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CASE STUDY – THE USE OF ROBOTICS IN THE CONSTRUCTION OF TIMBER STRUCTURES USING WESTERN AUSTRALIA'S LARGEST MASS ENGINEERED TIMBER BUILDING AS A TEST BED

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ABSTRACT: In 2023, Murdoch University in Australia opened a new teaching facility, called Boola Katitjin. The focal point of this building is the use of Mass Engineered Timber (MET). Boola Katitjin is the largest timber building in Western Australia (WA). Due to their modular and prefabricated nature, MET buildings provide a fertile testing ground for deploying robotics in construction. This paper presents the research that was undertaken to explore the use of robotics in the construction of a MET building to improve the productivity of timber construction. It also presents the findings of the successful deployment of the robot on Boola Katitjin, in a collaboration between Aurecon, University of Technology, Sydney & Murdoch University – bringing an opportunity for academia to collaborate with industry. The findings demonstrated that by using robots to install screw fixings into CLT panels, approximately 15-20% saving in the timber installation construction programme could be realised, compared with using humans to install the screw fixings into CLT. Furthermore, our results show that a robot can install screw fixings at a faster rate (on average) than a human, and with greater accuracies. Finally, this paper presents the challenges faced and assumptions made.

KEYWORDS: Mass Engineered Timber; Robotics; Innovation; Automation, Academia & Industry Collaboration

1 INTRODUCTION

In a world first, Murdoch University (MU), in partnership with Aurecon & University of Technology, Sydney (UTS) deployed robots on a live construction site to construct part of Murdoch's Mass Engineered Timber Building, Boola Katitjin. This tripartite partnership created an academia & industry collaboration to investigate the use of robotics to improve construction productivity.

2 SYNOPSIS

Boola Katitjin is Murdoch University's (MU) new teaching and learning facility, opened in February 2023. Using mass engineered timber (MET), it is the largest mass timber building in Western Australia (WA).

MET buildings can be exemplar in sustainable, circular design by using local renewable materials, designing out waste through modular design and construction, and reducing the carbon footprint of materials using timber, which sequesters carbon. However, due to their relative niche status in Australia, the price of MET buildings often remains a barrier.

In engineering Boola Katitjin, Aurecon challenged traditional mindsets around financial viability through:

• Deep engagement with the timber industry, including a WA Timber Forum to identify risks, challenges and opportunities with timber supply and construction

• Incorporating a world-first robotics technology trial to provide a proof of concept to increase construction efficiency and safety and reduce cost.

The deployment of robotics on Boola Katitjin was led by Aurecon, leveraging an Aurecon Design Academy [1] research thesis on robotics in timber construction, in partnership with the University of Technology, Sydney (UTS). The modular and prefabricated nature of MET buildings provides a fertile testing ground for deploying robotics. Seizing this opportunity, the client, Murdoch University and contractor, Multiplex, were supportive of using the construction of Boola Katitjin as a testbed and exemplar for this emerging innovative technology.

3 INNOVATIONS

3.1 ACADEMIA/INDUSTRY COLLABORATION

The commitment to deploy robotics resulted from a brainstorming session between MU and Aurecon where we explored the challenges the construction industry is currently facing around safety and productivity.

During the workshop, a blue-sky question emerged "Wouldn't it be cool if robots built Boola Katitjin?". This simple question turned into an opportunity to embed academic research into Boola Katitjin around deployment of robotics. This idea gained further traction with the inclusion of UTS, creating a tripartite partnership.

Together, Aurecon, UTS and MU created an academia/industry collaboration project to investigate the use of robotics in construction to advance innovation and improve productivity and safety, through the robotic installation of up to 100 screws (300-400 mm long) into the timber slabs. There are 200,000 – 300,000 screw

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fixings in total on the Boola Katitjin project. The proof of concept concluded with the successful deployment of the robot – Quenda-bot - on a live construction site in May 2022. This research predicts that it is possible to achieve time savings of 15-20 per cent of the construction schedule once the technology is fully developed and deployed.

3.2 DISRUPTING THE CONSTRUCTION INDUSTRY

This innovation not only has the potential to improve construction productivity and safety on a larger scale, but also contributes to the decarbonisation of the construction industry, with the potential to improve efficiency to embed timber as a preferred material of choice. There are great opportunities for this innovation to be replicated on future timber construction sites and change the way in which we design and construct buildings, to increase speed of construction and reduce embodied carbon. Ultimately, this innovation has the potential to significantly disrupt the construction industry – historically a laggard when it comes to innovation and automation.

