompasses electronic, acoustic, and optical inputs and outputs, facilitating effective collaboration. The robots' operation is synchronous with human workers, emphasising real-time coordination without direct physical contact, ensuring safety and efficiency. Given its complexity, this topic will be further addressed next.

B. Human-Robot Communication

This section briefly dissects the communication strategies encompassing verbal and non-verbal cues, commands, and signals, vital for mutual understanding and coordination. Special attention is given to physical interactions in collaborative tasks, highlighting how shared manipulation of objects reinforces the vision for seamless HRC.

1) Human-Robot Verbal Communication (Acoustic): Despite the noisy, chaotic environment of construction sites, effective verbal interactions between humans and robots are deemed essential for seamless integration into existing workflows. Verbal cues facilitate natural, efficient exchanges, crucial for complex task execution and immediate decision-making, such as confirming material selections or ensuring secure attachments during assembly processes. Recognising the ambient noise challenges, the project prioritises advanced audio equipment to maintain clear communication lines, supporting the overarching goal of enhancing human-robot collaboration through well-designed verbal interactions.

2) Human Non-Verbal Communication (Optic): According to Albert Mehrabian's 7%-38%-55% rule on the importance of words, vocal tone, and body language, recognising non-verbal signals can greatly improve project communication, crucial for the effective collaboration between humans and autonomous machinery [11]. Standard signals, crucial for safety and coordination, lack a universal "language" yet are indispensable on dynamic sites, with research supporting their importance for tasks, like crane operations [12], [13]. The FORTIS project aims at integrating these signals following guidelines from experienced partner Garcia, Garcia, SA, alongside leveraging advanced AI, such as LSTM networks and Transformer models, to analyse kinematic and physiological data from wearables, aiming to improve HRC [14]. This approach ensures that robots can interpret human behaviours for optimal safety and efficiency, demonstrating the project's commitment to pioneering communication strategies in construction environments.

3) Robot Non-Verbal Communication: Amidst the construction soundscape, distinct acoustic signals, like unique tones, emerge as critical, cutting through the noise to alert humans to dangers or necessary actions to avoid accidents and identify/prevent near misses. Leveraging high-power amplifiers and industrial-grade beepers, the project's acoustic strategy aims to enhance safety and coordination in collaborative human-robot tasks. Complementing acoustic signals, visual communication also play a crucial role in the dynamic and complex construction environment. The project employs visual indicators to create an effective visual language that captures attention and conveys important information. By integrating existing LED solutions on loader and telehandler robots and augmenting them with additional RGB LEDs, the project aims to signal hazards, task progress, and robot statuses, such as operational states.

4) Physical Interactions: At last but not least, in the FORTIS construction pilot, we explore groundbreaking physical interactions between heavy-duty autonomous machines and human workers, particularly within the sandwich panel assembly task. This initiative aims to enable coordinated physical collaboration, such as the 'following' interaction, where the telehandler robot and a ground worker jointly manipulate a sandwich panel, with the robot lifting and the worker guiding its placement (Fig. 3). This collaboration showcases a unique synergy, achieving physical proximity through shared object manipulation without direct contact. While the concept draws on prior robotics research, including studies on collaborative manipulation and force feedback, the FORTIS project extends these principles into more complex, real-world construction settings. This approach not only demonstrates advanced human-robot collaboration but also addresses the challenges of implementing such technologies in the dynamic and demanding environment of construction, pushing the boundaries of current HRC capabilities.

Fig. 3. A high degree of physical interaction is maintained between telehandler and ground worker until the sandwich panel fits in the structure.

IV. CONCLUSIONS AND FUTURE WORKS

The FORTIS project stands at the forefront of advancing HRI in challenging domains, introducing here an innovative pilot as a testament to its commitment to overcoming challenges within the construction sector. This paper showcased the project's potential to transition from current practices to future advancements, enhancing interaction and communication channels between humans and robots. Looking forward, the FORTIS project is poised to refine these initial findings, particularly on the groundbreaking domain of physical interactions within construction settings, aligned with health and safety good practices. The early preparations for the pilot site underscore a practical commitment to addressing real-world challenges, offering a fertile testing ground for FORTIS technologies. As the project progresses, it will continue to adapt and evolve its strategies, hardware, and software based on emerging technical and functional requirements, aiming to ensure seamless, efficient interactions in complex construction environments.

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