Despite being one of the oldest and largest global industries, the sector remains resistant to change, preferring to use historically prevalent materials and construction techniques.

3.3 SUSTAINABILTY AND COST REDUCTION

Building and construction are responsible for 40 per cent of global carbon emissions. Timber building systems can help reduce these emissions. Not only is timber renewable, but it also has a lower embodied carbon footprint than traditional materials, while lending itself to modular design and construction techniques that cut waste and enable reuse of elements, improving the circularity of the construction. When sustainably sourced and manufactured, timber can play an important role in a regenerative economy. Yet it remains more costly in practice. This project aimed to demonstrate cost savings through supply chain collaboration and technological innovation. If cost-effectiveness can be improved to the point where building in timber is cheaper than traditional alternatives, we expect the flood gates to open in terms of uptake of timber as a structural material of choice.

3.4 IMPROVING SAFETY

On Boola Katitjin, there are approximately 200,000 – 300,000 screw fixings. The traditional method of installation is for a construction worker to use a battery-powered impact driver to install these individually, in a crouched position. Being crouched in the same position, while exerting downwards force on the screw, causes back/leg and ergonomic issues.

Aurecon conducted a stakeholder interview with the site team, which uncovered that worker fatigue and morale was a major concern, which the site team had to mitigate by giving the operators more regular breaks every 45 minutes. The introduction of robotics has the potential to largely eliminate these related health and safety concerns. The robot can autonomously install screw fixings throughout the day and night, potentially eliminating robot/human interactions. This will enable construction workers to undertake higher value tasks, assisting with physical and mental health and skill development.

By coupling automation and MET, timber buildings will become safer to build, more efficient, and less costly, enabling the construction industry to move towards a more sustainable and innovative future.

3.5 SUPPLY CHAIN COLLABORATION

As MET is a relatively new material in the Australian context, engagement with the timber industry was conducted via industry workshops, hosted by Aurecon, to identify risks, challenges and opportunities with timber construction and support the timber industry to emerge and scale up.

With exemplar projects such as Boola Katitjin, we remain hopeful that the industry will continue to scale to embrace the opportunities created by the existence and promotion of projects such as Boola Katitjin.

4 PROOF OF CONCEPT TRIAL

4.1 QUENDA-BOT TRIAL

There are 200,000 – 300,000 screw fixings in total on the Boola Katitjin project. The proof of concept concluded with the successful deployment of the robot on a live construction site in May 2022, installing around 100 screws. This research predicts that once the technology is fully developed, it will be possible to save 15-20 per cent of the construction schedule.

The challenges around the robotics technology trial were considerable, which were solved through creating a digital twin and using 3D simulations.

Figure 1: *Quenda-bot on site at Boola Katitjin*

4.1.1 Creating a digital twin

The robot is equipped with a LIDAR (Light Detection and Ranging) navigation system for autonomous travel. However, while the robot could navigate around a place, it needed to still understand where it was globally.

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As the civil and structural consultant engineers on the project, Aurecon already had a BIM model (REVIT) of Boola Katitjin. Aurecon and UTS devised a workflow whereby the UTS team exported Aurecon's BIM model and inserted it into their robotics software - Gazebo. This created a digital twin of the building, to allow the robot to understand where in space it was and where it was in the building relative to grid references. Once the robot understands where it is from a global perspective, it then switches to an onboard navigation system to pinpoint where to install the screws.

This workflow has redefined the term 'digital twin'. Historically, we have always considered digital twinning from a construction/built environment/infrastructure perspective. We have now created a new workflow where the digital twin is relatable to robotics, opening a new offering to two industries. Based on this workflow and navigation system methodology, the robot was then able to install the screw fixings to within +/-5mm accuracy, which is acceptable and, in many cases, exceeds the accuracy of manually installed screws.

4.1.2 3D simulations

Pandemic restrictions limited usual lab experimentation practices, hence numerous complex 3D simulations were used to prototype virtually and learn. The robot 3D simulation tests are conducted inside the Gazebo software, which allows the simulation of robots in complex indoor and outdoor environments. This was a fast way to prototype virtually. We were able to trial new and different elements, fail fast in a virtual environment, learn, reset and move on. Following the successful completion of the simulations and virtual prototyping, the robot was then built and tested in a physical lab environment, prior to the successful deployment on site.

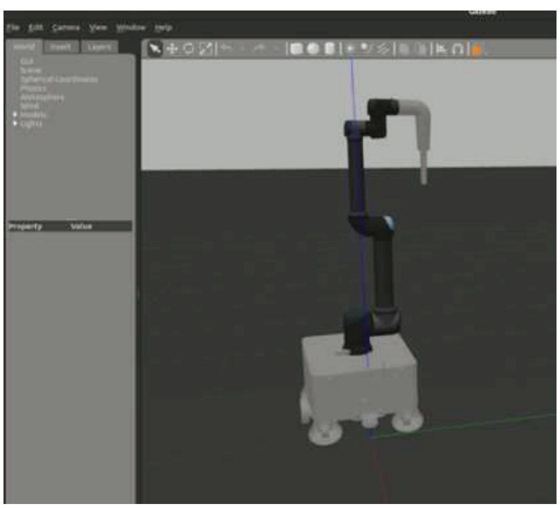

Figure 2: *Robot simulation*

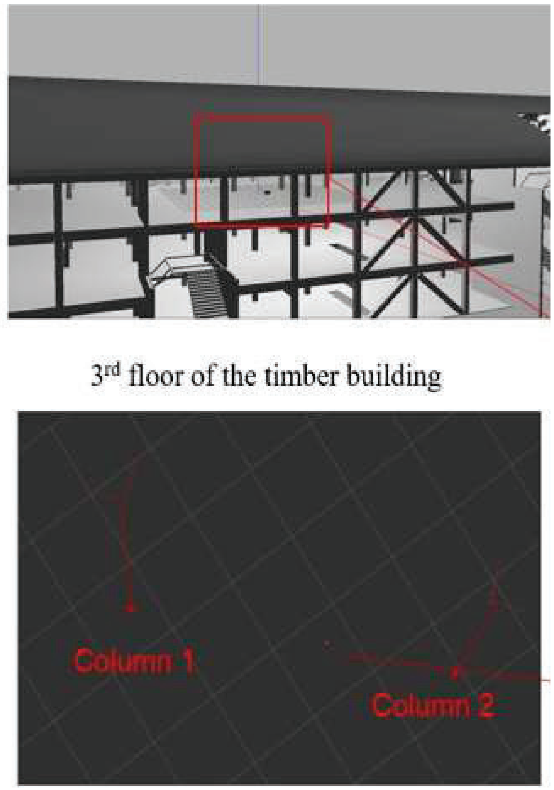

Figure 2: *Estimation of location based on relationship to building columns*

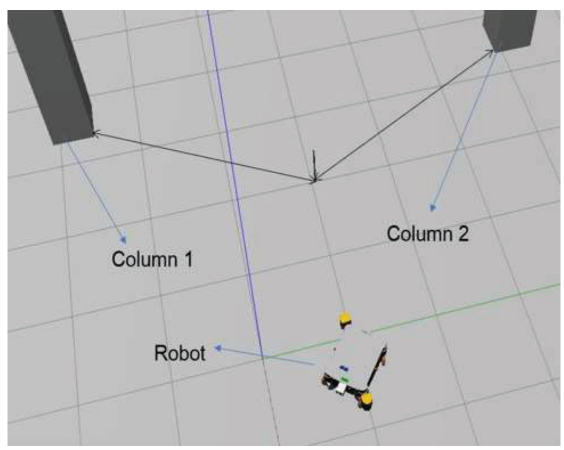

Figure 3: *Virtual model of robot locating process*

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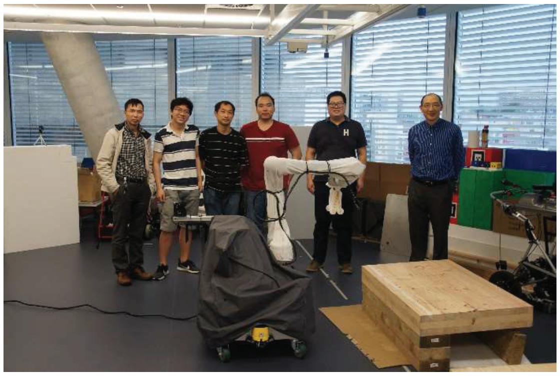

Figure 4: Physical robot testing at UTS labs, Sydney

4.2 Outcomes of the innovative application of the technology

The objectives of this project were to create a sustainable, circular building and to enable projects of this type to flourish across the Asia Pacific region, by demonstrating economic viability, safety, and sustainability.

5 FUTURE OPPORTUNITIES

5.1 THE OPPORTUNITY

MET building systems can help reduce carbon emissions, of which the building and construction sector contributes 40 per cent. It also lends itself to modular design and construction techniques that cut waste and enable reuse of elements in the future. When sustainably sourced and manufactured, timber can play an important role in a regenerative economy. By enabling the efficient and safer construction of timber structures, the aspiration is to make timber the building material of choice. This will contribute to a "step change" in the decarbonisation of the construction industry.

5.2 THE CHALLENGE

MET construction remains costly in practice. This project provided a testbed to research innovations that seek to drive greater efficiencies through supply chain collaboration and technological innovation. If timber construction can achieve greater efficiency to be directly cost competitive to concrete and steel, volumes would increase, further reducing the cost of timber construction. Another challenge will be the ability of the supply chain to meet demand without diminishing supply volumes to traditional markets such as stick built housing. Once cost competitiveness is achieved, then we believe that the focus of the timber industry will shift to meeting the demand in a sustainable way.

6 OUTCOMES

The research commenced with industry engagement to identify risks, challenges and opportunities, and concluded with the successful deployment of the robot – Quenda-bot - on a live construction site, through the collaboration of Aurecon, UTS, Murdoch University and Multiplex. The following outcomes were achieved:

- The robot successfully installed 100 screws as a world-first proof of concept.
- The research predicts a saving of 15-20 per cent off the timber construction schedule if the robotics are suitable developed and deployed fully on site.
- Further gains in productivity and safety could be realised via a 24-hour construction site.
- Worker safety can also be improved through the removal of rote and repetitive tasks, enabling a greater focus on higher value tasks and skills development.
- This research is highly replicable and scalable and is ready to be deployed onto future projects.

6.1 OVERVIEW OF FUTURE APPLICATIONS

Timber remains the only truly sustainable mainstream building material yet has not reached its full potential for commercial applications in the region due to cost and supply chain challenges.

The objective of the Boola Katitjin robotics project was to demonstrate that MET buildings, which also lend themselves to modular design and construction, are economically viable, safe, and sustainable – contributing to a regenerative economy. This in turn reduces waste and increases the potential for future reuse of some elements.

Aurecon has amassed an enviable track record in successful timber design over the past 40 years, including Australia's tallest commercial timber building, 25 King St, one of Australia's tallest residential timber buildings, Monterey Apartments, both located in Brisbane and one of the world's largest timber buildings, Nanyang Technological University Academic Building South in Singapore.

Boola Katitjin is the largest mass timber building in Western Australia. Through the successful design and construction of these and future timber buildings, Aurecon aims to consolidate our reputation as the 'designers of choice' for MET and low carbon buildings of all typologies.

Following the successful deployment of the robot in May 2022, which demonstrated potential savings of 15-20 per cent off the timber construction schedule, the project team have been working on the next stage of robot development. Future developments include improvements to the robot to enable it to install screw fixings more autonomously and at a faster rate.

The project team is currently working on sourcing funding and have identified potential future timber projects on which the robot could be deployed at scale. The aspiration of the next project is for the robot to do an entire floor plate without any human intervention.

This innovation not only improves construction productivity and safety, but also contributes to the decarbonisation and circularity of the construction industry.

Ultimately, this replicable and scalable research has the potential to disrupt the construction industry for more sustainable outcomes.

6.2 MEDIA COVERAGE

The project generated significant interest from local media outlets, resulting in elevated profile for the project and interest in the emerging technology from various parties:

FINANCIAL REVIEW

Murdoch Uni pilots robot construction

Michael Bleby

The newest worker fixing screws in the framing of Murdoch University's Building 360 is not doing it in hi-vis jackets, or even with eye protection.

Rather, it is on wheels and has a six-axis arm, in a world-first operation to use a robot to install screw fixings – the industrial-sized screws that secure the timber framing to the wooden floor – in a further step down the road to manufacturing-like processes in construction.

It is only a pilot at this stage, testing the safe use of the University of Technology Sydney-designed robot on a live site. It will only place between 50 and 100 out of a total 200,000-300,000 screw fixings on the four-storey structure that will be WA's largest engineered-timber building.

But the productivity gains were potentially huge, said Tim Spies, Aurecon's built environment managing director and a consultant to the project.

"On a typical 18-month schedule for a building of this scale and configuration, it would be possible to save between 15-20 per cent of the timber construction schedule," he said. "This could represent a saving of between 4-8 weeks on the overall build."

Further gains could come from the work robots could provide during night work, he said. Humans could "drop in" the timber slabs during the day, and the robot work throughout the night installing screws.

Multiplex is the construction contractor on the building with a $145 million budget. Practical completion is due in November.

UTS Robotics Institute and the project leader, Dikai Liu, said intelligent robots were changing construction.

"Construction sites are varied, complex and changing – and that can be a real challenge for a robot to navigate and conduct operations," Professor Liu said. "What we have been able to design is an intelligent robot that can focus on an important task even amidst this disruptive environment."

Mass Engineered Timber buildings offer a good testing ground for robotics in construction. Installing screw fixings into CLT slabs is typically the most repetitive task in any timber project.

Figure 4: *The Australian Financial Review article*

We were informed that Rory Campbell from 7 News Perth would attend site briefly during the trial. Such was the enthusiasm for Quenda-bot that he and the 7 News team ended up remaining on site for 3 hours during the trial, resulting in coverage on multiple media platforms.

Figure 5: *7 News Perth coverage*

The project also generated significant interest in engineering circles, including an article in the Innovation section of Create, Engineers Australia's magazine and website [2].

Figure 6: *Engineers Australia coverage*

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7 CONCLUSIONS

International design, engineering and advisory company Aurecon has introduced robotics technology into the construction of Murdoch University's new Boola Katitjin building in a world-first trial, in collaboration with major partners Murdoch University (MU) and University of Technology, Sydney (UTS).

Boola Katitjin is Western Australia's largest mass-engineered-timber (MET) building. MET buildings can be exemplar in sustainable, circular design by using local renewable materials, designing out waste through modular design and construction, and reducing the carbon footprint of materials using timber, which sequesters carbon. However, due to their relative infancy in Australia and New Zealand (ANZ), the price of MET buildings can be perceived as a barrier.

The objectives of the research project were to create a sustainable, circular building and to enable projects of this type to flourish across Australia and New Zealand, by demonstrating economic viability, safety, and sustainability. Conceptualised by Aurecon as part of an Aurecon Design Academy [1] thesis project and delivered as an industry/academia collaboration between Aurecon, University of Technology, Sydney (UTS) researchers, Murdoch University and Multiplex, the aim was to demonstrate that robots could deliver cumbersome screw fixings - a repetitive and time-consuming task that causes fatigue and injury in workers.

The robot – "Quenda-bot" – was successfully deployed on the 'live' Boola Katitjin construction site in May 2022, demonstrating how automation could improve worker safety and construction efficiency, with potential savings of 15-20 per cent from the timber construction schedule.

There are around 200,000 to 300,000 screw fixings on the Boola Katitjin construction site. The proof-of-concept trial successfully installed around 100 screw fixings.

Following the successful deployment of the robot, the project team have been working on the next stage of development. The future application is for the robot to be refined to enable it to install screw fixings at a faster rate. The project team is currently working on sourcing funding and have identified potential future timber projects on which the robot could be deployed at scale. An aspiration for the next project is for the robot to screw fix an entire floor plate without any human intervention.

Ultimately, this research has the potential to disrupt the construction industry for more sustainable outcomes

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- Murdoch University – for having the vision to build WA's largest Mass Engineered Timber building, and entrusting Aurecon to conceptualise and deliver that game-changing building for them. Also, to allow Aurecon to assist them in developing a process for achieving a world-first innovation, using their project as a testbed. We will forever be thankful for the support and trust they put in us to deliver.
- University of Technology, Sydney – Robotics Institute, and particularly the leadership of the quintessential gentleman Professor Dikai Liu, and his team led capably on site by Professor Shoudong Huang. Without access to the eminent skills and capability contained in that Institute, and their innate willingness and ability to collaborate, the outcomes presented here would not have been possible.

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